Bulletin 130

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BLAST-FURNACE BREAKOUTS, EXPLOSIONS, AND SLIPS, AND METHODS OF PREVENTION

BY

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BLAST-FURNACE BREAKOUTS, EXPLOSIONS, AND SLIPS, AND METHODS OF PREVENTION.

By F. H. Willcox.

INTRODUCTION.

This publication is the third of a series of reports on hazards and the prevention of accidents at blast-furnace plants that is being published by the Bureau of Mines, Technical Paper 106[a] being the first and Technical Paper 136[b] the second of the series.

This bulletin, which is arranged in three parts, treats of the causes and prevention of blast-furnace breakouts, explosions, and slips. The first part discusses blast-furnace breakouts, the hazards therefrom, causes, and features of furnace design and methods of operation that tend to prevent breakouts or lessen their number, and points out safety measures to be adopted. The second part takes up the theory and causes of gas explosions at blast-furnace plants and reviews the better methods in use for handling gas. The third part analyzes the causes of hanging and scaffolding in blast furnaces, with the resulting slips that frequently cause injury to the plant and danger to the workmen, describes features of construction and furnace design and methods of operation employed to prevent hanging and slipping, and suggests precautions and safeguards.

ACKNOWLEDGMENTS.

Acknowledgment is gratefully made to the officials of the numerous blast-furnace plants through whose cooperation this bulletin was made possible.

Acknowledgment is made of the assistance of D. A. Lyon, metallurgist of the Bureau of Mines, under whose supervision this work has been conducted.

Thanks are due Mr. Frederick Crabtree, professor of metallurgy at Carnegie Technical Schools, Pittsburgh, Pa., for amendments and suggestions.

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[a] Willcox, F. H., Asphyxiation from blast-furnace gas: Tech. Paper 106, Bureau of Mines, 1915, 69 pp.

[b] Willcox, F. H., Safe practice at blast furnaces, a manual for foremen and workmen: Tech. Paper 136, Bureau of Mines, 1916, 73 pp.

PART I.—BLAST-FURNACE BREAKOUTS.

PURPOSE OF INVESTIGATION.

Breakouts are an infrequent and insidious hazard of furnace work. A study of their dangers, the technical aspect of their occurrence, and the methods in use for preventing them has been made by the writer. The results of this study are presented in the following pages.

DEFINITION OF THE TERM "BREAKOUT."

A "breakout" is the term employed to denote the conditions and results of the escape of gas and coke, or slag, or iron, from the bosh, tuyère breast, or hearth of a blast furnace. Breakouts may occur at any point below the fusion zone in the furnace, but the most frequent breakouts are of molten iron at a level below the surface of iron lying in the hearth, and are either through the hearth walls and jacket or into the hearth bottom and out under the hearth jacket.

EXPLOSIONS FROM MOLTEN IRON.

If this runaway fluid iron comes in contact with water or wet material an explosion occurs which may wreck the furnace or cast-house equipment. An explosion in one plant caused damage amounting to $80,000. Several furnaces have been put out of blast by such accidents, and in numerous instances men have been injured or killed by flames, flying metal, brickbats, and castings when these explosions take place.

The term "explosion," as applied in this sense, should not be confused with explosions of gas, which are discussed in Part II of this report.

HAZARDS FROM BREAKOUTS.

BREAKOUTS OF IRON.

At most plants in this country the danger of hearth breakouts has been reduced remarkably during the past 10 years, and at these plants, so the writer believes, is becoming almost negligible as a factor in the accident risk. The hearth has received much attention, and heavier, stronger, and more expensive construction has been developed until the two types of hearth now standard rarely permit explosive breakouts.

BREAKOUTS OF SLAG OR CINDER.

Slag breakouts occur from the top of the hearth jacket and about the cinder notch up to the level of the tuyéres. They are seldom dangerous to life or limb but may cause some damage to the brick lining and are a considerable nuisance and annoyance, because of the resulting delay for repairs and the time necessary to clean up the "mess" they cause.

BREAKOUTS OF THE BLAST, GAS, AND COKE.

Blast, gas, and coke breakouts, usually known as bosh breakouts, are almost a thing of the past; the last one in this country was in the spring of 1914. Their elimination may be attributed quite as much to improvements in practice, smoother work on increasingly inferior ores, and less violent "slips," as to strengthening of boshes. Although improvement in boshes is generally keeping pace with other furnace construction in augmenting security, nevertheless at many plants the bosh is not as strong, proportionately, as other parts of the furnace. With the present control over furnace operation, the bosh does not fail except at infrequent intervals. However, if plants with somewhat weak boshes should be subjected to periods of heavy driving for large production, with consequent severe slips, such as have happened in the past, it may be that some boshes although adequate for normal pressures and slips would give way. One such accident has happened.

BOSH BREAKOUTS.

CAUSES OF BOSH BREAKOUTS.

Bosh breakouts may be caused as follows: (1) By conditions inside the furnace, such as high pressure of blast, very heavy slips, or severe working on the hearth walls, all of which may lead to (2) breaking of the hearth bands, ejection of cooling plates, or parts of the brickwork between the bands and the plates, or (3) cracking and opening of bosh jackets. The second and third items may usually be traced back to deficient construction or questionable design.

POSITION OF BOSH IN FURNACE.

The bosh of the blast furnace shown in figure 1 is an inverted truncated cone, so designed as to bring its top just below the zone of fusion, the limits of which depend on the grade of ore used and the temperature and volume of the blast; the bottom is arbitrarily fixed at 12 to 24 inches above the center line of the tuyères.

Inside of this cone, which is usually about 22 feet in diameter at the top, 17 feet in diameter at the bottom, and 12 feet high, there is burned every minute about 750 pounds of carbon, which liberates approximately 3,000,000 heat units at a temperature of 2,750° to 3,200° F. and produces 62,000 cubic feet of gas. This gas, which is under a temperature of 3,000° F. and pressure of 15 pounds, is expanded to approximately 210,000 cubic feet, and rushes upward with a velocity of probably not less than 3,000 feet per minute. At the same time the coke in the bosh is sliding down and grinding the walls, which are

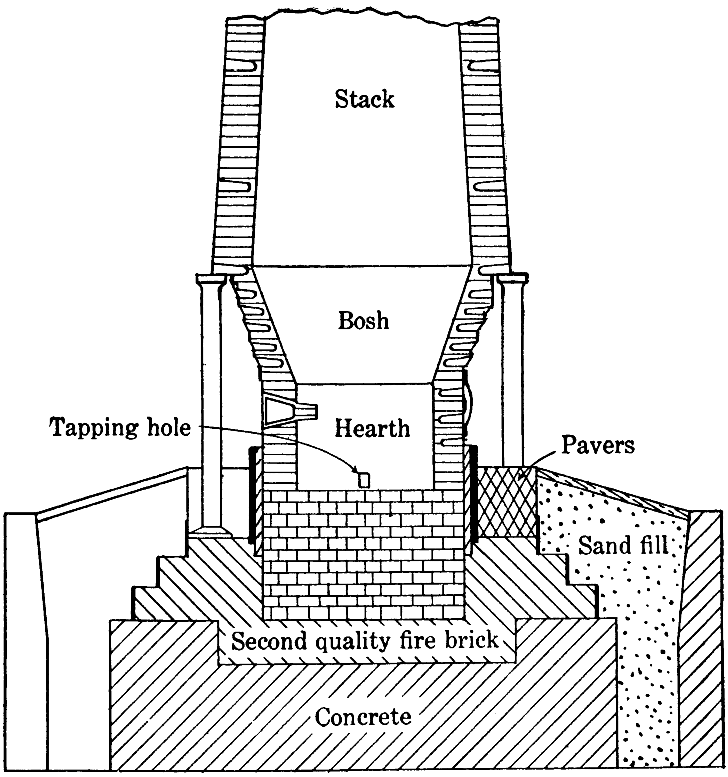


FIGURE 1.—Section of hearth bosh, and foundation of typical modern blast furnace.

incandescent but firm and solid, and down which globules of corrosive slag and iron continually run and drip. Under these conditions of high heat, strong pressure, and the scouring action of descending raw slag and iron, and ascending gas at high velocity, it is evident that the construction and maintenance of the bosh present difficult problems.

DEVELOPMENT OF PRESENT TYPES OF BOSH.

The type of bosh now being built is a development of about 50 years' experience, its growth being markedly accelerated during the decade of 1900 to 1910. During this decade the increasing use of Mesabi iron ores resulted in heavy scaffolding and bridging in the furnace and in severe slips, which added to the normally heavy duty of the bosh the necessity of withstanding the impact of columns of stock, weighing hundreds of tons, which fell from a height varying from 10 feet to an estimated height of 30 feet. Several serious and fatal accidents were caused from the boshes bursting under the blow of a falling stock column and the compression of the gas beneath the stock. This subject is discussed at greater length under slips.

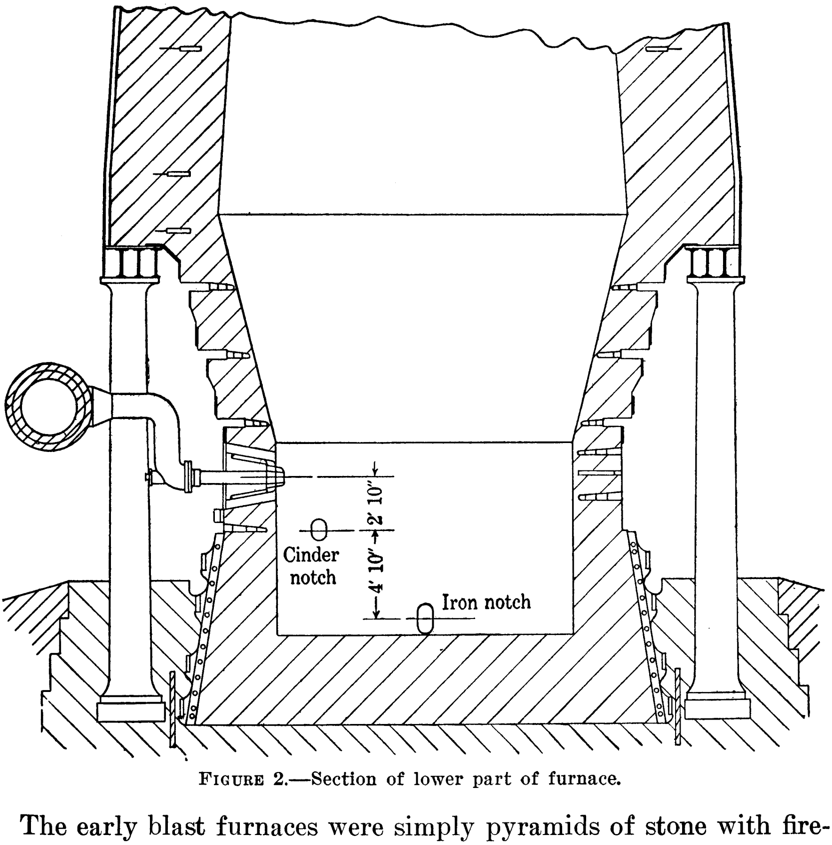


FIGURE 2.—Section of lower part of furnace.

The early blast furnaces were simply pyramids of stone with fire-brick linings. They had boshes, but these did not show on the outside, being surrounded by means of masonry. An opening was left on one side for the tapping hole. The use of tuyères in larger number introduced more openings or arches on the sides, until the stack was partly supported on brick or masonry pillars and the bosh assumed external form. About 1860 the stone or brick pillars were replaced by iron columns, but the fire-brick lining was still held in place by a massive ring of ordinary red brick, not water-cooled. This hearth fire brick, of course, was badly eroded and the bosh construction was made thinner, was banded with flat iron straps, and iron cooling plates were inserted. To describe in detail the development to the present form would require too much space. It was, in brief, a progressive evolution; changes in fuel and ore required more limy slag, a more limy slag required hotter combustion, and this in turn required a stronger and hotter blast, which resulted in larger production, and larger production required better construction. Weaknesses developed, accidents happened, deficiencies were corrected, and one improvement led to another until there are now two distinct types of bosh construction which, so far as may be conceived, are the last word in construction, design, strength, and security.

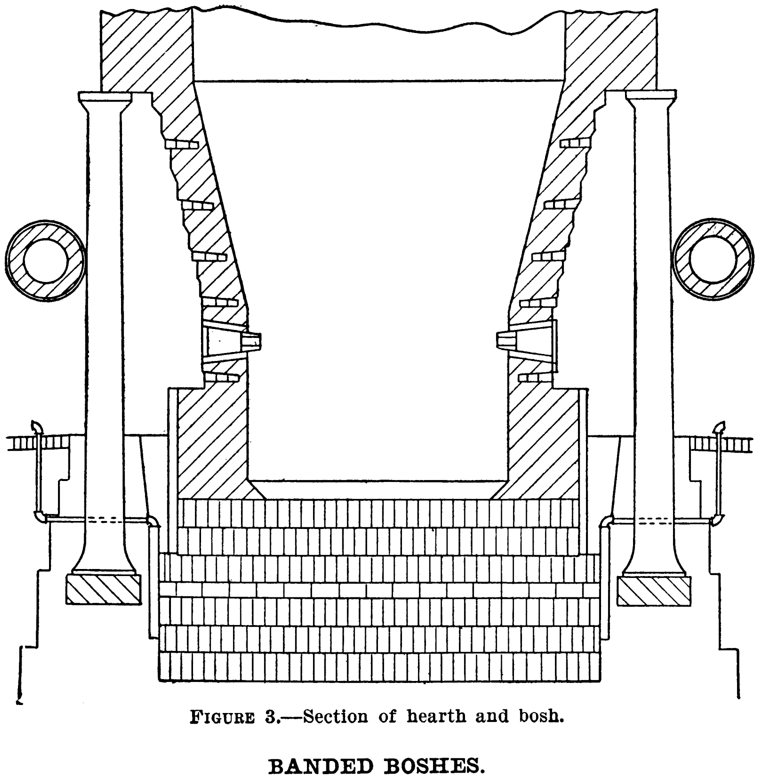


FIGURE 3.—Section of hearth and bosh.

BANDED BOSHES.

A type of construction largely used in plants dependent on Lake ores is illustrated in figures 2, 3, and 4. It consists of brickwork, in which is inserted five to eight horizontal superimposed rows of bronze cooling plates. These plates are, as a typical example, $4\frac{1}{4}$ inches thick at the back by $3\frac{1}{8}$ inches thick at the nose, which is rounded; are 2 feet 3 inches wide at the back and taper to 1 foot $11\frac{1}{2}$ inches at the nose. The depths of the plates differ according to the manner in which they are placed. In most furnaces a flat brick arch is turned in the brickwork above the plate and the plate extends from the outside to the inside face of the lining or 1 inch back from the inside face. When these plates must be replaced they are likely to be exceedingly difficult to withdraw. They should be easily removable, for, in spite of the best water-cooling, plates will crack or burn. Also the new plate should fit tightly enough in the opening left from the old one that the blast or gas can not blow out, erode the brick seat, and let cinder run through, but the opening should be large enough to permit the new plate to extend inward the same depth as

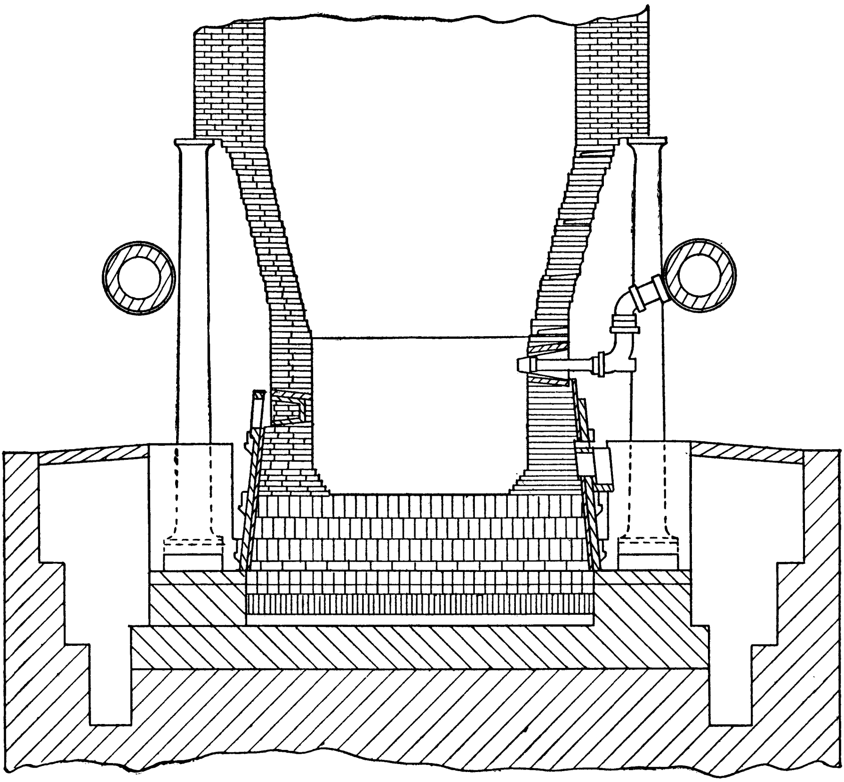


FIGURE 4.—Section of bosh and foundation.

the old one withdrawn to prevent the wall from becoming dangerously thin. Putting in a new plate may be more difficult with a brick arch than with a plate box, because the brickwork may have wedged down and the old plate may be sprung.

Typical examples of erosion of bosh walls between the plates are shown in figure 5. Instances are known where the brickwork has disappeared almost to the band, being replaced with a mixture of dust, slag, carbon, and partly reduced ore. When the scouring action has thinned the walls too much these plates, being laid in the brickwork, are not held firmly, and in some instances have been tilted down by the weight and motion of the descending stock, breaking the water connections and weakening the adjoining construction.

USE OF PLATE BOXES.

To simplify the changing of plates, the use of cast-iron boxes is much in favor. These boxes are built in the brickwork one-half or one-third the thickness of the bosh wall, and the cooling plate inserted through the box, as illustrated in figure 6. Such boxes are recommended, by those who use them, as being free from any tilting of plates, admirably adapted to being tied in with the overlying and lower bosh bands to make a strong reinforcement immune to blowouts, and as reducing the weight of metal in the copper plate by one-fourth, and thus lessening the cost. The plate may be blocked in position in the box by a short lug, as has been done at some furnaces.

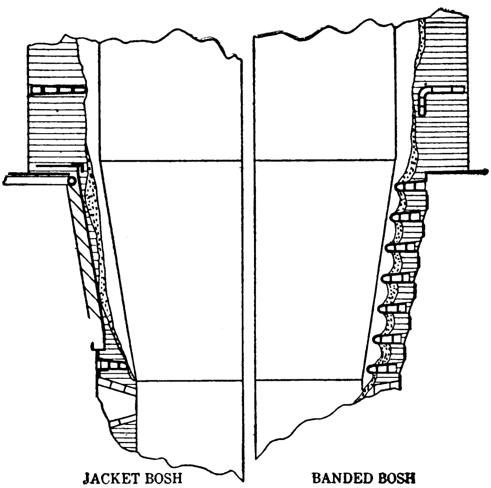


FIGURE 5.—Erosion of bosh walls.

There are 18 to 26 plates in each row, and they are usually separated by brickwork laid between the boxes, which are $13\frac{1}{2}$ to $14\frac{1}{2}$ inches apart, horizontally. In some plants the boxes are laid continuously about the entire row. The vertical distance between centers is $20\frac{1}{2}$ to $31\frac{1}{2}$ inches, of which 12 inches is usually covered with a steel band. This leaves a segment of brickwork, inclosed at the sides by the plates and at the top and the bottom by bands, ranging from $4\frac{1}{2}$ to $13\frac{1}{2}$ inches by $8\frac{1}{2}$ to $19\frac{1}{2}$ inches in size. This brickwork between the plates is usually not reinforced or backed on the outside with steel or iron plates. However, the practice at a few plants and the tendency at many others is to reinforce this small segment of brickwork with a short vertical buckstay extending from the lower to the upper band. A furnace thus equipped has no brickwork exposed on the outside, except the small areas between buckstays, plates, and bands. As the bosh brickwork is all held together by wide bands, with plate boxes held in by buckstays backed against the band, it is difficult to conceive that such boshes can blow or break out, and to date they have not.

BRICKWORK CONSTRUCTION BETWEEN PLATES.

The brickwork of the bosh averages, on modern furnaces, $31\frac{1}{2}$ to $40\frac{1}{2}$ inches thick, and is built in various shapes, as the construction is made complicated by the insertion of plate openings. Figure 7 shows a typical example of brickwork construction between plates.

The bosh bricks are almost exclusively $2\frac{1}{2}$ inches thick and are laid flat; only a few plants have used 3-inch bricks on the bosh, although it is customary to use 3-inch in the inwall above the bosh. The bricks are laid in concentric circles with the joints broken or staggered vertically and radially; their dimensions closely conform to the circles with no cutting. The only unbroken joint is along the horizontal plane between each course. This construction is interrupted at each plate by an arch, as shown in figure 8.

In this figure the diagram at the left shows an end view of the arch. The view at the right shows a section on the vertical plane through the center of the arch.

The insertion of plates that vary in dimensions from the standard dimensions of the brick requires either considerable cutting of bricks or the manufacture of special shapes of brick, the dimensions of which are calculated from preliminary drawings showing the plate location.

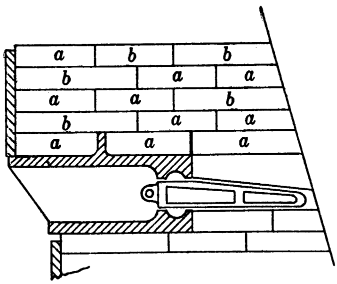


FIGURE 6.—Cast-iron box for cooling plate.

STRENGTH OF BOSH BRICKWORK AGAINST DISPLACEMENT.

Such a construction is very safe from blowouts if it holds together. The brickwork itself possesses no resistance to being pushed out other than the resistance due to its inertia, and to the compression of the superincumbent brickwork of the stack, yet it must withstand the pressure of the blast, stock, and slag, and the strain due to expanding of the bosh from heating. Under these conditions it is easily conceivable that sections of brickwork may be ejected from the bosh, and it is not surprising that such failure does occur, more especially as the thickness of the lining may be reduced from 36 inches to 18, and even less. This possibility is generally recognized, and the bosh brickwork, as has been previously stated, is usually reinforced between the plate rows with a metal band or, where plate boxes are not used, the brickwork between each two rows of plates is reinforced by two bands which, although they may not cover the brickwork because of the necessity of "stepping" the exterior face, should not allow more than one course of brick to be unbound. (See fig. 8.)

PLACING OF PLATES.

As a rule, in most furnaces the same shape and size of plates is used in each row, the number of plates being increased as the circumference of the rows up the bosh increases. There may be 20 plates in the bottom row and 26 in the top row, the horizontal distance between centers of adjacent plates being kept as nearly equal as possible. The plates in the different rows are not vertically above each other, but are alternated so that the brick between each pair of plates is covered and shielded to some extent by the plate above. This alternation is more exactly accomplished by using different widths of plates, and a few plants have as many different plate patterns as there are rows of cooling plates in the furnace. This arrangement can not be said to give more efficient protection than the use of plates of one pattern which do not permit such exact alternative spacing.

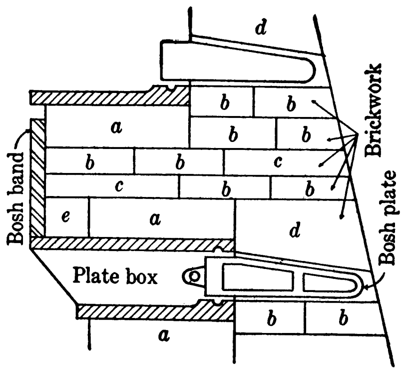


FIGURE 7.—Brickwork between plates; *a* to *e*, various shapes of brick.

COOLING EFFECT OF PLATES.

The cooling water is always fed in at the bottom of the plate, so as to displace mud deposited or carried in the water, and discharged from the top to prevent air bubbles accumulating near the roof of the plate, which would allow the plate to crack or burn or, possibly, explode. It is solely by the cooling effect of these plates that the bosh is preserved. A bosh, although built strong enough to withstand mechanical pressure and abrasion at low temperatures, might not last an hour if it was not cooled with water. This protection is essentially effected by keeping the temperature of the brickwork about the plates below that at which slag can combine with the brickwork. In fact, the temperature is usually kept lower than is necessary, and at times cooling is carried to excess, so that instead of an equilibrium between cooling effect and slagging action being obtained, scaffolding takes place—that is, slag, or pasty, partly reduced ore, or carbon dust freezes on the side of the bosh and impedes the descent of the stock from above. Overcooling of the bosh is serious and dangerous because it may lead to heavy slips; also the furnace may be put out of commission for days when the scaffold is dislodged.

COOLING-WATER SUPPLY.

The number of plates that can be used is not arbitrary, or even standardized. For instance, three furnaces in the same district, with closely identical production and dimensions, are equipped as follows: Furnace A, 5 rows, 91 plates; furnace B, 8 rows, 178 plates; furnace C, 6 rows, 132 plates. Furnace C works smoothly and regularly; furnace B is characterized by frequent and continual slips; furnace A works much more smoothly than B, but loses more plates.

The amount of water used is about the same, regardless of the number of plates in the bosh. When 90 plates are used, the bottom two rows of plates have an individual feed and discharge for each plate, whereas with 180 plates, the bottom two rows have two plates

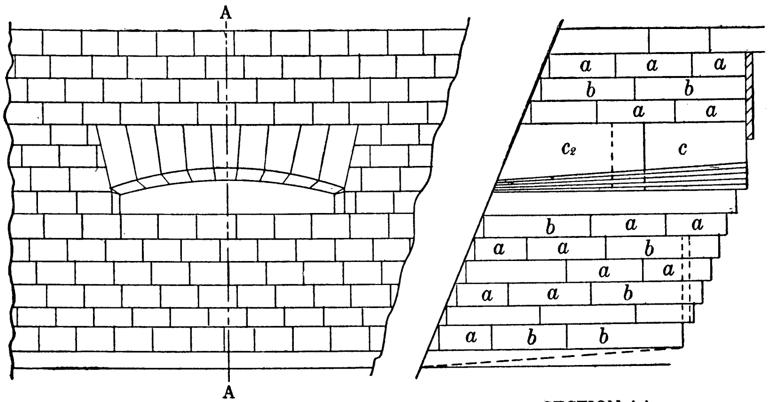


FIGURE 8.—Diagrams showing construction of arch.

connected in series. The plates in the higher rows are always in horizontal series of two, three, and four each; the top rows, being under less severe temperature conditions, have the larger number of plates in series.

A less common method of cooling the plates is to lead the feed into a plate on the bottom row; the discharge forms the feed for a plate immediately above in the second row, and so on up to the top row, five to eight plates being thus connected in series. The plate on the bottom row, at the hottest part of the combustion zone, is supplied with the coldest water; whereas the top-row plate, where overcooling is most to be feared, is supplied with water at a comparatively high temperature, but rarely more than 110° F. However, this arrangement uses less water, the piping is less in the way, and it appears to have been as efficient in cooling and preserving the bosh walls as the other method.

The temperature rise in the cooling water is very inconsistent; it varies, even with very cold water, from 4° F. to about 50° F. Furnace men from abroad have invariably commented on the large volume of cooling water used at American plants, it apparently being much in excess of that used in foreign practice. It goes without saying, however, that American managers err, if anything, on the side of overcooling, which, if not markedly excessive, is toward the safety of the men and plant, although resulting in some theoretical or actual increase in coke consumption. That it is somewhat hazardous to experiment with diminution of cooling effect is indicated by an experiment in which the water cooling in two alternate top rows was eliminated. This led to failure and breakout of the bosh, but, fortunately, no lives were lost.

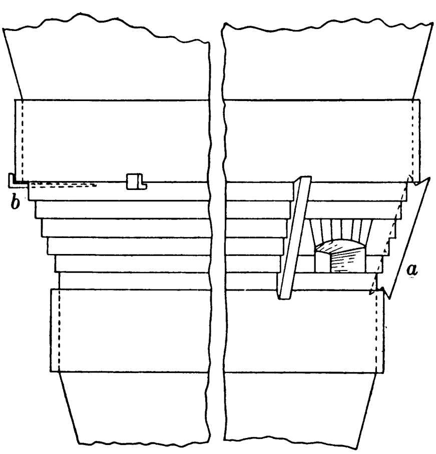


FIGURE 9.—Two methods of holding bosh bands in place. *a*, Iron strap laid in brickwork; *b*, lug laid in brickwork. The best method is to rest the bands on the plate boxes and not use straps or lugs.

CONSTRUCTION OF BOSH BANDS.

On furnaces having plate cooling there are usually between each row two bands about 5 inches by 1 inch each, or one band 12 or 14 inches by three-fourths inch up to 1½ inches, to give circumferential strength. With six rows of plates there are, then, seven circles of single bands or ten double and two single bands about the bosh. The most recent bands are 1½ inches thick and a few are 1¾ inches thick; they are of sufficient width to cover all the brickwork between the plate boxes, except for one-half inch vertically to provide for any slight expansion. These bands are strong enough, as a rule, to resist a bursting pressure of 160 to 350 pounds per square inch of bosh area. They are butt-strap riveted in two to four segments, thirty ¾-inch to 1⅛-inch rivets generally being used. The bands are usually so arranged that no two riveted parts are vertically in line, so that if one segment of the bosh is under heavy stress the load is distributed equally over the butt riveted and the other sections. The brickwork is always laid tightly against the bands, with no packing space, as is sometimes permissible in the stack and hearth, because lateral displacement of brick in the bosh can not be permitted.

Some means of holding the bands in position is necessary. In one accident the bosh bands slipped down after a hearth breakout, the bosh walls were immediately pushed out, and three men were overwhelmed in an outburst of flame and incandescent coke. The bands are best held by resting them on top of the plate boxes. This arrangement, which is shown in figure 4, is absolutely secure. Another method is the use of a distance piece between the plates, extending from the lower to the upper band, as shown at *a*, figure 9. A third means is to lay an iron strap in the brickwork so that the strap projects and affords a base for the band, as shown at *b*, figure 9. This construction is the least satisfactory of all, though perhaps most widely used, as the strap may become loose.

JACKETED BOSHES.

There are two stock objections to the plate-and-band construction: (1) The cost is excessive; (2) when the brickwork between the cooling plates has eroded back 12 or 18 inches, as inevitably happens, it forms a series of ledges on which slag and other material can lodge. When the furnace is working irregularly under conditions of heavy driving, and a large scaffold forms and then the furnace slips, this mass of relatively cold material slides down in front of the tuyères and closes them up, chills the furnace, and perhaps freezes the tapping hole or cinder notch. This has led in some districts to the use of the jacketed bosh.

In this construction the bosh is entirely inclosed by a riveted steel-plate jacket. The lining is usually made very thin, 9 to 13 inches, although a lining 24 inches thick is occasionally put in, and the exterior surface is cooled with a film of water, sprayed at the top, which in descending covers the plate work of the bosh and carries the heat away rapidly enough to cool the brick lining of the hearth below the slag-forming point. In this way the cutting action of the slag is prevented.

DURABILITY OF BRICK LINING.

It is invariably found that in the course of a few days or weeks the original 18, 13, or 9 inches of brickwork is reduced to 2 to 6 inches thick, and it may completely disappear. However, owing to the sloping surface of the bosh and the chilling effect of the cooling water, any slag coming in contact with the thinly protected or naked plate work cements itself together with other material, largely carbon, on the exposed surface and builds a skin of insulating refractory material which, as long as it remains in position, is just as effective a protection as the original brick lining.

JACKETS COMPARED WITH PLATE-AND-BAND CONSTRUCTION.

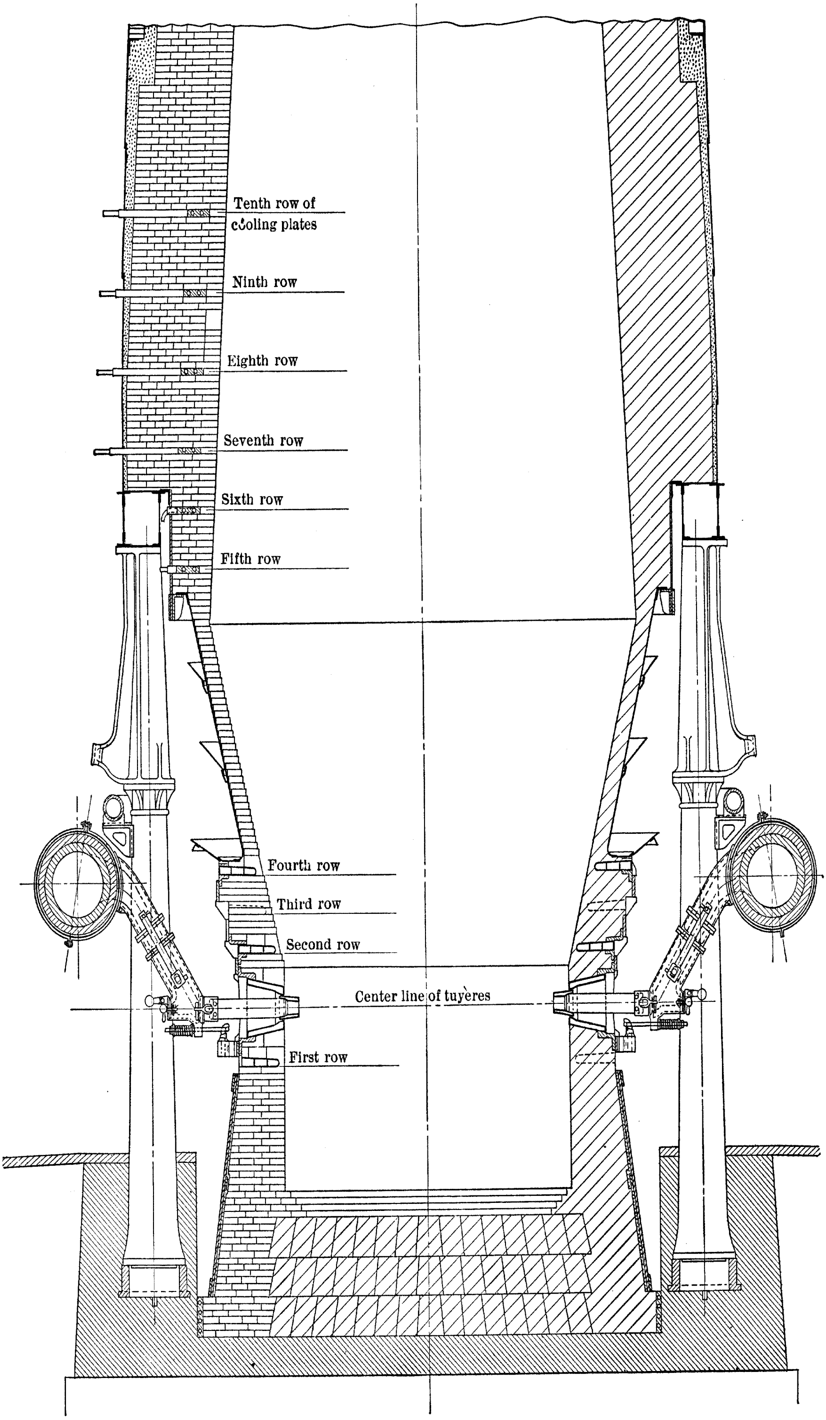
Theoretically, such a jacket has much to recommend it. It can be made as strong as desired, cooling should be effective over the entire surface, and the interior surface should be smooth instead of corrugated. Yet, so far as known, not a single furnace in the Pittsburgh, Youngstown, Buffalo, Cleveland, or Chicago districts, nor in contiguous territory, is jacketed. In northern New York, central and eastern Pennsylvania, southern Ohio, and the South jacketed furnaces are used in considerable numbers, but even in these districts the plate-and-band construction seems to be largely replacing the jacket. This tendency is not, however, based on considerations of safety so much as on advantages in operation, a discussion of which is not germane to this paper. Indeed, a superficial review of the history of the jacketed bosh would indicate that with regard to safety it is superior to the banded construction. The hearth and stack of the blast furnace were formerly constructed of fire brick and banded with steel strips, and historically the banded bosh might be considered a remnant of early building, which at other parts of the furnace less subject to heat, pressure, and erosion has been replaced with jacket construction, dictated by requirements of strength and resistance to bursting and outbreaks of blast and stock.

However, in spite of the theoretical advantages of smooth slope, strength, cooling, and tightness, furnace men going from plants smelting Lake ores to those using magnetites, hard ores, cinders, and local ores usually construct the bosh, at the first relining, according to their former experience—that is, with plate-and-band construction—while those who have tried the jacketed bosh on Lake ores express themselves as perfectly satisfied with the plate-and-band bosh and have no desire to try the jacketed bosh again.

JACKET CONSTRUCTION.

Bosh jackets are constructed of half-inch to 1¼-inch steel plate, riveted vertically on butt straps. Riveting and calking the seams is not unusually difficult or different from other riveting work, except that it is necessary to have all seams absolutely tight, the riveting first class, and the rivets fill the holes completely so that no opportunity may exist for gas to blow out. The interior and exterior conditions of service when the furnace is in blast are too rigorous for any possibility of outbreaks to be permitted, which may be obviated by special care in construction.

The bosh jacket is usually provided with riveted flanges at the top or is flanged to provide means of making connection at the mantle plate. Sometimes this flanged top is not riveted to the mantle, but is anchored or imbedded in the brickwork above the mantle, or it is riveted to a segment of the stack jacket. The stack jacket is, however, riveted or otherwise attached to the mantle plate and extends vertically downward to the junction point of jacket and bosh. (See fig. 10 and Pl. I.)



JACKETED FURNACE WITH BOTTOM OF BOSH RESTING ON BRICKWORK.

In the same way the bottom may be flanged or angles riveted on for attaching a trough to collect the cooling water running down the surface of the jacket. In some cases the bosh jacket is simply extended farther down to the hearth jacket, the lower part forming a tuyère-breast jacket, which is cooled by the water running off the bosh jacket.

As contrasted with the plate-and-band bosh, in which the weight of the whole bosh—brick, plates, bands, and boxes—with part of the weight of the stack lining rests on the hearth walls, in jacket boshes practically the whole weight of the jacket and brick lining is hung from the mantle, and this is one source of weakness. Contrasted with the thick, sturdy brickwork of the banded bosh, the lining in the jacketed bosh is very thin, and as the bosh and stack brickwork gets hot the compression may crush the brickwork and buckle the jacket, a possible though remote contingency. When the bottom of the jacket rests solidly on a structure of brickwork, as in the furnace shown in Plate I, or is riveted to the tuyère-breast jacket, as in the type shown in figure 11, such accidents may occur. Usually allowance is made for this expansion, as in the furnace shown in figure 12, in which the bosh jacket in expanding may slide over the water-cooled tuyère-breast jacket.

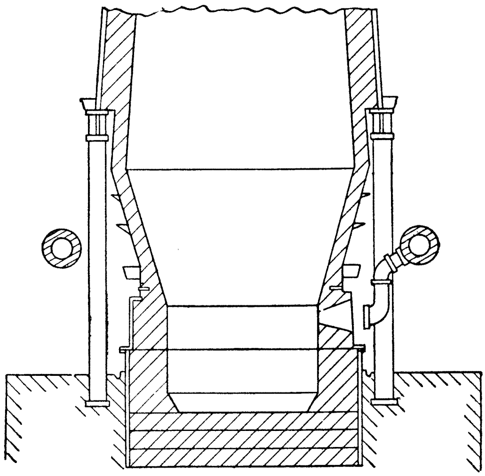


FIGURE 10.—Jacketed bosh.

FACTORS TENDING TO DESTROY JACKET.

POSITIVE WATER COOLING ESSENTIAL.

Buckling is evident at certain furnaces, and introduces the main operating difficulty, because if the surface of the jacket is not perfectly smooth, the film of water essential for cooling and preservation of the brickwork will not cling to it. In a short time the small space not water-cooled becomes hot and then white hot as the brickwork or conglomerate on the inside melts off. The jacket is quickly exposed to the attack of iron and slag, which may melt an opening through it. This, of course, lets out a jet of incandescent coke, gas, and slag and iron globules, which rapidly enlarges the opening and may result in a serious breakout. The formation of surface in-

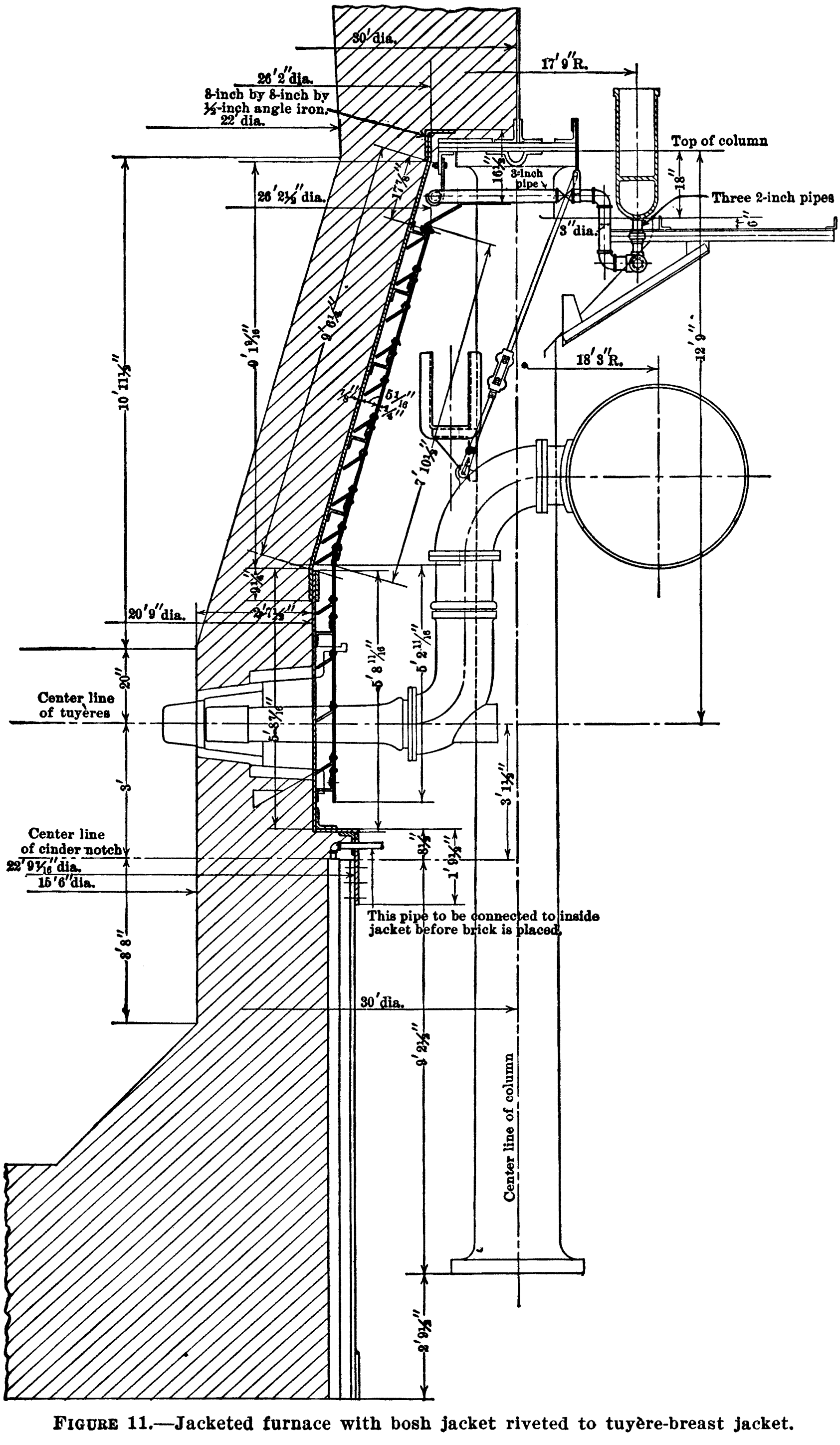


FIGURE 11.—Jacketed furnace with bosh jacket riveted to tuyère-breast jacket.

equality during operation is discouraging, for it makes useless the care and money spent during construction to insure a perfectly smooth surface.

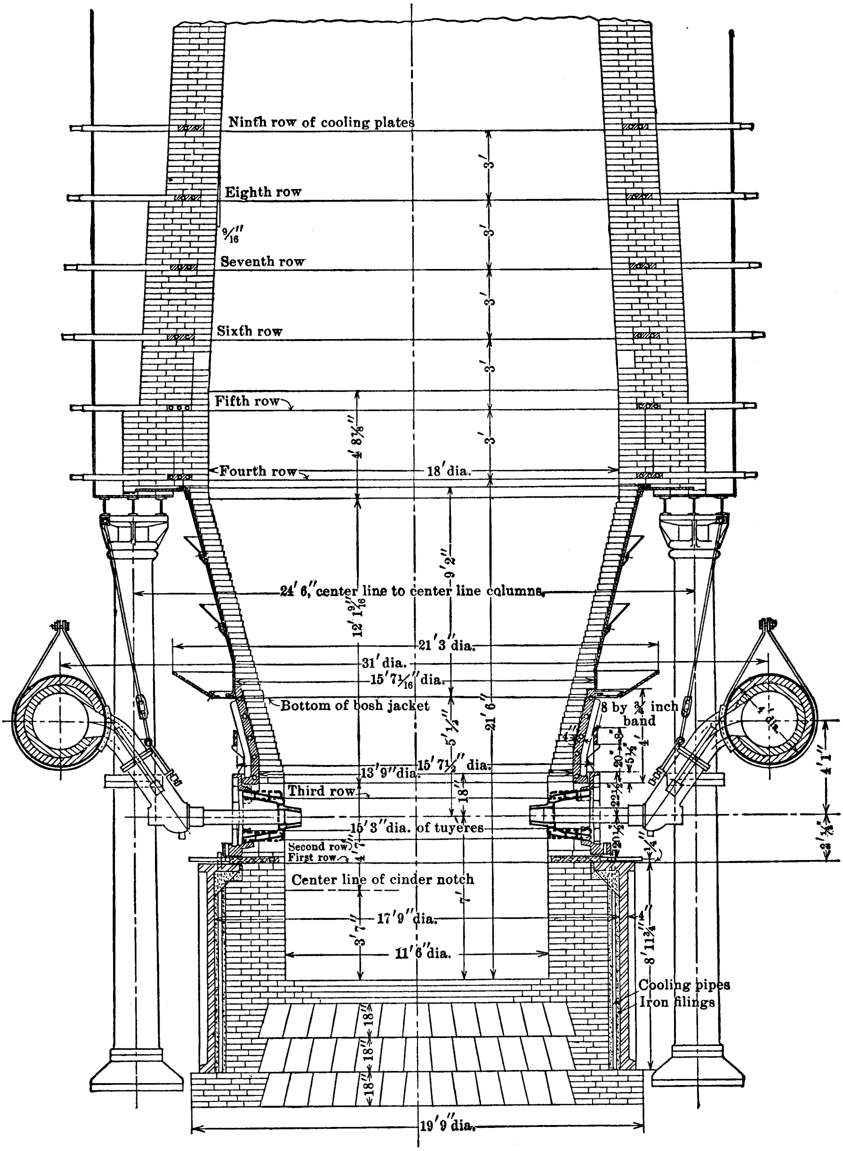


FIGURE 12.—Jacketed furnace in which expansion of bosh is provided for. The bosh jacket in expanding may slide over the water-cooled tuyère-breast jacket.

The rivets are countersunk flush with the surface so as not to present any interruption to the flow of water. From 2 to 10 annular funnels are placed about the jacket to catch the water thrown off and return it to the face of the jacket, or a spiral or helical trough is riveted onto the jacket with tap bolts. These spiral troughs are held away from the jacket by distance pieces (iron straps), part of the water running down over the surface while the rest runs down the spiral trough. This is probably the most efficient means developed for obtaining a positive contact of water with the shell.

FORMATION OF SKULLS.

Even with positive water cooling assured, other factors remain which may destroy the jacket. The skull that forms on the interior of the jacket may peel off and build up intermittently and thus cause warping, cracking, and opening of the jacket, as it is constantly subjected to extreme fluctuations of temperature. Sometimes when the skull slips or melts off, the gas may blow out between the jacket seams and unless immediately stopped may erode a dangerous hole. If these apertures or holes formed in other ways get beyond repair by calking, it is necessary to stop the furnace and put on a patch. Such a patch is difficult to cool and is of questionable strength and tightness, as it must be held externally by tap bolts.

EROSIVE ACTION OF CHARGE.

The occasional tendency of the furnace charge to work on the walls, or the necessity of so running the furnace at times that this condition can not be avoided, is a severe ordeal for jacketed boshes. As an example may be cited a furnace in Alabama, where this tendency proved too severe and the bosh was burned out. In many instances a similar accident has been averted only by the prompt use of longer tuyères. Long tuyères, although effectual in averting the difficulties and possible dangers of jacket construction by reason of excessive slagging of the walls or local cracks developing from intense heat, have the disadvantage of reducing the useful hearth area and changing the descent of the charge so that the burden moves too slow or "goes to sleep" on the walls.

USE OF AUXILIARY SPRAYS.

At plants having jacket boshes it is not unusual to see men engaged in putting on auxiliary sprays to take care of hot spots, deficient regular sprays, corrugations in the jacket, or gas blowing from rivet holes or riveted seams. However, at one plant the jacket bosh is entirely covered by an auxiliary shield to confine splashes of water, although this shield effectually prevents emergency first aid to the bosh, or noting signs of its failure. Although such "running in the dark" seems objectionable, when the difficulties at some other plants are considered, it has nevertheless been found practicable at this plant. However, the fire-brick lining is here approximately twice as thick as in the usual practice.

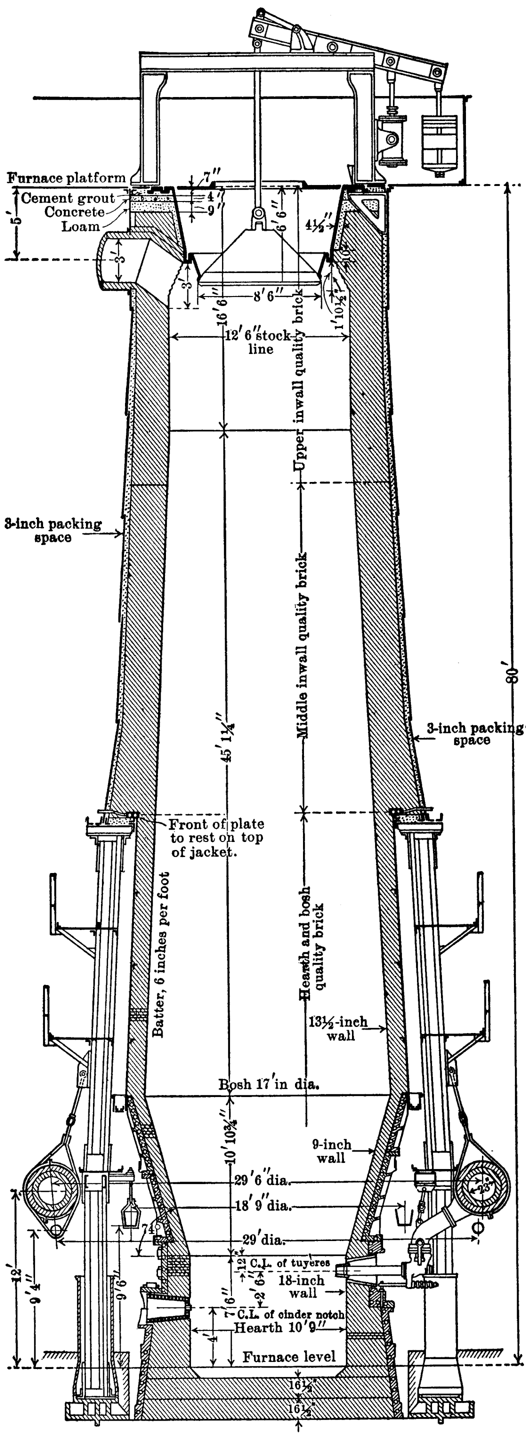


FIGURE 13.—Jacketed bosh built with cast-iron segments and circulating water pipe cast in.

OTHER TYPES OF BOSH CONSTRUCTION.

Several types of bosh construction have been developed to avoid the corrugations of the banded bosh and the warping or local failure of the jacketed bosh. One of these boshes consists of built-up sections of cast-iron segments with the water-circulating pipe cast in (see fig. 13). Another type consists of a riveted steel plate jacket, inside of and next to which are laid cast-iron staves with the water-circulating pipe cast in, which extends from the top to the bottom of the bosh (see fig. 14). These two types may be said to leave something to be desired in that any clogging of the water supply that might cause failure of the sections through overheating is a serious matter. Another type is the Roberts Farrell bosh (fig. 15), in which the entire bosh is inclosed by a steel jacket. Holes are cut in the jacket and through them plates are inserted in the brick lining. Provision is made for anchoring the plates to prevent tilting or ejection. This type of bosh, in modified form, is meeting with considerable favor, as it offers obvious advantages as regards security, structural strength, and operating convenience.

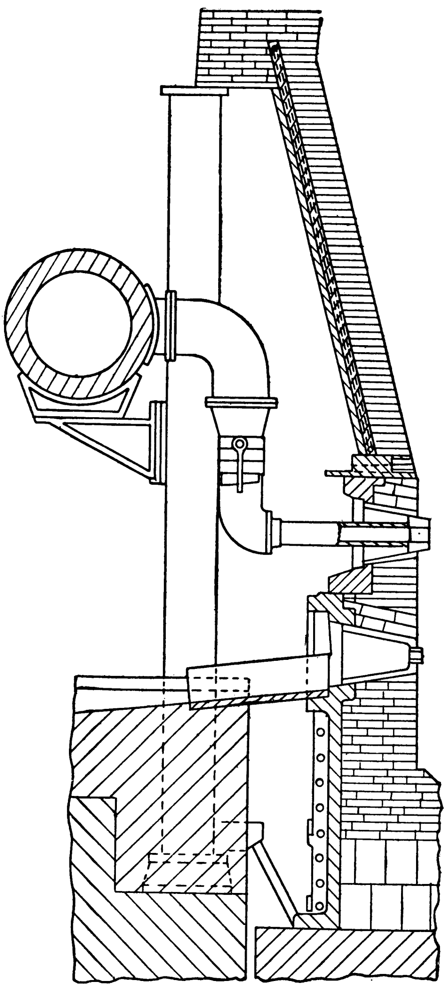


FIGURE 14. — Jacketed bosh built with riveted steel plate lined with cast-iron staves, water pipe cast in.

CAUSES OF BOSH BREAKOUTS.

Before describing bosh breakouts, it will be useful to summarize their causes. The causes of breakouts in banded boshes are as follows: (1) Excessive blast pressure, owing to scaffolding in the furnace; (2) excessive load or pressure caused by columns of stock falling or slipping in the furnace; (3) weak bands; (4) bands not held in position; (5) ejection of plates or brickwork between bands; (6) collapse of bosh by excessive corrosion of the brickwork; and (7) improper design, as where the top line of a weakly banded bosh extends below the mantle.

The causes of breakouts in jacketed boshes are: (1, 2, and 3) As in banded boshes; (4) formation and enlargement of holes through (*a*) rivet holes or riveted seams, or from (*b*) local failure of water cooling, or from (*c*) severe corrosion of walls and segregated melting or combustion adjacent to the walls.

EXAMPLES OF BOSH FAILURES.

BURSTING OF BOSH BANDS.

At one plant a plate-and-band furnace had been working irregularly for four days, the pressure varying 18 to 25 pounds per square inch after casting. About 40 minutes after each cast it was necessary to reduce the pressure to make the furnace move, and thereafter at about 40-minute intervals between the casts, which were at four-hour intervals. The furnace frequently failed to slip at the first check, and it was necessary to put the wind on again for 15 or 20 minutes and then take another check. Various expedients were tried to correct the difficulty, but the furnace persisted in slipping heavily, the tests showing slips of 8 to 30 feet. The furnace had been checked shortly before casting, when the charge moved slightly. The crew went on the drill, got the iron out, and after about one-third of the cast was run, the blowing engines were slackened, thus reducing the pressure from 19 to about 11 pounds. Then the furnace slipped and the bosh burst at the top, directly beneath the mantle. An outburst of flame, incandescent coke, fine carbon, ore, and in fact the entire content of the stack, was ejected as if from a gun, and engulfed a number of men working about the furnace or passing through the cast house. This furnace had 7½-inch by 1¼-inch bands about the bosh, which were broken both at the riveted joints and also between the riveted joints. The strength of the bosh was supposed to be approximately 10 times that of any pressure to which it might be subjected.

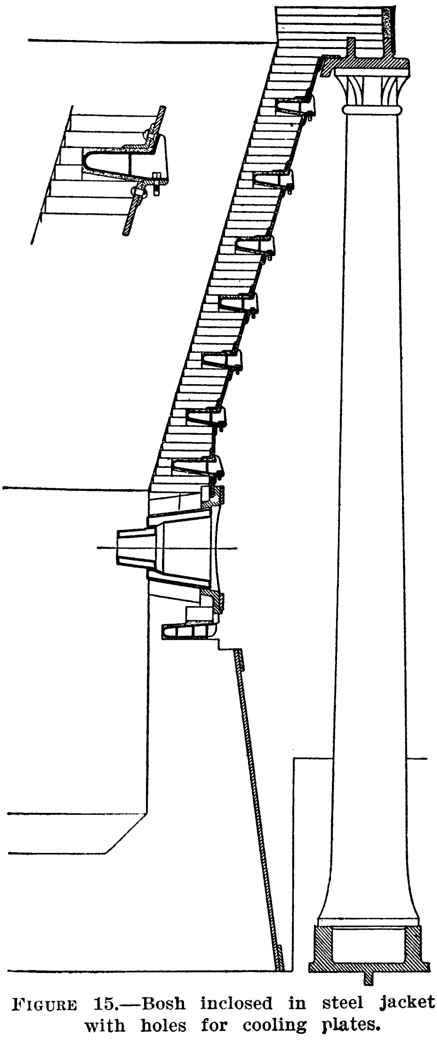


FIGURE 15.—Bosh inclosed in steel jacket with holes for cooling plates.

ESCAPE OF IRON INTO COOLING-WATER DITCH.

Another accident happened at a small plant having a banded bosh furnace, and was presumably caused by a hearth breakout. The iron escaped underneath the jacket and came up in the cooling-water ditch about the hearth jacket. An explosion followed that shook the entire plant and jarred the bands about the bosh so that the bands above the second, third, and fourth rows of plates slipped down. The brickwork, which obviously was under compression from within, was pushed out at one side of the front of the furnace and engulfed two men.

FALLING SCAFFOLD.

A plate-and-band furnace had been working on abnormally high pressures, with a scaffold in it. The scaffold fell and the gas ignited on the bosh and burned fiercely, indicating that a large mass of material had slid off and had thinned the walls. A large quantity of excess coke and sand, which had been charged previously to the slip, had about arrived at the bosh, and as it melted began to exude through the joints of the brickwork. Several water hose were being played on various parts of the bosh when at one side the brickwork between two adjacent plates and bands of one row blew out. The bricks and following flame and coke fatally burned a man who was standing in its path.

FAILURE FOLLOWING HOT SPOTS ON JACKET.

At a furnace built with a jacketed bosh, trouble had been caused by hot spots on the jacket, owing to the tendency of the furnace to burn on the walls, there being presumably a core of cold stock in the center. The bosh blew out at the rear, the furnace contents running out like water. Considerable damage was done to the plant but no men were injured. The failure was probably due to melting of the plate work and not to weak construction, because the furnace, aside from making raw cinder and off-grade iron, was not working abnormally or on high pressure, or making severe slips.

FAILURE FROM BURSTING OF RIVETED SEAM.

At another furnace which had a jacketed bosh, the jacket burst vertically along a riveted seam because of a heavy slip, and the furnace contents caught and killed a foreman and four workmen.

FAILURE FROM A HEAVY SLIP.

At an old stack, originally built with a high bosh, the top of the bosh was lowered on a relining 6 feet 9 inches below the mantle plate, the brickwork being inclosed by a vertical steel jacket of $\frac{1}{2}$-inch riveted plate hung from the mantle. This jacket was reinforced on the outside with four 6-inch by 1-inch bands and had three rows of cooling plates inserted. Below the jacket the bosh was of substantial banded construction. The upper part—that is, the banded steel jacket with 2 feet of fire-brick lining—burst in consequence of a slip, filling the cast house with a mass of white-hot coke and flame. The furnace had not been checked, and the pressure chart, which stood at 14 pounds, did not indicate any increase in pressure at the time the bosh burst. The failure probably was due to the impact of a falling column of stock on the contents of the bosh.

FUTURE HAZARD FROM BOSH BREAKOUTS.

In the trade journals from 1885 up to 1907 frequent mention was made of bosh breakouts; since 1907 they have steadily decreased. Rarely are any details given in these notices, and they are mentioned here only because of the significance of their decreasing number.

At plants which are in nearly continuous operation, with relining and reconstruction of the bosh at three to five year periods, the strength of the bosh has generally been brought to a point where the factor of safety is large and so far as managers and engineers can design with former failures in mind, or anticipate future requirements in view of the trend of raw materials and practice, such plants are free from any dread or possibility of bosh failures.

At plants that operate chiefly in times of good market conditions some boshes are liable to be deficient in strength and armoring, and with heavy driving bosh breakouts may be expected.

TUYÈRE-BREAST BREAKOUTS.

CONSTRUCTION OF TUYÈRE BREAST.

The tuyère breast is comprised in that part of the hearth which extends from the bottom of the bosh to the top of the hearth jacket. The brickwork at this point is 18 inches to 2 feet 9 inches thick and is built of standard 9-inch brick inclosing the tuyère-cooler arches and cooling-plate openings. The tuyère breast in a modern 500-ton furnace is about 5 feet 6 inches high and the outside surface, with a 2-foot 6-inch wall inclosing a 17-foot hearth, 22 feet in outside diameter, is about 390 square feet, which is diminished by 12 cooler openings 30 inches in diameter and usually by 36 cooler-plate openings 5 inches by 24 inches in size, making a total exposed surface of approximately 330 square feet.

FACTORS TENDING TO DESTROY THE BRICKWORK.

SOFTENING OF THE BRICKWORK.

The most energetic combustion of coke and the strongest inthrust of the blast are directly within this part of the furnace. The temperature at the nose of the tuyère may reach 3,300° F., and may be as high for a considerable space adjacent, because the combustion of 750 pounds of coke can not be instantaneous at the 12 or 16 small spaces in front of and above the tuyères. As the nose of the tuyère is but 6 to 15 inches beyond the face of the brickwork the combustion temperature must reach nearly maximum intensity at the face of the brick. This temperature is sufficient to melt any but the best hearth brick and to soften the best brick so that it becomes plastic or will flow under compression.

EROSION BY THE BLAST.

To the effect of this high temperature must be added the effect of the blast. In an average furnace 40,000 cubic feet of air, expanded to 60,000 cubic feet at 1,000° F. and at 15 pounds blast pressure is forced in each minute through twelve 7-inch tuyéres at a velocity of 310 feet per second. As the blast emerges from the nose of the tuyère with this high velocity it impinges on the mass of coke in the hearth. As this coke is held down by the weight of the furnace burden, the only way of escape open to the gaseous products of combustion is through the interstices between the pieces of coke. In spite of the great weight of the ore, limestone, and coke the force of the blast makes the coke in front of the tuyères and presumably that in the interior of the hearth above the tuyères and along the walls dance briskly. On seeing this movement at the tuyères one may imagine that the blast is thrusting the coke, which is still strong and harsh, against the hearth walls, and this is found to be the case on stopping the furnace. In some instances the hearth lining above, below, and between the tuyères has disappeared for a depth of 6 to 18 inches and may even be cut to so thin a shell that the furnace has to be blown out.

SLAGGING OF THE BRICKWORK.

In the lower part of the tuyère breast the accumulated slag lying in the hearth attacks the brickwork. In normal work this slag rarely comes within 1 foot of the tuyères, although it occasionally perplexes furnace men by persisting in lying in front of the tuyères and running back in them, when no cinder can be drawn from the cinder notch below. In this zone of slag accumulation there is, of course, slagging of the brickwork and thinning of the walls.

PRESSURE WITHIN TUYÈRE BREAST.

The chief factor in corrosion of the tuyère-breast lining, however, is held to be erosion by the cutting action and back thrust of the blast and the particles carried in it at the high temperature and pressure of the hearth.

If it be assumed that the hearth has a diameter of 16 feet and inclosing walls $31\frac{1}{2}$ inches thick, and is $4\frac{1}{2}$ feet high, then the inside surface is 226 feet square and the exterior surface is 301 feet square. The interior surface is reduced by 12 tuyère openings to 185 square feet and the outside surface to 242 square feet. With a blast pressure of 15 pounds at the tuyères there is a drop in pressure inside the furnace which amounts to approximately 2 pounds, so that the pressure inside the hearth may be taken as 13 pounds. Under the most unfavorable conditions of hanging the pressure might mount as high as 30 pounds. The total lateral pressure which tends to produce rupture on a circular area 1 inch high about the tuyère breast may then be: $P=d\times p$, where d=diameter and p=pressure. $P=16\times 12\times 30=5{,}760$ pounds pressure, which is the total force on a longitudinal plane against the 1-inch high circular area about the tuyère breast.

This pressure, exerted on a wall built up of small bricks, $2\frac{1}{2}$ inches thick by $4\frac{1}{2}$ inches wide by 9 inches or $13\frac{1}{2}$ inches long, laid without cement other than a thin seal of fire clay between the joints, may conceivably displace and force out segments of brickwork, although in fact such failure does not often occur. The writer has seen furnaces at which the brickwork at the tuyère breast had started and was held from bulging out farther and causing a breakout by being braced against the column with wooden blocking.

USE OF COOLING PLATES IN TUYÈRE BREAST.

The danger of breakouts between the tuyère coolers, when the brickwork gets thin from melting, slagging, and mechanical abrasion from the back thrust of the gas, is usually provided against by the insertion of bronze cooling plates. These plates are usually built solidly into the brickwork from the outside face to within 9 inches to $4\frac{1}{2}$ inches of the inside face. Occasionally only one plate placed vertically is used; more often two plates are laid horizontally one above the other about 15 to 18 inches apart, center to center; infrequently three plates $12\frac{1}{2}$ inches apart, center to center, are used. The plates are roughly of the same type as those used in the bosh, being tapered horizontally and vertically. Although the wearing action is most severe, such plates have proved entirely satisfactory. A few managers go a step further and provide water-cooled plate boxes in which to place the plates, but many furnace men do not consider it necessary or advantageous to do so, as a water-cooled plate cools the brickwork just as effectually and also prevents thinning and breakouts of the tuyère-breast wall.

Figures 16 and 17 show clearly how the insertion of cooling plates between the cooler arches reduces the noncooled part of the tuyère breast and lowers the temperature of the brick below the slagging point before it has been reduced to an unsafe thickness.

PROTECTION OF BRICKWORK ABOVE THE TUYÈRES.

That part of the brick lining above the line of the tuyères is similarly cooled by radiation of heat to the lower row of bosh plates above and to the water-cooled tuyère coolers and the tuyère-breast plates between the coolers. The vertical distance between the tuyère cooler and bosh plate is, on an average, about 16 inches on the inside face; the distance between the tuyère-breast plate and bosh plate is 15 or more inches. This obviously leaves only a small volume of brickwork unprotected.

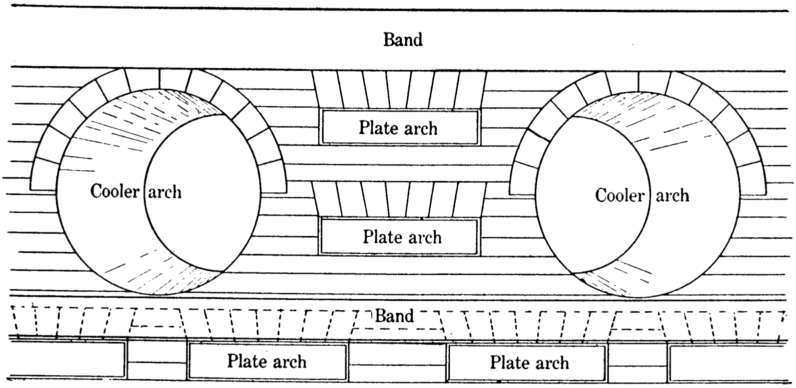


FIGURE 16.—Sketch showing construction of tuyère-breast wall with cooling plates between cooler arches.

PROTECTION OF BRICKWORK BELOW THE TUYÈRES.

That part of the brick lining below the tuyère coolers is under a rather severe load, as it is subject to the slagging action of cinder, which accumulates and rises along the hearth walls and is then drawn off, and also to the back thrust of the blast. To prevent severe erosion this part of the hearth walls is almost always copiously cooled. As a general rule two plates per tuyère are inserted at this point, or 24 plates for a furnace with 12 tuyères. On a 500-ton furnace the plates are usually placed 32 to 36 inches below the center line of the tuyère, being spaced horizontally about 3 feet center to center. As the plate opening is about 2 feet wide, there is only 1 foot of brickwork horizontally between centers. The plates are set back about 9 inches from the inside face of the lining, the idea being that this depth will be sufficient to obtain an equilibrium between the cooling effect on the brickwork and the attack of blast and slag, so that a sufficient thickness of brick will be left in front of and above the plates. However, such a result is almost never attained. Examination usually shows that at one or more periods when corrosive conditions have been unduly severe the brickwork has disappeared and been replaced with graphitic carbon, slag, and other substances, so that although the plate may have been naked intermittently, it may be assumed to be insulated normally by furnace deposits. It is rather essential that some covering about the plate be preserved, as sometimes labor conditions, slowness in handling ladles in the yard, or hard tapping holes delay the cast so that iron accumulates in the hearth and reaches the level of the cooling plates. Unless the plates are insulated from the molten iron by a scab of slag or graphitic carbon

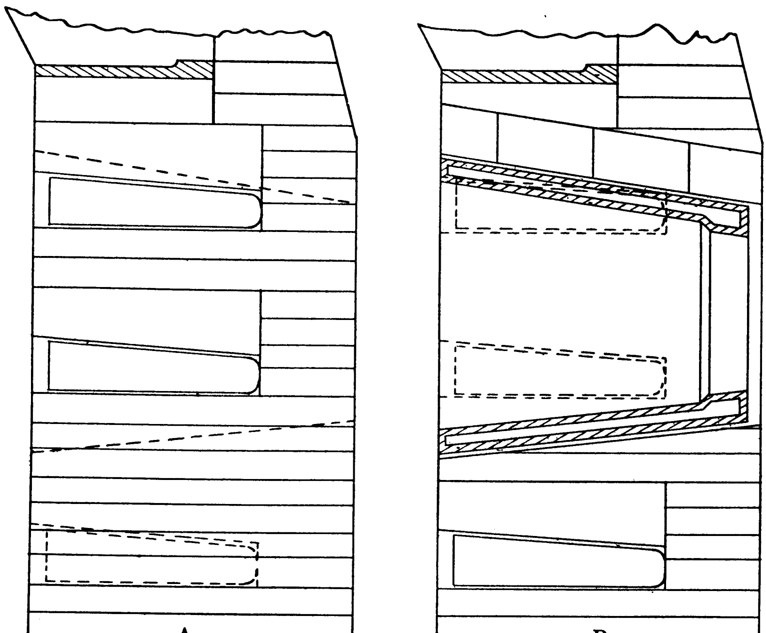


FIGURE 17.—Sectional view of tuyère-breast cooling plates.

they are likely to be cut and explode when the water reaches the fluid iron.

Such plates are usually cooled by connecting them below and between the cooler arches in series, the inlet being at the first lower plate, thence to the second, and then through the two upper plates between the coolers.

OMISSION OF PLATES BENEATH THE TUYÈRE COOLERS.

A few plants do not insert the plates below the coolers, but bring the water-cooled hearth jacket up to the bottom of the cooler arch, thus relying on exterior cooling. Though the wall becomes much thinner before a cooling effect sufficient to arrest erosion is established, officials of these plants claim immunity from explosions of plates or breakouts at this point.

The objection to this construction is that the brickwork beneath the tuyère coolers becomes so thin that only an insecure foundation is left to support the coolers, and they may drop down or failure may develop beneath them. This is a valid objection, for the weakest place in a furnace equipped with cooling plates is immediately about the cinder-cooler opening, where at times the plates must be left out because of lack of room. Cinder breakouts occur at this point, between the top of the hearth jacket and cooler arches, not infrequently at some plants. There is, of course, the additional effect of increased erosion from the blast when the furnace is "blowing on the monkey" (flushing cinder when the blast blows through with the slag).

USE OF PLATE BOXES.

At a few plants boxes similar to the plate boxes in the bosh have been used at this point, but they are not satisfactory because they require cooling with sprays on the inside to prevent cinder breakouts. Evidently there must be cooling from the outside face. In Southern practice, when these plate boxes are used with outside cooling also, they are cast with hollow walls in which water is circulated. This arrangement has proved satisfactory, but probably is not more so than a simple bronze plate.

REINFORCEMENT OF BRICKWORK.

Although there are a few plants at which the entire tuyère breast is inclosed in cast steel or iron segments, cooled by water circulating through pipes cast in them, the tendency seems to be to inclose the tuyère-breast brickwork in a jacket of steel plate, holes being cut in it for cooler and plate openings. This jacket extends from the hearth jacket up to the bottom bosh-band and makes a breakout of brickwork literally inconceivable, provided it is water-cooled by plates.

Where the brickwork is held in only by the lower bosh-band and a band between the cooler arches and bottom row of bosh plates, there is nothing to prevent displacement of the segment of brick between the coolers and bands except the binding effect from the weight of the bosh above and the wedging effect of the cooler arches. The pressure is applied on the under or concave side of the arch, which obviously offers no resistance other than its own weight and inertia. Such construction is not safe.

The reason that unreinforced brickwork on the tuyère breast is unsafe is apparent from the previous statement (p. 25), in which it was shown that the pressure applied to the inside of the brick wall amounted to, in an extreme case, 5,760 pounds, which tended to move the walls outward and to produce rupture. If the resistance of the built-up brick wall to this rupture be ignored, and its resistance may in fact be slight, it follows that a reinforcing jacket about the tuyère breast is necessary. These are almost universally used nowadays on large furnaces, and when built up of steel plates are $\frac{1}{2}$ to $\frac{7}{8}$ inch thick. The factor of safety in blast-furnace construction is very large at this point, as may be seen from the following figures:

$$T=\frac{p \times d \times f}{2 \times S}$$

T=thickness of plate.
p=pressure in pounds per square inch.
d=diameter in inches.
f=factor of safety.
S=tensile strength of plate.

$$T=\frac{30 \times 192 \times 10}{2 \times 55{,}000}=0.52 \text{ inch.}$$

When instead of a tuyère-breast jacket only two 12-inch bands are used, one immediately below the bosh and just above the cooler arches, with the other just below the cooler arches and a short distance above the hearth jacket, then if the tuyère breast be $4\frac{1}{2}$ feet high, it is evident that the bands will cover but four-ninths of the total area and should therefore be made correspondingly heavier than the tuyère-breast jacket. For example, if a factor of safety of 10 requires a thickness of tuyère-breast jacket of $\frac{1}{2}$ inch, then if the duty of the jacket is to be carried by two bands like the ones mentioned above, they should be $1\frac{1}{8}$ inches thick by 12 inches wide. As a rule these bands are 1 inch to $1\frac{3}{4}$ inches thick, and the lower band is often made the heavier of the two. The reason for this is that the lower one carries most of the load unless buckstays are placed about each cooler arch and held by the bands to prevent bulging of the brickwork. Without such buckstays in addition to the two bands, it is apparent that each cooler inserted in its opening, which has the shape of a truncated cone, forms a pier that receives the thrust of adjacent brickwork resulting from its expansion and its tendency to be forced by interior pressure. The cooler is primarily held in place by the pressure of the blowpipe against the tuyère stock. The stock is held by the bridle rod, which is attached to the bridle post, and the post is fastened to the lower band, which thus prevents displacement of the brickwork about the cooler. This is obviously a roundabout way of transmitting the thrust of the cooler to the band, and as a rule the cooler is anchored by inserting a forged steel piece between the cooler and the bridle post. When resistance to internal pressure is provided by vertical buckstays between the bands, the cooler is anchored to the buckstays, which is preferable in that it distributes the load over both bands. Another practice is to provide a second auxiliary bridle rod between the tuyère stock and the upper band. (See fig. 18 and Pl. II.)

PACKING OF TUYÈRE COOLERS.

In addition to the possibility of breakouts from the brickwork being displaced, cut through by the blast, or slagged away by cinder,

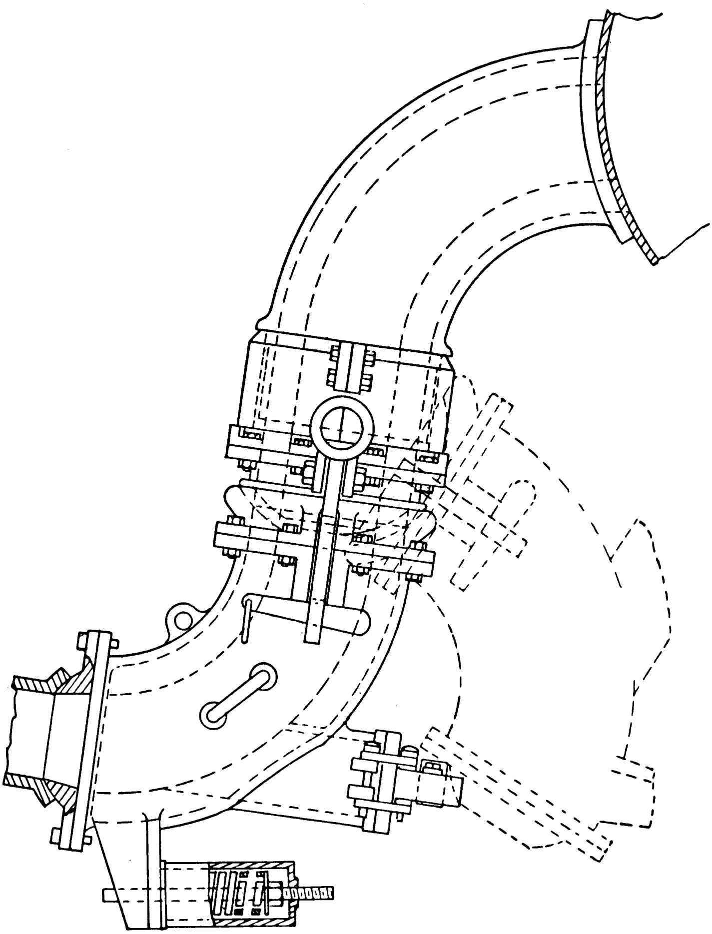
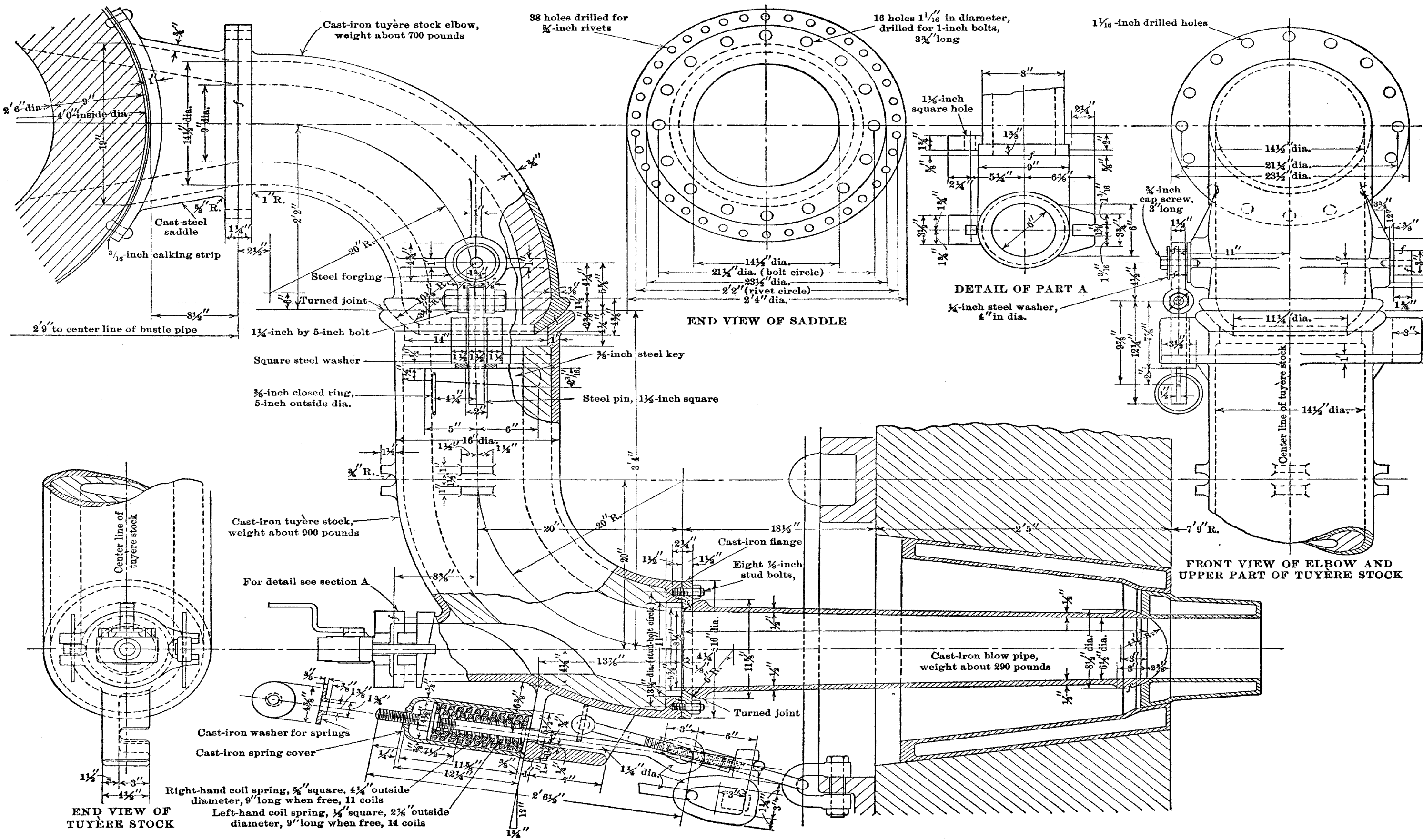


FIGURE 18.—Tuyère stock, showing lug for auxiliary bridle rod.

there is also a possibility of cinder breakouts between the brickwork and tuyère coolers, which is only minimized by good packing. The coolers are never made to fit snugly in the cooler arches, because it is impossible to get the necessary continuous contact and because the cooler arch may not give the cooler a true position if it must fit in it snugly between the brick and cooler surface by this means, so a packing space of 1 to 1½ inches is left. The coolers are set before



DETAILS OF TUYÈRE STOCK AND BLOWPIPE EQUIPMENT.

starting the furnace and are usually packed much more tightly than is possible when they must be replaced later on. One method, not much in favor, is to run neat cement in about the cooler and brickwork. Another is to pack the space with clay, tightly rammed in from both inside and outside the furnace; sometimes asbestos rope is rammed in the front space to make an extra tight packing. A few plants use asbestos packing throughout. The plates are similarly packed. Whether the job is done on relining, or, as is occasionally necessary, during the blast, it is recognized that the packing must be thoroughly done, it being the poorest economy to save time by improper packing. This is for two reasons; the blast will find the weak spot in the packing, and a cinder breakout will follow, making another shutdown necessary; or the weak spot will yield from a slip and the slag and gas burst out. The cooler nose is generally set back $\frac{1}{2}$ inch to 2 inches from the inside face of the lining, so that it becomes covered with a crust of graphite and slag and is not exposed to pockets of molten iron, which will cut it, come in contact with water, and cause an explosion.

BLOWPIPES AND EYESIGHTS.

Another danger point of a slag breakout is in the blowpipe and eyesight. Sometimes through a furnace working cold on the bottom, or to one side, or for no apparent reason, cinder will lay in front of the tuyère where it can be seen through the eyesight, tossing and rolling away as the blast rushes from the tuyère nose into the furnace. This condition may persist even after repeated draining of slag from the cinder notch, and sometimes only gas and a few globules of slag can be drawn at the cinder notch while a large volume of slag is banking up about one or more tuyères. The usual remedy is to reduce the blast as much as possible and still keep the slag from running back and raise its temperature as high as possible. This sometimes "dries" the tuyères, but occasionally the slag suddenly runs into the blowpipe, where, as it usually carries metallic iron, it cuts through and makes an opening through which a large volume of slag, coke, and gas blows out. Another possibility is that the furnace burden will slip and force the slag into the blowpipe. Sometimes the slag is driven up into the bustle pipe over into the hot-blast main, and has been known to fill one or two hot-blast valve chambers. The blowpipe may burn at this time and cause a similar or worse "mess." The force of the impact of slag against the pipe and stock may burst the glass of the eyesight, or with old types of eyesights, throw them open, when a jet of red-hot liquid slag will spurt out, as if from a high-pressure pump, into the cast house.

There is no adequate safeguard to prevent slag coming into the blowpipes, although, of course, many flap valves and relief valves have been patented which have never been long used because they are without exception intricate or difficult to keep in working order. The blowpipes are made as heavy and with as thick walls as possible compatible with the necessity of taking them down and putting them up by hand almost daily. For this reason the pipe walls should not be thicker than seven-eighths inch, which is sufficient to withstand a very severe attack, and are usually one-half inch thick. They are usually made of the best grade of Bessemer iron, as a poor grade will bend and cut more easily. A few plants use blowpipes made of lap-welded steel pipes. Such pipes may be cheaper under local conditions, but are not as resistant to attack by slag and iron.

TYPES OF EYESIGHTS.

The eyesight has received much attention, and several safe and excellent types are now in use. It is to be kept in mind that when the furnace is being taken off at cast, or checked, it is usually necessary for some one to watch the tuyères to see that cinder does not enter them. If the slag is suddenly dashed back, the glass of the eyesight may be shattered or the eyesight may be pushed from its seat, and the observer be caught and burned.

Obviously, the elementary precaution is to have a glass eyesight, but there are plants at which the keeper, blower, or helper opens a blind sight and, with the blast blowing in his face, attempts to peer into the tuyère. Because of the difficulty, and the danger of flying dust getting into his eyes, it is apparent that the watcher may devote minimum attention to the working of the furnace at the tuyères, thus increasing the possibility of a blowpipe burning.

The size of the aperture for the glass need not be large; three-eighths inch is as near standard as any other figure, although many are twice as large. It may be as small as one-eighth inch with certain types of eyesights, and the smaller the aperture the less chance of the glass flying out if a splash reaches it or if it should crack from any other cause. Many furnaces use an eyesight (see fig. 19) one-eighth inch in diameter, and it affords a good view of the entire surface of the tuyère. The farther back from the tuyère cap the eyesight is, the larger the eyesight opening may be without danger of breakage from coke or slag. An example of such an eyesight is shown in figure 20.

Both these types are also safe from being thrown open. A third type is shown in figure 21, and a fourth in figure 22. A type still in use at many plants in western Pennsylvania is shown in figure 23. This type, being held down only by the counterweight *a*, can be thrown open on severe slips to allow cinder, coke, or gas to blow out; so that it is disliked in other districts.

EXAMPLES OF TUYÈRE-BREAST BREAKOUTS.

In the following paragraphs are given instances of tuyère-breast breakouts.

1. At a plant where the iron was cast in beds, both beds were full, owing to trouble with the iron carriers, and the furnace had gone beyond the usual casting time. Cinder had been flushed several times, and at the last flush the iron had risen so high that it came over the "monkey" (or cinder notch) and burned it. As it was thought that the bed would soon be cleared, the blast was kept on until cinder showed at the tuyères. Under these conditions the blast could not be taken off without the blowpipes becoming filled with cinder, nor could cinder be drawn off at the cinder notch for fear of the cinder-notch cooler exploding. About two hours after casting time one bed was cleared and the crew went on the drill, when the furnace wall collapsed near one of the tuyères next to the tapping hole, throwing out the brickwork together with molten iron and slag. Several men were injured. The furnace did not slip, had been working regularly, and the accident was evidently due to failure of a presumably thin wall under too heavy a load. The tuyère breast was held in by bands above and below the coolers and had no cooling plates in the brickwork.

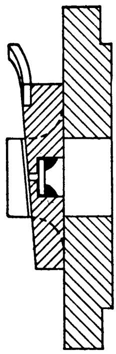


FIGURE 19.—Eyesight with $\frac{1}{8}$-inch aperture.

2. The furnace at another plant had been working badly and scouring the walls, while cinder and iron kept coming into the blowpipes. The iron finally ran out between the cooler and brickwork, where it cut the bronze and exploded on contact with the cooling water. The cooler was blown out with great violence; slag, coke, and gas shot from the furnace and killed two men. This accident may be regarded as purely accidental and a hazard of the work.

3. A furnace, which was hanging, slipped after about two hours; a section of brickwork blew out between the cooler arches, bursting the band. Incandescent coke and cinder blew out above the tuyère and burned a helper fatally.

4. In another instance a blowpipe was loose and the hot-blast man started to tighten the nut on the bridle rod. The bridle post was a round pin which, under the added strain, evidently turned in its socket, allowing the bridle rod to slip off. The blowpipe dropped immediately and the man was caught in a sheet of flame from the tuyère.

5. At another plant the furnace walls beneath the tuyères were eaten away by the slag and blast. and failed at a place near the

cinder cooler. The cinder with melted iron came through, caused some damage by cutting the iron hearth jacket, and, cutting a large hole, flowed out over the cast-house pavement. No men were injured. After the mess had been cleared away, fire clay and crushed brick were rammed into the hole, and a 9-inch wall was built on the face and wedged in tightly. A small water spray was put on and the furnace started. No more trouble was experienced. This incident is typical of the usual slag breakout, and many other examples could be given.

6. A furnace was being checked under difficulties as it was "sloppy" at several tuyères and the cinder tended to run into the blowpipes. The foreman had checked the furnace once and was stepping from eyesight to eyesight to watch the tuyères; the helper was also similarly engaged. The helper suddenly shouted, indicating that cinder was coming back, and jumped aside. The foreman sprang to the whistle switch to signal for the blast to be put on, and while standing at the switch for the brief instant necessary, the blowpipe burned through and he was struck on the back with a shower of coke and slag and burned severely.

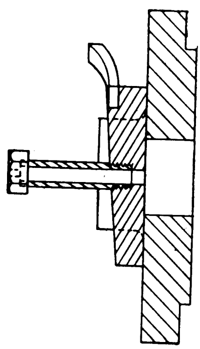


FIGURE 20.—Eyesight with glass set back from tuyère cap.

7. At another furnace there had been difficulty in taking the furnace off at cast. Cinder came into the blowpipes, and the snort valve could not be opened. As a fierce flame showed at the tapping hole, preparations were made for a quick stop, the blast was thrown off, and the men swung the nose of the mud gun into the hole. At the same instant, cinder and iron came into the blowpipe, which was above them, burned through, and caught two men, causing severe burns on their faces, arms, and bodies.

8. In another instance iron accumulated in the hearth of a furnace and rose up in contact with the cooling plates beneath the tuyères. An explosion, caused by a leaky plate or by the molten iron cutting the plate, threw the plate about 200 feet from the furnace. A shower of molten iron followed, but fortunately no men were injured.

9. A similar explosion blew out the side of a furnace above the hearth jacket.

10. A breakout of gas, coke, and cinder from a tuyère opening was caused by a lug, cast on the gooseneck breaking off. This allowed the stock hanger to fall; then the stock swung aside, the blowpipe dropped, and the furnace contents blew out. No one was injured. A similar accident occurred when a bridle rod burst and allowed the blowpipe to drop. In this case a workman was killed. Both acci-

dents happened without warning and in absence of any such work being done as tightening the stock hangers or bridle spring.

11. The hazard from occasional duties about the furnace is shown by an accident in which several men were severely burned. The furnace had been blown out and after the last cast the crew were engaged in taking down the blowpipes, two gangs being at work. Without warning, a mass of material, presumably a scaffold which had become loosened by the heat and water, incident to blowing out, fell into the hearth and blew a cloud of incandescent carbon dust and gas from the tuyère openings. A similar accident which occurred at another plant cost several lives.

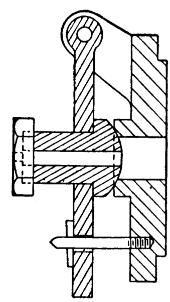


FIGURE 21.—Eyesight, keyed type.

PREVENTION OF TUYÈRE-BREAST OR BOSH BREAKOUTS.

IMPORTANCE OF CORRECT CONSTRUCTION.

Safe methods of practice are of little avail in preventing tuyère-breast or bosh breakouts, if by faulty design or construction, weakly built, insufficiently reinforced, or improperly cooled segments of brickwork have been incorporated in this part of the furnace. Modifying methods of practice is of little benefit because of the suddenness with which such accidents occur. Possibly 95 parts of prevention lie in construction and 5 parts in experience, resourcefulness, and arrangement of the cast house for accessibility of signals and possibilities of escape.

COOLING.

The bosh plates should be flushed out regularly to prevent loss of cooling efficiency from sediment depositing in them. Hot spots on the bosh jacket should be remedied by putting on additional sprays. The use of longer tuyères is effective in correcting any tendency to local heating on the side of a bosh jacket. A longer tuyère also diminishes the tendency to cutting about the bosh plates, between the tuyère arches, on the tuyère breast walls, or near the cinder cooler. At best longer tuyères, tuyères with a smaller nose, or plugged tuyères are but temporary expedients and if they must be persistently used to prevent fast or abnormal working on the walls and severe erosion, their use is likely to produce off-grade iron and dangerous conditions of scaffolding, hanging, and slipping.

REGULARITY OF FURNACE OPERATION.

This brings the discussion into the realm of stock distribution, location of gas offtakes, blast distribution in the hearth, burdening and fluxing, lines of the furnace, use of high heat, regular blast, and the various and many factors contributing to uniformity in practice, freedom from slipping and scaffolding, and long life of the lining. These factors are not without relation to bosh breakouts, but must be passed by with the statement that careful operation is a requisite for prevention.

ARRANGEMENT OF CAST HOUSE AND SIGNALS.

The arrangement of the cast house should provide for security in case of bosh breakouts. Means of exit should be provided about the furnace itself, on at least two sides, and in addition there should be an exit from the foot of the cast house. If the cast-house floor is at a considerable height from the yard level, steps or, still better, inclines, should be provided with strong railings. There should be a shield between the snort-valve lever or wheel and the furnace, and the wheel should not be in direct line with a tuyère opening. In addition to the blowing-room signal at the snort-valve wheel an emergency signal should be placed at some other point about the cast house, preferably in some unexposed place outside—for instance, near and behind the No. 1 stove. When this is inconvenient, the emergency signal can be placed in the cast house on the opposite side of the furnace from the one in common use or immediately outside a doorway. A noteworthy safety device is an auxiliary arrangement by which the snort valve on the cold-blast main may be opened from beneath, independently of the cast-house lever or wheel.

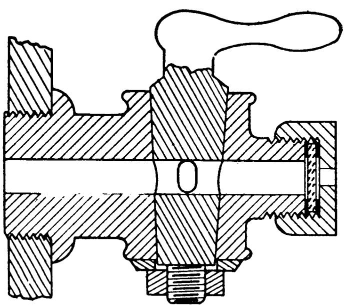


FIGURE 22.—Eyesight, stop-cock type.

OTHER PRECAUTIONS IN CAST HOUSE.

With these arrangements made the last precaution is to insist that members of the force not belonging to the cast-house crew must not make a habit of walking through the cast house in proximity to the furnace. When the furnace is working irregularly, slipping heavily, or being checked after hanging, men should be warned to keep away from the front, from underneath blowpipes, and to use every precaution and be alert when watching the tuyères.

HEARTH BREAKOUTS.

During the past few years serious breakouts occur more frequently at the hearth than at the bosh and tuyère breast. In fact, this has always been so, but with small amounts of iron in the hearth the breakouts were not necessarily serious, especially as the blast pressure was not high. With increasing tonnage and fast driving, they assumed serious proportions, sometimes wrecking the furnace, occasionally costing lives, and almost always causing bad messes, delays, and inconvenience.

BREAKOUTS THROUGH THE HEARTH JACKET.

The destructive agencies within the hearth walls are as follows: (1) Erosion of the hearth walls by the blast, especially over the tapping hole; (2) disintegration of the brickwork by the chemical action of liquid slag and iron; (3) mechanical action of fluid iron in penetrating the joints of the brickwork. The result of these attacks is indicated in figure 24.

It is evident that the bringing down and accumulation of molten iron and slag in a zone of intensive combustion, pressure, and heat require exceptional construction. Improvement in strength, insulation, and cooling has developed this part of furnace design to a point where plants at which one or more breakouts always occurred during a blast, have reduced the danger of breakouts to an almost negligible factor.

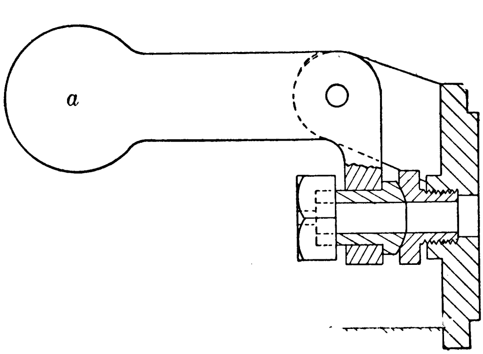


FIGURE 23.—Eyesight with counterweight.

THINNING OF THE HEARTH WALLS.

One point should be kept in mind in regard to hearth breakouts, and that is—regardless of the thickness of hearth walls or the cooling intensity on the exterior, all furnaces become worn away on the inside in much the manner shown in figure 24, so that the wall becomes relatively thin and retains its form only by virtue of the cooling and reinforcement of a metal jacket. This condition is found in furnaces blown out even after a short run. The study of the cause of this condition and of means of holding the hearth walls after it has developed provide a basis for understanding the occurrence of breakouts.

ABRASION BY THE BLAST.

The thinning of hearth walls is partly attributed to the erosive action of currents of gas, caused from combustion and the blast, when the cinder and iron is low after a cast. Erosion is effected as in the bosh and tuyère-breast walls, and is especially active when at casting or flushing the gas sweeps down along the wall and blows out of the tapping hole or cinder notch. Although the temperature may be theoretically too low to melt fire brick, it is high enough to soften it so that it may be abraded by coke ground against it by the back thrust of the blast.

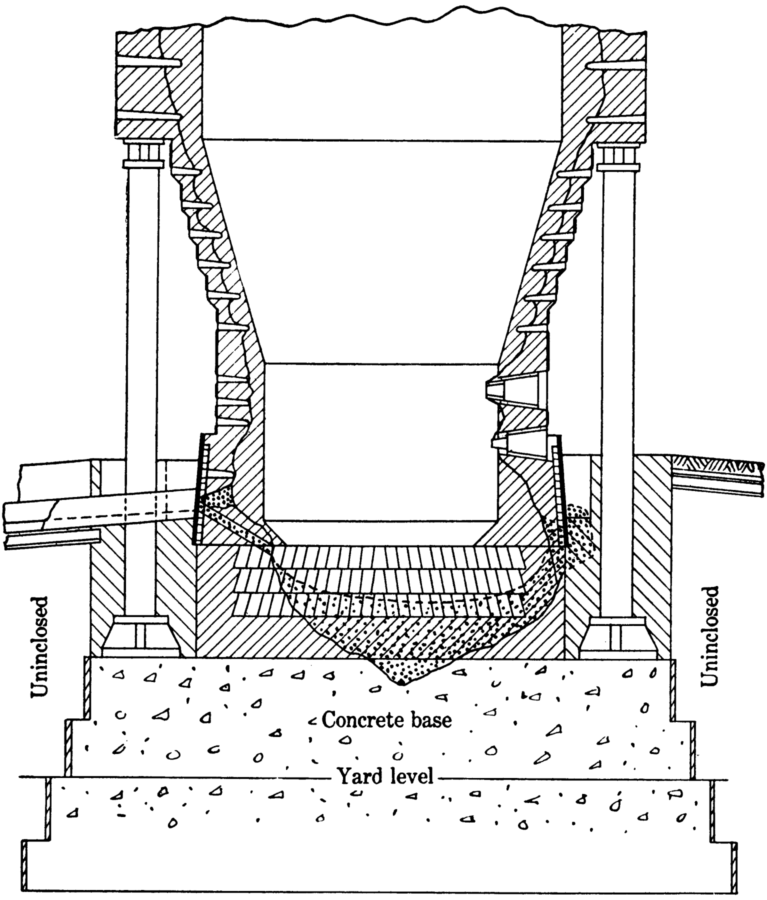


FIGURE 24.—Diagram showing how hearth walls are attacked.

ATTACK OF SLAG.

Added to this erosion is the attack of slag. While the composition of blast-furnace slag is frequently acid, that is, rich in silica and alumina, nevertheless even when viscous with silica, it will combine with avidity with more silica. This is because slags of even pronounced acidity, as regards furnace requirements, are basic from a mineralogist's standpoint. Of greater significance, however, is the physical state of the slag and its effect on the facility with which the slag will attack brickwork. A thinly liquid slag will penetrate the interstices and joints of the brickwork more easily than will viscous aluminous or mucilaginous limy slags. Such slags tend to adhere to the walls and to freeze in cavities, whereas a fluid slag is more likely to drain from the walls at each cast and flush, and on rising it again attacks the exposed surface of the constantly enlarging cavities in the brickwork. All refractory materials tried are destroyed by the physical-chemical activities of heat, erosion, and slag, and with a sharp slag and highly heated furnace, corrosion will bring about an unperceived destruction of hearth walls in a very short run, the hearth walls sometimes losing 3 feet of thickness.

This action continues to the point where the chilling effect of the water-cooled hearth jacket is sufficient to prevent softening or slagging of the brick. Erosion is also retarded by the separation of graphite from the iron, but this factor probably does not assume much importance until the hearth wall has been cut back to a point where the cutting action of the blast is less vigorous than in the plane 12 to 18 inches back from the nose of the tuyère and where the chilling effect becomes more intense. This is indicated by the contour of the hearth walls of furnaces blown out after a short run. In one case the hearth walls of a furnace in blast only six weeks showed a depth of erosion of 22 inches on a 31½-inch wall at the deepest point. This is as much as is found in some furnaces in blast for a number of years. After the destruction of the hearth wall has been arrested by the cooling jacket, the graphitic coating deposited over the brickwork aids greatly in preserving the remaining ring of brickwork, as the graphite is not affected by nonferruginous slag.

The graphite coating is rarely homogeneous. On examination it is found to be composed of flakes, layers, and stratifications, between which are veins of slag and iron. These layers are evidently built up as the furnace alternately scours and incrusts the wall with varying conditions of graphitic or white iron, limy or raw cinder, hot or cold working. Various analyses have been made of this material; three typical analyses are given below:

Typical analyses of graphitic coating on hearth walls.

Constituent.	Per cent.	Per cent.	Per cent.
Graphite	25.3	48.4	70.0
Iron	70.0	18.3	12.0
Silicon	1.9	.1	3.0
Titanium	1.9	.1	....
Slag	....	27.1	....

CRACKING OF THE WALLS.

The protected brickwork may be destroyed unless held solidly in a tight, jointless ring, with no opportunity to develop cleavage cracks through displacement by expansion. Fire brick expands approximately 0.5 per cent in volume on being heated to incandescence and before it vitrifies. Consequently if the hearth walls are not held equally rigid about their circumference, that segment or wedge opposed by the least resistance will move out bodily, forming a crack from the inside to the outside face.

It is considered that loosely held brickwork, because of the possibility of cracks developing in it, gives the greatest danger of breakouts. When such a crack forms, the molten iron penetrates it instantly, and if not checked by the hearth jacket may come through. There may be 6 feet of fluid iron above the tapping hole and 2 feet of slag above the iron. The pressure per square inch of 1 foot of iron is 3 pounds, and 1 foot of slag, 1 pound, so that in this case the pressure is 20 pounds. If to this a blast pressure of 25 pounds be added, a total pressure of 45 pounds per square inch is exerted on the molten iron at the bottom of the hearth.

DEVELOPMENT OF BREAKOUTS THROUGH THE JACKET.

As a rule, breakouts through the hearth jacket occur suddenly. If cleavage cracks form slowly with the iron following them, the water on the hearth jacket or in the circulating coils becomes steamy several hours before the crack reaches the jacket, and, by cooling the jacket vigorously with a large volume of circulating water, the fluid iron may be chilled and the crack stopped. Undue thinning of the walls is similarly shown up and combated. However, if the crack opens suddenly, as is frequently the case, a jet of fluid iron is forced through the joint and penetrates without warning to the hearth jacket. Unless this invading molten mass is instantly solidified by the cooling effect of the hearth jacket it melts a hole in the jacket and the entire fluid contents of the hearth above this point are ejected with considerable velocity. The opening enlarges very fast, sometimes until it is large enough to put a barrel through.

If the liquid iron comes in contact only with dry masonry, sand, or filling, no explosion takes place. If it runs into small amounts of water, violent explosions and heavy concussions result. Frequently at a single breakout a series of sharp detonations occur in rapid sequence, the sound of which is not comparable to that of any explosive, and is never forgotten. When the iron runs onto damp material, similar explosions may take place or steam may be rapidly generated and heave the pavements and floor plates. If there is enough water to chill the iron, there may be no explosion.

The cause and nature of explosions from iron is fully discussed on pages 172 to 174.

THICKNESS OF THE HEARTH WALLS.

The combating of breakouts through the hearth walls above the tapping hole has developed standard forms of construction. Although a few plants persist in building the wall of the hearth very thick, in some cases as much as 5 feet, it is more generally thought that safety does not lie in thick walls but that they rather increase the danger.[a] Many believe that the lining of refractory brick in the hearth walls should not be more than 36 inches thick. After such a wall has been eroded to a thickness where cooling is effective, the contour of the furnace interior as finally established brings the face of the lining far enough from the nose of the tuyère so that the cutting effect of the blast is not severe. Few plants go as far as to reduce the initial thickness of the brick to that observed in heavy walls after thinning is effected. Making the walls only 18 or 22½ inches thick insures efficiency in water cooling from the start, but it is urged that the cutting action of the blast on such thin walls may extend to nearly the same depth as with a 3-foot wall, resulting in an extremely thin sheet of brick between the hearth jacket and hearth contents. This is perhaps hazardous in that with a change in the composition and character of slag and iron, or blast pressure and penetration, a different shape of face and different rate of erosion of the hearth walls is introduced; a more serious result is that a wide joint at the foot of the jacket lining, between the hearth walls and bottom is lacking or may fail partly so that the anchoring effect of a substantial hearth wall over the hearth bottom brick is lacking, which makes it possible that the bottom will float up.

Although average hearth-wall thickness can not be calculated, the thickness generally lies between 31½ and 42 inches. The wall is built of standard hearth and bosh fire brick, 13½-inch and 9-inch keys, and straights being employed. These bricks are laid in a thin grouting of fire clay of the same material and are rubbed together and beaten in place with wooden mallets to make the closest possible joints, all joints being lapped on adjoining courses.

USE OF PACKING BETWEEN HEARTH WALL AND JACKET.

Practice varies in regard to the packing space between the hearth wall and hearth jacket; some plants use packing, others do not. The use of packing is based on the presumption that cracks are bound to develop in the brickwork, and that a ring of some material, independent of the brick, must be placed between the brick and jacket so that molten iron following a crack can not penetrate to the jacket. Also, it is claimed that packing allows for the inevitable

[a] Konig, R., Uber Mittel zur Verhütung von Roheisendurchbrüchen bei Hochöfen: Stahl und Eisen, 1913, Jahrg. 33, pp. 485–486.

adjustment of hearth walls that results from expansion stresses. The two claims are somewhat contradictory in that the packing is supposed to combat the effects of the cracking which it permits.

At some plants no packing is used and the brickwork is laid tightly against the jacket, the jacket being made extra strong with a view to prevent expansion and cracking. This method has been tried at some plants with the result that the hearth jacket cracked, and at these plants the sentiment is largely in favor of the use of packing. With walls more than 3 feet 6 inches thick, the expansion strain is apt to crack even the strongest jacket, as it is sufficient to overcome the tensile strength of even prohibitively heavy jackets. The packing space when used is one-half inch to 4 inches wide and is packed with stamped fire clay, a mixture of fire clay and loam, ganister, ganister and boiled tar, iron borings, granulated slag, or various combinations of the above materials. The packing is stamped in very firmly, but it still possesses some yielding power, for the expansion force of the brickwork exceeds the resistance to compression of the packing material. another method of packing is to lay strips of soft pine between the jacket and brick. A few plants pour neat cement in the packing space, which makes an extremely rigid construction, but one apt to crack when it becomes heated and stresses set up in it. Probably if the packing is put in very tightly and offers sufficient resistance so that the expansion of the brick will close every joint, and is not more than 2 inches thick, it offers the greatest security, both against breakouts and the possibility of cracking the jacket.

TYPES OF JACKETS.

As regards the jacket itself, a wide variety of types are in use. The two most in favor will be described in detail.

THE ROLLED STEEL-PLATE JACKET.

The first consists of a rolled-steel jacket, usually butt-strap riveted both externally and internally. The jacket on a 500-ton furnace is usually 1 to 1½ inches thick and extends approximately 5½ feet above and 4½ feet below the bottom of the hearth, and is frequently reinforced by steel bands 12 inches by 1 inch riveted in at the top and bottom.

Inside of this steel jacket are placed vertically 12 to 15 cast-iron plates 3 to 5 inches thick with 1½-inch pipe cast in for circulation of cooling water. These cooling plates are continuous about the entire circuit of the hearth jacket and usually extend to the bottom of the outside steel jacket. They are not tied together, the strength being furnished by the exterior steel jacket; neither are the edges machined to make a close fit. A packing space is essential on account of the inequality of surface furnished by the rivet heads on the steel jacket and the space between the butt straps. This is filled as described above, the brick in this case being laid solidly against the plates. This type of jacket is usually vertical, that is, cylindrical.

JACKETS WITH COOLING PIPE CAST IN.

The other construction consists of 10 to 16 cast-steel or, more usually, cast-iron segments 5 to 6 inches thick and 8 to 10 feet high, forming a truncated cone perhaps 22 feet in diameter at the top and 25 feet in diameter at the bottom. These segments are held together by six sets of forged-steel links per segment. The links are made of 2-inch square bars and are shrunk onto lugs extending $2\frac{1}{8}$ inches from the face of the segment. In addition to these links three to five steel bands $1\frac{1}{4}$ inches thick by 10 to 12 inches wide are placed about the jacket and tightened by driving steel wedges between the bands and a set of lugs on the faces of the segments. The segments are water-cooled by $1\frac{1}{2}$-inch extra heavy pipe, which is bent and cast in, with feed and discharge ends at the top, and their edges are machined to make a tight joint when the links are shrunk on.

OTHER TYPES OF JACKETS.

The two types mentioned above are most generally in favor, but a great variety of other types are in use. Of these the one probably in most common use is a steel-plate jacket which is generally of truncated-cone shape. It is cooled by water which runs down in a thin film over the surface from a spray at the top of the jacket, the water collecting in a ditch about its base. Somewhat infrequently this steel jacket is protected by pipes, spaced 6 inches center to center, about the inside of the hearth jacket. These are set in clay or iron borings packed between the brick and jacket, and extend down to the bottom of the jacket. They are usually closed at the bottom and water circulation maintained by means of a $\frac{3}{4}$-inch pipe which is inserted in the 2-inch pipe and the water delivered to it. The overflow is sometimes down the exterior of the jacket, or a number of pipes may be connected in series. At some plants the bottom of two adjacent pipes are welded to make a coil or U tube, and a number of these connected in series, the inside $\frac{3}{4}$-inch pipe being omitted.

Another variation is to use a cast-steel jacket of 12 segments which are bolted together by flanges and banded and are cooled by exterior sprays or by pipes inside. In connection with these five types of jackets as usually constructed, one may also find combinations of types, such as water-cooled plates behind water-cooled cast-iron jackets, or cooling pipes between steel jackets and water-cooled plates.

COOLING THE JACKET.

It should be borne in mind that the cooling effect of the jacket extends only slightly into the brick on account of the low heat conductivity of the brickwork and does not hinder the molten iron from working back to where the cooling is effected. From this point a sudden crack or erosion of the wall will admit the iron to the jacket. This has happened so frequently that repeated experience has demonstrated that a simple rolled-steel jacket does not suffice to hold the iron in. A $\frac{1}{2}$-inch jacket is often useless in this emergency, and a 1-inch jacket occasionally so. Although the jacket is covered with a film of water that cools it sufficiently under normal conditions, the mass of cold metal is not sufficient to freeze the fluid iron by dispersing its heat, and thus the advantage of the cooling water is not utilized. Practice shows that breakouts with this type of jacket are frequent. The breakout assumes more serious consequence because the jacket is surrounded by a ditch which contains a few inches to two or three feet of water. If only a small amount of this iron comes in contact with a large volume of water there is no explosion, but when the iron continues to escape in increasing quantities explosions usually occur. This danger has been so repeatedly demonstrated that most plants have eliminated the ditch and abandoned the idea of surface cooling.

A few plants still retain surface cooling, but reinforce its effect by cooling pipes behind the jacket. This idea is discounted by many operators because they feel that it has been demonstrated that material for prevention of breakouts must be able to solidify suddenly penetrating iron by quick absorption of a large amount of heat, and they do not think that this requirement is met by circulating water in the interior of refractory material which has a very low heat conductivity. Fire brick of hearth and bosh quality has a heat conductivity of 1.32 (kilogram-calories per square meter per hour). The requirement is better met by a material having a high heat conductivity, and this demand is satisfied by iron or steel with a heat conductivity of 300. Also the plate must be thick enough so that in addition to its high heat conductivity and the quick dissipation of heat to cooling water it offers a large mass of cold material to absorb the heat and chill the fluid iron. This is the case with a 6-inch cast-iron jacket, cooled by water circulating in pipes, or by a 4-inch cast-steel jacket with spray cooling. In the South, the cast-iron jacket with pipe cast in is sometimes designed with a corrugated surface and is cooled with a spray in addition to the circulating water in the pipes. This is probably the most intensive cooling possible.

Practically all plants having cast-iron jackets with pipe cast in, or steel jackets with water-cooled staves behind, have eliminated surface cooling and have no ditch whatever. Though some cooling efficiency is lost by discontinuing the spray or water-filled ditch, a gain is effected in that if the iron does come through the joints it comes in contact only with warm, dry brickwork, and there can be no explosion, and in addition there is no open space into which it can run quickly and cause a shutdown by the cutting of a large hole. If it cuts a cooling pipe inside the casting, the possibility of great danger is removed because the resulting explosion has little chance of escape. The water surface exposed inside a 1½-inch pipe is small, and as a rule the fluid iron simply runs into and fills up the coil, where it solidifies.

To eliminate the danger of iron coming through the joints between water-cooled castings, one firm uses two rows behind a rolled-steel jacket, the joints being lapped. In order to eliminate the danger of losing the cooling effect of an entire section by intrusion of iron, the pipes may be bent and cast in in **U** shape, the feeds and discharges of several being connected in series so that if one is lost the others in the casting may still be kept in commission. To take care of water from temporary discharges of tuyères, plates, and other cooling parts, there is left a shallow ditch 6 inches deep by 12 inches wide, but even this is sometimes eliminated. In some plants a circle of 6-inch pipe is laid about the hearth with funnels at each column, or there may be a circle drain pipe with funnels at columns laid in the brickwork about the jacket.

BREAKOUTS BELOW THE TAPPING HOLE.

DANGER IN USING SPRAY-COOLED, STEEL-PLATE JACKETS.

Where rolled-plate jackets are provided for holding in the hearth brickwork the spray cooling does not extend down to the base of the jacket. Commonly it extends only to the level of the tapping hole or, perhaps, up to 2 feet below the hole, which is approximately the level of the hearth bottom. It is thought dangerous to have the bottom of the ditch about the jacket lower than the bottom of the hearth because of the probability of very severe breakouts, and the jacket is bricked up solidly from this point down, completely around the furnace. The jacket usually extends 2 feet 6 inches to 4 feet 6 inches below the bottom of the hearth and rests on second-quality fire brick, ordinary river brick, or even concrete, the lower segment of hearth being filled with fire brick of hearth and bosh quality.

FORMATION OF "SALAMANDERS."

Under these conditions, it is apparent that this mass of brickwork without water-cooling comprises a highly heated reservoir, which continually attains higher and higher temperatures and affords ideal conditions for melting and penetration of the bottom brickwork by iron. This is found to be the case. Upon blowing a furnace out, the brickwork of the hearth bottom is seen to be replaced by a mass of pig iron, or a mixture of pig iron, slag, and graphite, varying in depth from 4 feet to, in one instance, 26 feet below the tapping hole. Comparatively shallow depths are usually liquid, while deep pockets are usually solid or, unless drained, solidify after the furnace is blown out. These masses of material have long been known as "salamanders."

CAUSES DESTROYING HEARTH BOTTOM AND WALLS.

The penetration of this fluid mass into the foundations of the furnace gives rise to breakouts beneath the tapping hole. The cause is due to a variety of conditions. The erosive action of the blast may be eliminated, and also corrosion by slag, for except prior to the first cast and at infrequent intervals during the first part of the run, the hearth bottom is covered with liquid pig iron, which would prevent any slag coming in contact with the brickwork or gas circulating adjacent to it, except for brief periods immediately after casting. As the depth becomes greater, even this occasional contact is eliminated.

SLAGGING ACTION OF PIG IRON.

There remain therefore the chemical action of pig iron and the mechanical effect due to the weight. Stead[a] has called attention to the fact that manganese in iron attacks fire brick. He found that ferromanganese containing 80 per cent manganese attacked and slagged away portions of a fire-clay crucible.

The action is as follows:

$$4Mn + Al_2O_3.2SiO_2 = 4MnO + 2Si + Al_2O_3$$

The silicon goes into the pig iron, whereas the manganese oxide reacts with additional silica to form manganese silicate, according to the following reaction:

$$4MnO + 2Al_2O_3.2SiO_2 = 4MnSiO_3 + 2Al_2O_3$$

Both reactions are endothermic and would require abstraction of heat from the fluid manganiferous iron. If it be assumed that such a condition is possible, 1 pound of manganese would require 1.6 pounds of silica, and if the silica content of the fire brick was 50 per cent, 3.2 pounds of fire brick. If 0.01 per cent maganese, of the 0.75 to 2 per cent of manganese, in every ton of iron, thus entered into

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[a] Stead, A., Blast-furnace bears and what they teach us. Proc. Cleveland Inst. Engineers, vol. 6, 1913–14, p. 169.

reaction there would be dissolved by a furnace making 500 tons of pig iron a day, or 150,000 tons a year, 717 cubic feet of brickwork, as follows: $150{,}000 \times 0.0001 = 15$ tons, or 33,600 pounds of manganese, and this quantity of manganese would dissolve $33{,}600 \times 3.2 = 107{,}520$ pounds of fire brick, or $\frac{107{,}520}{150} = 717$ cubic feet of fire brick. Therefore on a 16-foot hearth a layer of brickwork $\frac{717}{201}$ or 3.5 feet in depth would be disintegrated and replaced by pig iron in the course of a year. Such action is conceivable only as long as the pig iron continues to possess sufficient heat to accelerate the reactions noted above. To what depth this action might extend is again problematical, but considering that the iron must be fluid at all places where it effects penetration, and this may be more than 20 feet below the tapping hole, the above action is not unworthy of notice and consideration.

BUOYANT EFFECT OF SUPERINCUMBENT IRON.

The other and most accepted explanation of the formation of salamanders is that the individual shapes comprising the hearth bottom are buoyed up by the weight of the supernatent iron, and being insecurely bound in, float up and dissolve in the slag. A cubic foot of brickwork weighs approximately 150 pounds, as compared with a corresponding weight of 450 pounds per cubic foot of pig iron. It is to be noted that it is not at all unusual for a furnace with a 16-foot hearth to make six casts per day of 100 tons each, and this presupposes a height of molten metal in the hearth of 2 to 4 feet, according to the extent of erosion and widening of hearth walls. With two feet of slag on top of the iron and 15 pounds blast pressure in the interior of the furnace the force exerted over the surface of an area 12 inches square would be equivalent to a hydrostatic pressure of 2,800 foot-pounds. Unless every joint between the shapes making up the hearth bottom is absolutely flush and tight along all vertical and horizontal faces, the fluid iron under such high pressure will penetrate the joints.

When one or a group of these shapes has been isolated from the adjacent brick by a skin of fluid iron, the mass must, by reason of its lighter density, float up in the overlying molten iron.

SEPARATION OF GRAPHITE.

A third influence which disrupts the hearth walls and bottom is the separation of graphite from the molten iron. This action has been mentioned as tending to preserve the brickwork, and such is the case after the cooling effect has checked further destruction of the brick. From what is noted in the furnace after it is blown out, the action that takes place is somewhat as follows: When the pig iron accumulates in the hearth and cools off very slowly under the influence of variations in the burden, increased moisture in the blast, and disturbance of equilibrium between the heat furnished and that lost by water-cooling and radiation through retarded rate of driving or local chilling effects, graphite crystals separate out.

When this separation takes place in joints or cracks in the hearth brickwork into which the iron has penetrated, the brickwork is wedged asunder by the volume increase from graphite separation. Consequently more iron intrudes and the process may repeat itself, and though taking place on an exceedingly small scale, the cumulative effect may entirely destroy considerable amounts of brickwork. This intrusion of graphite-coated iron veins into the joints of brickwork, as yet undestroyed, can be noted in both the walls and hearth bottom of furnaces where the bottom is being torn out for renewal. A similar condition is usually found next the hearth walls, where graphite flakes, iron, brick fragments, and occasionally slag, intimately mixed together, may be seen with intrusions of graphite and iron in the joints. This condition, which presents a view of brickwork destruction arrested while in progress, probably results from sudden chilling of the pool of iron, through exterior causes, while disintegration was in full play. Such conditions are usually found in the salamander accumulated under the tapping-hole level.

RATE OF LOWERING OF HEARTH BOTTOM.

The eating away of the hearth bottom is usually slow. Upwards of six weeks may elapse after the blowing-in of the furnace before it becomes evident, from the way the furnace casts iron, from the increasing angle of the tapping hole, and from the volume of iron per cast becoming greater than the designed capacity of the hearth will contain, that the bottom is becoming lower. One furnace blown out after six weeks showed a lowering of the hearth bottom of about 20 inches. Years ago, when the distance between the center line of the tuyères and the hearth bottom was half the distance now general, the position of the tuyères is said to have had considerable effect on the hearth, and it was believed that if the distance was too small there was little means of preventing the danger of breakouts. To what extent this relation was blamed for weaknesses in the hearth jacket and brick, now corrected, is beside the mark. With a distance of 8 feet 6 inches or more between the center line of the tuyères and the hearth bottom in large, modern furnaces dictated by the necessities of tonnage output, no significance whatever is attached to it.

In many cases furnace men report that after the furnace bottom has reached a depth of 4 to 6 feet below the tap hole, little further burrowing of the iron takes place, but that the furnace bottom works up and down, varying with the working of the furnace. When a furnace is working hot in the bottom and fast, the hearth deepens, and when it is working cold or slow, the hearth builds up. The latter condition should, in fact, promote building up, because the equilibrium between the heat supplied to the furnace bottom and the amount given off to the surroundings is changed in favor of the latter. If the hearth bottom is laid snugly and on heating up expands slightly so that it is tied in, this same heat equilibrium should arrest the downward growth of the salamander, both by retarding any slagging action and also by the decreased fluidity due to chilling of the iron at depth.

This balance or alternation between growth or deepening may remain steady for months or during the entire blast. If the brickwork is poorly laid the deepening may progress throughout the entire run. Infrequently the furnace may "lose its iron," which indicates that the iron is deepening at an extremely rapid rate or is escaping through some crevice in the bottom into the soil, sewers, or filling about the furnace foundation. In such cases there is nothing obtained at cast except a heavy run of slag and a quantity of iron short of the tonnage corresponding to the number of charges. Such losses are also usually indicated by the pavements getting very hot, steam coming up about the columns, or gas burning with a blue flame about the brickwork inclosing the hearth. The abnormality may persist for several days, though if it is serious the furnace may be temporarily shut down or driven slowly with a very limy slag to stop the loss of iron.

EXAMPLE OF A FURNACE "LOSING ITS IRON."

A case in point may be of interest. The furnace had been in blast for nearly three years and had been working with a very deep tapping hole, frequently at cast time giving a heavy run of cinder before running the iron. The furnace was at this time making about 440 tons of iron per day, though its capacity with a good lining was about 530 tons. The fact that the furnace was losing iron became apparent on a Tuesday, when the 3 a. m. cast gave only two ladles of iron. The 7 a. m. cast was three ladles. The furnace was taking the customary number of charges and should have averaged five and one-half ladles per cast. At the end of the 7 a. m. cast a 24-foot pricking rod was pushed completely into the tapping hole without finding bottom. Considering the oblique position of the rod, the furnace bottom must have been at least 12 feet below the bottom of the tapping hole. The blast was reduced from 42,000 feet to 37,000 feet per minute, 600 pounds of limestone added to the burden during the day, and 6 holes drilled through the pavement outside the brickwork about the hearth jacket into the filling about the foundation and water turned in. At this furnace the practice was as follows:

Practice in operation of furnace.

Day of week.	Day or night.	Number of charges.	Time of cast.	Iron (tons).
Monday	Night	46	3 a. m. 7 a. m. 11 a. m.	75.4 68.5 75.0
Do	Day	44	3 p. m. 7 p. m. 11 p. m.	70.2 68.2 51.7
Total		90		409.0
Tuesday	Night	47	3 a. m. 7 a. m. 11 a. m.	24.6 35.1 23.4
Do	Day	39	3 p. m. 7 p. m. 11 p. m.	(a) 18.3 48.6
Total		86		150.0
Wednesday	Night	43	3 a. m. 7 a. m. 11 a. m.	70.8 61.1 67.5
Do	Day	38	3 p. m. 7 p. m. 11 p. m.	59.7 66.2 67.8
Total		81		393.1

a Cinder.

Thursday morning the blast was increased again to the normal amount, as the furnace from all indications had effected its own repairs and had stopped losing iron. The water about the hearth bottom was left on to cool the surroundings and thoroughly chill the iron vein leading from the hearth. The salamander in the hearth was not removed at relining, nor was the brickwork removed lower than a couple of feet beneath the bottom of the hearth jacket, so the depth to which the salamander had burrowed or the place where the iron made its escape is not known, though it is certain that it took place at least 12 feet below the tapping hole and 8 feet below the bottom of the hearth jacket. About 330 tons of iron was lost, calculated from the charges, during the above period.

DEEP SALAMANDERS A SOURCE OF DANGER.

Whenever a furnace shows indications of such a condition there is danger of an explosion if the iron comes in contact with moisture. Even if the hearth alone becomes unusually deep the danger of a breakout is increased, for as the iron in the hearth becomes lower than the brickwork inclosed by water-cooled jackets it begins to eat outward. The deeper the hearth becomes, the farther downward the hearth walls extend and the greater is the lateral pressure, owing to the increasing head of liquid iron. Once displacement is fairly started by reason of bricks insecurely tied in, uneven shape, thick joints, inadequate anchoring by the hearth walls, or shrinkage cracks, the iron, as the hearth becomes deeper, automatically acquires an increasingly uncontrollable and destructive power and tends to penetrate downward and laterally into the brickwork. The danger which threatens if this deep pool of molten iron suddenly breaks through is evident. The iron, in fact, sometimes works out sideways several feet, and sometimes under and beyond the column base plates, the brick foundation being replaced by a mass of iron. There is always considerable speculation when this state of affairs is revealed in removing a salamander, as it is evident that at some time the weight of the stack under one or more columns must have been carried by a pool of fluid iron. Often lumps of iron weighing many tons are found extruded outside the hearth jacket and below the surface, where they have replaced the fire brick. Just how they melt or displace the brick is also a cause for speculation, especially as the iron, if it does not come in contact with water, shows no sign of intrusion. To date the efforts of furnace men and engineers to prevent the formation of salamanders have failed. Except on special grades of iron and on a few cold-blast furnaces a salamander always forms to a greater or less depth and presents the annoying condition arising from a pool of iron that can not be removed through the tapping hole. So long as salamanders form there will always be uncertainty concerning the depth to which the iron is penetrating, the distance to which it is working sideways, and the possibility of outbreaks beneath the tapping-hole level.

TYPICAL EXAMPLES OF HEARTH BREAKOUTS.

EXAMPLE NO. 1.

At one furnace a serious explosion was caused by the iron breaking out from the hearth foundations. The iron came out about 20 feet below the tapping hole and on the yard level in such great volume that it overflowed the hot-metal tracks and ran along until it came to the manhole of a waste-water sewer. It ran into this, and on coming in contact with the water caused an explosion which threw brickbats, chunks of concrete, and earth over a wide area and fatally injured six men who were standing nearby watching the stream of iron. These men had been ordered away, but in the short time between the breakout and the explosion there was no opportunity to compel them to leave, and their ignoring of the warning was the primary factor in their death. This hearth foundation was not inclosed, as is usually the case, the idea being that if it was exposed to the air sufficient cooling would take place to chill any fluid iron which might penetrate near the exterior of the brickwork, and thus prevent a breakout. The foundations were strongly banded with 15 inch by 1¼ inch bands to prevent displacement.

EXAMPLE NO. 2.

In another instance the furnace had a rolled-steel jacket, three-fourths inch thick, cooled by a spray and ditch in which about 2 feet of water was maintained. The bottom of the ditch was 12 inches beneath the bottom of the tapping hole. The iron came through the jacket about 3 feet from the iron notch, on the side away from the cinder notch and beneath the bottom of the ditch. It ran beneath the bottom of the ditch, not causing any disturbance, and came through the 4 feet of brickwork surrounding the jacket, where it came in contact with wet sand. The explosion that followed threw brick and flame through the cast house and caused the death of the foreman and one cast-house man.

EXAMPLE NO. 3.

In a third instance the furnace jacket was of rolled steel, behind which vertical cooling pipes were inserted at 8-inch centers. Each pipe had an individual feed, the overflow running down the face of the jacket and collecting in a ditch. A 3-inch packing space was filled with a mixture of granulated slag and loam, in which the cooling pipes were set. Without warning, iron came through the jacket into the ditch, which had only about 6 inches of water in it, where it caused an explosion. The force of the explosion stripped the water connection from the bosh and seriously damaged the stack. One man was killed and another seriously burned. The iron lying in the ditch was not removed, but was chilled and left in the bottom, where it covered the hole cut in the jacket by the outbreak. No further trouble was experienced at this place.

About 36 hours later, however, the furnace broke out again on the same side and lost a cast, the iron running out beneath the pavement and into the cinder pit about 100 feet away, where it emerged beneath the surface of the water and chilled, forming a large skull. Aside from violent boiling of the water, considerable flame from gas generated by the contact of iron and water, and throwing about of granulated cinder left in the pit, no damage was caused.

EXAMPLE NO. 4.

The furnace had a cast-iron hearth jacket 4 inches thick, with cooling pipe cast in. An expansion space was provided between the jacket and brickwork in which were placed packing strips of pine. A ditch about 18 inches deep carried discharge water from the columns and also from the "monkey" and intermediate cooler. The iron came out beneath the ditch and worked its way up into the bottom of the ditch, where it exploded. The supposition is that the brickwork suddenly developed a crack, as no preliminary heating of the cooling water was noticed. The explosion is stated to have occurred shortly after the outbreak was discovered. Some men had run up and were in the vicinity when the explosion occurred. One was thrown out of the cast house and severely injured, another received burns of the back and other injuries which proved fatal, and a third minor burns. After the breakout stopped, the brickwork was dug away and a hole found cut through the segment of the jacket between the cooling-pipe coils, the coil being cut by the widening of the hole and rendered useless. The hole was only partly filled with iron as the tapping hole had been opened and the hearth drained immediately after the breakout. The hole was rammed full of crushed fire brick and fire clay, and then the entire face of this segment of the hearth jacket was reinforced by pouring concrete in front of it, forming a block which overlapped a few inches on the adjoining segments. No further trouble was experienced.

EXAMPLE NO. 5.

At another furnace the hearth foundations were not inclosed. The jacket was of cast iron with cooling pipes cast into it and extended 3 feet 6 inches beneath the tapping hole. The iron broke out beneath the jacket and came out about 6 feet above the yard level in large volume, and a huge flame continued to blow out of the opening. Considerable damage was done to the plant. At the next relining the hearth jacket was extended down 2 feet farther and the entire space between the hearth jacket and foundations, and the outside of the cast house about the furnace, filled in with concrete. A space was left about the hearth jacket which was filled in solidly with paving brick set in cement mortar to allow removal of the jacket when necessary on relining and digging out the salamander. No ditch about the jacket was allowed. No further trouble with breakouts has been experienced.

EXAMPLE NO. 6.

Another furnace of the same type as above had uninclosed foundations and a cast-iron jacket with cooling pipes cast in. A breakout occurred in the same manner, but was accompanied by a series of violent explosions as the iron flowed out onto the yard and into a sewer and also onto wet ground. The hearth was completely emptied, and after the iron had chilled, the hole was plugged with clay and fire brick, a wall wedged in on the face, and a water spray put on. This construction held until the next relining, when the opportunity was utilized to dig out the salamander and put in a subjacket beneath the original jacket. This subjacket is water-cooled with water circulating pipe cast in, and brings the depth of water-cooling 2 feet lower. The furnace is now running with the base uninclosed as before, but with no further trouble.

EXAMPLE NO. 7.

The furnace had a rolled-steel jacket 1 inch thick. At one period, cooling was effected by cooled cast-iron plates set vertically behind the steel jacket. The edges were not machined, and there was a packing space of 1 inch filled with a mixture of iron borings and loam. The iron came out between the plates, between the cinder and iron notches, and below the ditch, in which 2 feet of water was maintained. An explosion followed which tore out some of the brickwork and threw about the cover plates over the ditch. Three men were injured and slight damage done. After this experience the furnace was provided with two rows of cooling plates behind the hearth jacket, the edges being lapped. No further trouble has been experienced.

EXAMPLE NO. 8.

Another furnace had a rolled-steel jacket one-half inch thick, with packing space of 3 inches. There was 42 inches of brickwork in the hearth walls, and the jacket was spray cooled, the water being collected in a ditch 30 inches deep, in which about 20 inches of water was maintained. The jacket was 7 feet 6 inches deep, and below the ditch a wall of paving brick was built around the jacket, which extended down to the bottom of the jacket. This wall retained the heat and permitted the jacket to melt away beneath the ditch, an area extending nearly halfway around and from 12 inches to 24 inches high being melted. Eventually the iron broke through, not being retarded by the cooling water in the ditch, and a series of breakouts followed. The iron came up in the ditch and ran along the bottom of the ditch beneath the water until the hearth drained and the iron was chilled. No explosions resulted. This iron was not removed, and finally, in consequence of a number of breakouts, the bottom of the ditch was entirely covered with chilled iron to depths varying from a few inches to about 2 feet. The spraying of the jacket was continued and the water level in the ditch raised from time to time. As this auxiliary iron jacket was built up the breakouts gradually decreased in frequency until finally the furnace ran about three years without a breakout. This experience illustrates the efficiency of a large mass of cold iron to check the melting and failure of fire brick close to the jacket, or to solidify and check, by virtue of its high heat conductivity, any intrusion of iron in contact with it.

EXAMPLE NO. 9.

Another furnace had a cast-steel jacket which was spray cooled, the water being collected in a ditch, the bottom of which was 1 foot above the base of the jacket. The ditch had slope enough to carry off the water quickly and to prevent its becoming more than 5 or 6 inches deep, the outlet being at the rear of the furnace opposite the tapping hole. The brickwork beneath this jacket was also inclosed in a rolled-steel jacket to prevent cracking by expansion. This subjacket was not cooled, but was solidly bricked in with miscellaneous paving brick, second-quality firebrick, and other brick left over from various jobs. The furnace gave warning of a breakout by vigorous steaming about the base in front of the tapping hole for several hours. During the night gas that burned with a blue flame began to issue from the pavement in such quantities that the blower took the blast off and ordered the crew out of the cast house. The volume of gas generated increased, and about midnight a violent eruption took place halfway down the cast house. The floor of the cast house was of cast-iron plates, laid on sand filling held in by concrete retaining walls. The eruption, which continued vigorously for a half hour, hurled the plates and the cast-iron runners about, upset one retaining wall, and bulged the opposite wall. A column of burning gas arose through the cast-house roof. When the eruption quieted down, there was a hole in the cast-house floor about 12 feet deep and over 20 feet across. No explosion took place. The filling about the furnace foundations was saturated with water while repairs were being made, these taking several days. The furnace was started up and run slowly and on a limy burden for two days, and as there was no further evidence of a breakout, it was quickly put up to normal output. About 18 months later the furnace "lost its iron" for several days in succession, but without any damage or alarming signs of breakout other than moderate steaming about the columns and pavement.

EXAMPLE NO. 10.

This furnace had a rolled-steel jacket, one-half inch thick, inclosing very thick hearth walls, so that the hearth jacket was about 15 inches outside the tuyère-breast walls. One-inch holes were drilled in the brickwork between the jacket and tuyère breast, down to the tapping-hole level. A $\frac{1}{2}$-inch pipe was inserted in these holes and led the cooling water to the bottom, whence it rose up in the hole and overflowed down the face of the jacket. These holes were drilled at a slight angle, and at the top were about 4 inches from the hearth jacket. Without warning a severe explosion occurred inside the jacket, cracking it and tearing it open to the top. It is supposed that a crack or joint opened which admitted molten iron to the water-saturated brickwork adjacent to the jacket.

EXAMPLE NO. 11.

A furnace had been in blast for several years, and at the time of the following accident was on its third lining. At neither of the previous relinings had the salamander been removed, it being simply split off about the sides down to the bottom of the hearth jacket, 3 feet below the tapping hole, to permit a new hearth wall to be built in. The furnace began to work sloppy at the tuyères, and conditions became so bad that it could not be dried at the tuyères at the end of the cast. As two tuyères had been cut by iron lying at their noses, the blast was thrown off and the cinder and iron permitted to come back into the blowpipes, which were then taken down. While one gang was cleaning them and other gangs were changing the two burned tuyères and sledging cinder and iron out of the tuyères, an explosion inside the furnace threw coke and flame from the tuyère openings, fatally burning several men. After this all men were withdrawn from the cast house, the approaches roped off, and watchmen stationed. At irregular intervals of one-half hour these interior explosions continued, throwing material from the tuyère openings, but gradually diminishing in frequency and violence. The furnace was allowed to stand 24 hours after the explosions had stopped, the mess was then cleaned up, the furnace gotten in shape, and gradually worked up to regular output. These explosions were not caused by gas nor by water leaking from plates or other cooling equipment, as none of the cooling pipe cast in the health jacket was cut. It is thought that the iron ate its way down into the foundations, forming a large body of molten metal which finally penetrated into damp subsoil. The furnace was built on originally wet soil, covered with refuse and cinder, which was excavated to put in the concrete foundations. A similar explosion occurred in England in 1909 in which the molten iron penetrated the concrete base and came in contact with water.

EXAMPLE NO. 12.

The iron came through a steel-plate, spray-cooled, hearth jacket at the bottom of the ditch and between the cinder notch and tapping hole, and an explosion followed. A shower of molten iron and cinder was thrown down the cast house and about the furnace, burning two men fatally and doing much damage to the stack.

Many descriptions of breakouts could be given, but it is thought that the preceding discussion of causes of failure of the jacket, hearth wall, and bottom brickwork, with the specific illustrations cited, gives a comprehensive review of the factors connected with the process of hearth destruction.

PREVENTION OF BREAKOUTS THROUGH THE HEARTH WALL OR JACKET.

USE OF MATERIALS OTHER THAN FIRE BRICK.

Thus far no material ever used in hearth bottoms has resisted the destructive agencies inside the hearth.

CARBON BRICK.

The presence of graphitic coatings on the hearth walls and in crevices in the salamander, which are seen when the furnace has been blown out, has presented the obvious suggestion of a lining of carbon or coke brick in the bosh, hearth, and bottom. Theoretically, such bricks should be highly satisfactory, because they are infusible at the highest temperatures reached inside the furnace and resist the corroding action of slags, either basic or acid. Also, they are not acted on by molten iron, unless the iron is unsaturated with carbon, in which case the iron would probably satisfy its requirements for carbon at the expense of the carbon brick. In addition, these bricks have a high heat conductivity—7, as compared to 1.3 for hearth-quality fire brick—which seemingly is of advantage, because the cooling effect of the jacket water would penetrate farther into the hearth wall and preserve a thicker wall, while conduction of heat from the bottom brickwork in the hearth would be more rapid and presumably check the lowering of the hearth bottom sooner than is the case with fire brick. Another property of less benefit is that such brick expand much less than fire brick at high temperature.

So far as is known, these bricks are not now, nor have been for many years, used in this country. Many works abroad and three works in America have introduced them, thinking that a panacea for the preservation of the hearth had been found and that the costly work and expensive delay in removing salamanders would be largely eliminated. It was found, however, that the carbon brick were failures when used about the tuyère breast and the tapping hole; that the hearth bottom tended to float up and disappear; and that if even the smallest gas flame issued from the joints between the brick, a hole formed in a few minutes, which steadily grew larger and had to be stopped with fire clay, so that a prejudice against their use developed in this country. They are, however, used abroad, but do not appear to possess any advantage over good fire brick. The results of a symposium prepared in Germany showed that of a total of 10 opinions, 3 were favorable, 5 unfavorable, and 2 noncommittal.[a] The following description of these brick is taken from this article:

Only coke of best quality, very hard and pure, can be used for this brick. The finished brick must not contain more than 12 per cent of ash. The coke is ground very fine in suitable mills, mixed with 20 to 25 per cent of the best specially prepared, hot steel-mill tar, with which it is thoroughly kneaded, and the mass is then carefully pressed into suitable molds. The brick when formed is enveloped in coke dust to make it air-tight and set into plates provided with a spring and nut and fired at temperatures of 2,375° to 2,550° F. The finished product must be ringing hard and dense, with a specific gravity of 1.2 to 1.35. The size should be as large as possible, to insure better adhesion of the masonry and lessen the number of the joints. They are no longer difficult to make, now being as heavy as 880 to 1,100 pounds apiece (?); heavier than this they are unwieldy and suffer greatly in transportation. The surfaces and edges must be carefully worked over on laying. The sole brick especially, should be put together on a perfectly level cement plate beforehand, in order to avoid outward joints during the work. The mortar consists of a mixture of coke dust containing up to 20 per cent of powdered fat clay, finely ground and mixed into a syrupy mush with pure water. A mixture of tar and finely ground coke dust may also be used as a mortar, which is applied warm. In some mills ordinary chamotte mortar also gives satisfaction. It is essential that the mortar be even and thin, and that the bricks be carefully ground to fit closely, so as to make the joints as small as possible. Contraction and expansion from cooling and heating when the furnace shuts down, especially at first, will cause changes in volume even in this carbon brick, and in insuring the permanence of the brickwork absolutely accurate work is essential. It is therefore a better plan to pay better wages to these workmen than to ordinary masons, and to employ them not by contract but on a per diem wage under steady supervision, and to promise them a bonus if the masonry proves durable after a specified time of operation.

SILICA, MAGNESITE, AND BAUXITE BRICK.

Besides carbon brick, various other materials which would supposedly be more inert than fire brick to the chemical actions taking place, such as silica brick, magnesite brick, and bauxite or alumina brick, have been proposed for hearth brickwork. In a practical way these proposals have not met with any enthusiasm, as furnace men feel that hearth failure is almost entirely due to mechanical causes. All efforts in this country have been in the direction of better quality and uniformity of shape of fire brick, rigid construction, efficiency in

[a] Geiger, C., Ueber die Verwendung von Kohlenstoffsteinen im Hochofenbetrieb: Stahl und Eisen, Jahrg. 32, 1912, pp. 1685–1690.

water cooling, and elimination of danger elements in advance of impending or possible breakouts.

TYPES OF FIRE BRICK USED IN HEARTHS.

The brick used in the hearth and bosh are made of a fire-clay mixture containing about 85 per cent flint clay and 15 per cent plastic clay. The flint clay is ground coarse or fine, as dictated by experience with different types, dissatisfaction with previous linings, or expectation of improvement. Until very recently blast-furnace operators and fire-brick manufacturers did not make much progress in combining knowledge of brickmaking with knowledge of furnace operation, and consequently furnace men were disposed to progress in a circle, constantly wanting a type of fire brick which they had not tried, but which some one else had tried, perhaps with entirely different conditions, and found more satisfactory. Within the past year, by means of tests ingeniously designed to conform to conditions in the furnace, it is becoming known exactly what effect abrasion, heat, and other factors have upon different types of fire-clay brick, and with the cooperation of fire-brick manufacturers progress is being made in the manufacture of brick that will stand up better. The furnace man is interested in results, and is beginning to care little about methods of grinding, weathering, bonding, or burning, as long as the brick does the work required.

Under these circumstances no definite statements can be made in regard to the best type of brick for the hearth. However, only enough plastic clay is used to bind together the more refractory clay. Refractoriness is the prime requisite in hearth and bosh fire brick, and as the more coarsely ground material is as a rule the more refractory, the flint clay, called the grog, is usually ground as coarse as is compatible with strength and resistance to spalling. It is burned at 2,800° to 3,000° F. in order to decrease shrinkage after it is placed in the furnace and subjected to high temperatures, because fire brick undergoes a progressive shrinkage the hotter it is heated, and if it is underburned in the kiln, shrinkage cracks develop later in the blast furnace.

The brick for the bosh and hearth walls consist of 13½-inch and 9-inch straights and keys with a few special shapes for plate and cooler arches. The brick for the hearth occasionally consists of the same shapes, but usually are larger than these. The largest shapes are 18 by 12 by 8 inches; other shapes are 18 by 9 by 4½ inches, 18 by 9 by 6 inches, and 13½ by 9 by 4½ inches. These blocks are machine-made under heavy pressure and must be true in shape and form. They are culled carefully and any soft-burned or warped blocks are rejected. Little or no attention is paid to porosity, conductivity, or density. Only rarely are they analyzed. The following information may be of interest in indicating the composition of the brick:

Composition of four samples of hearth fire brick.

Sample.	SiO_2.	Al_2O_3.	FeO.	CaO.	MgO.	TiO_2.	Alkalies.	Ignition loss.
A	52.80	42.50	1.17	0.50	0.53	2.10	0.53	
B	56.65	40.51	1.77	.30	.63			0.28
C	55.01	38.92	3.19	.58	.90	2.21	1.16	.66
D	50.57	42.73	3.87	.25	.34		2.17	.07

The average melting point of eight different makes was 3,218° to 3,290° F.

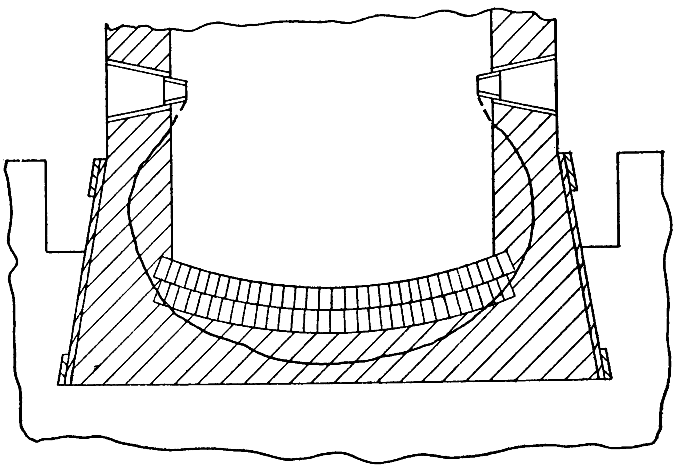

FIGURE 25.—Concave hearth bottom.

USE OF CONCAVE BOTTOMS.

Hearth bottoms were at one time built concave (fig. 25) on the theory that the destruction of the bottom resulted from the displacement of the brick from the pressure and greater density of the molten iron, so that the brick, not being tied in, float up. The layers, usually two, are arranged in concentric circles with a key brick at the center, and the outside circle is anchored down by the hearth walls.

These bottoms did not prove sufficiently superior in permanence to the less expensive shapes and it is not believed that any of these hearth bottoms are now being put in. The weak point was in the periphery, for as the hearth walls were eroded by various agencies the outside circle of blocks began to rise as the overlying brickwork disappeared, and once started the whole course was left without binding and floated up very quickly. The second course soon followed, leaving below the underlying brickwork of small shapes to bear the brunt of the work. In 1914 a few furnaces lined with this type of bottom were in blast, but they were relined with other styles of hearth brick.

USE OF KEYED BOTTOMS.

Figure 12 shows a modification of this style of construction, which is less expensive. Although the keying effect is of course not as strong on a perfectly flat as on a concave arch, it still possesses considerable resistance to the lifting effect of the iron. So far as known, these circles did not extend to the hearth jacket, but were anchored down by the hearth walls, as shown. It is here that their weakness lies; in addition, any defects in workmanship, in manufacture, or in laying, which open a way for the intrusion of iron, would be as fatal to the stability of the bottom as in brickwork not keyed in. Nevertheless, this method of constructing the hearth bottom is followed by many plants, as it is felt that the keying in delays or retards to a profitable extent the disappearance of the hearth bottom.

USE OF CONICAL JACKET.

In both of the above types of hearth bottom, bricks are laid with the vertical joints staggered, as shown in figure 25. This retards the intrusion of iron and promotes the permanence of the bottom. The erosion line shown in figure 25 brings out the significance of the use of a conical hearth jacket. The use of conical jackets was probably introduced to permit thicker brickwork at the juncture of the walls and hearth bottom, in order that the keys could be extended farther out, so that after erosion of the walls had been arrested a substantial ring of brickwork would remain to lap over the outside circle of keys and keep them from rising. A secondary advantage is that the conical shape wedges the whole mass of bottom brickwork in and prevents it from rising. This feature has, however, proved of detriment in some cases. A furnace was seen where the conical jacket had been forced up bodily on one side, away from the iron notch more than an inch, so that it sheared the nipples off the cooling-plate connections before depressions could be cut in the top of the jacket beneath the nipples. The expansion of the brickwork or salamander or the formation of graphite must have exerted sufficient force to overcome the weight of the jacket and its frictional resistance to the pressure on its interior. A possible result of such displacement would be cracking of the brickwork and penetration of iron through these cracks to the jacket. This result, however, did not materialize.

USUAL CONSTRUCTION OF HEARTH BOTTOM.

USE OF CONICAL JACKET.

The method of building the hearth bottom most generally followed is to construct it of large shapes, 18 by 12 by 8 inches, 18 by 9 by $4\frac{1}{2}$

inches, $13\frac{1}{2}$ by 9 by $4\frac{1}{2}$ inches being used. The two most favored styles of laying the blocks are shown in figures 26 and 27; another method not uncommon is shown in figure 28. The blocks are laid completely across the hearth, being in contact with the jacket entirely around the outer circumference of the brickwork, and the hearth wall rests on the blocks instead of 9-inch and $13\frac{1}{2}$-inch brick being laid between the special bottom shapes and the jacket, as in figures 12 and 14.

This construction is much stronger and more rigid than the keyed bottom, because the pressure developed by the expansion from heating after the furnace is in blast exerts its thrust across the hearth diameter, with no opportunity of the individual shapes slipping. The keying effect of the previously described bottoms is, of course, absent, but an equivalent tying-in effect builds up as the brickwork assumes its working heat, on account of the expansion stress against the hearth jacket.

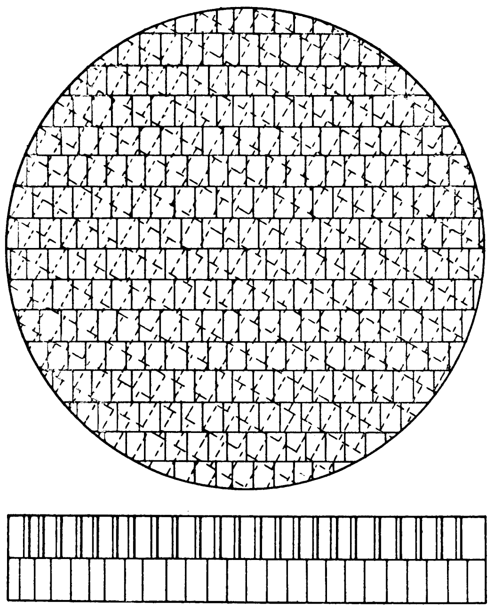

FIGURE 26.—Method of laying blocks in hearth bottoms.

These bottoms have proved as long-lived as the keyed bottoms when it has been possible to lay the brick tightly against the hearth jacket and on a 4-year blast have in a number of instances held the depth of salamander to less than 6 feet. A few plants that lay emphasis on removing the salamander find these types of bottom sufficiently resistant, so that they make a practice of removing the salamander only on alternate relinings.

As a general rule, the smaller size blocks are preferred, as they run truer to shape and permit thinner joints. The brick must be burned sharply to eliminate shrinkage cracks. It is of primary importance that the brick laying be absolutely accurate, with as small joints as possible, and if possible, tight against the jacket in order to allow the expansion completely to close every joint. Each course is preferably laid at an acute angle to the previous course, though it is often laid at right angles. This breaks all joints between the courses and tends to prevent the iron from working down between the courses and joints.

SMALL SHAPES IN HEARTH BOTTOM.

Hearth bottoms are sometimes laid with standard 13½ and 9 inch keys and straights. At the bottom of a 25-foot (inside diameter) hearth jacket, the first course is started by laying a circle of 13½-inch keys and straights next the hearth jacket, and continued by working into the center until 13½ keys complete the circle. The space inside of the circle of 13½ keys is completed by laying 13½ and 9 inch straights in straight courses. The next course on top of this is started by laying one circle of 9-inch keys and straights next to the hearth jacket, followed by circles of 13½-inch straights and keys until 13½ keys complete the circle. Straights are then laid across to complete the course, being laid in opposite direction to the course below. In this way alternate courses are laid until the hearth is completed.

In this manner all the joints are broken, the work of constructing the hearth is made easier, as cutting of fire brick is reduced to a minimum, and the construction sets together well when it is heated and expands. Much less advantageous is the method of laying 13½ and 9-inch straights in straight rows across the hearth, bricks in alternate courses being laid edgewise and flatwise.

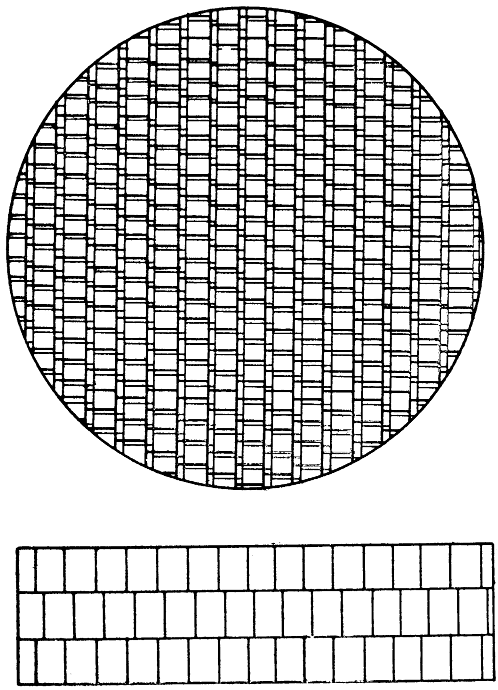

FIGURE 27.—Another method of laying hearth bottoms.

The most commonly advanced reason for the use of smaller shapes, of standard size, is that they are cheaper and truer in form than the larger sizes, having warped less in cooling off in the kiln, so that a minimum of clay is necessary in filling the joints when laying the brick. It is obvious, however, that the number of joints is greatly increased, and in direct proportion, the probability of iron penetrating the joints with inevitable disruption of the hearth bottom is increased.

DEPTH OF JACKET BELOW HEARTH BOTTOM.

The repeated experience of finding a salamander that extends to a considerable depth and has worked out under the jacket, even with the most painstaking care in selecting and laying hearth brickwork, has led furnace managers to extend the hearth jacket downward. In present practice the hearth jacket extends, on an average, 4 feet below the hearth bottom, and most of the jackets recently built extend 4 feet 6 inches and 5 feet below the hearth bottom. The writer knows of one which extends 6 feet, and another 8 feet below the bottom of the hearth; in each case, water-cooled plates set behind

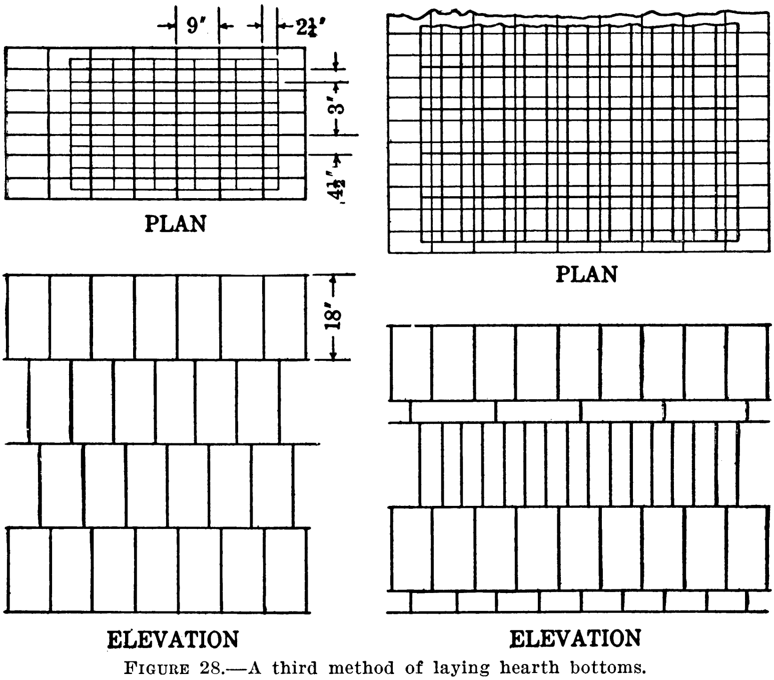

FIGURE 28.—A third method of laying hearth bottoms.

the hearth jacket are used to cool the bottom jacket. These figures, however, are extreme, as it is felt by the great majority of furnace men that 4 feet 6 inches provides a large factor of safety, provided that the hearth quality brickwork is carried down beneath the jacket for another 4 feet 6 inches and is bound in rigidly with steel bands or by a steel subjacket.

At this depth, 4 feet 6 inches below the original bottom of the hearth and, as an average figure, 12 feet to 14 feet 6 inches beneath the center line of the tuyères, it is only infrequently the case that the heat is sufficient to keep iron fluid so that by either mechanical or chemical action it can effect further disintegration of the brick. This hypothesis can hold only if the brickwork beneath the jacket is so strongly held in that expansion cracks can not form. If the brickwork is thus held and expansion closes the joints, the chance of a breakout beneath the hearth jacket may be disregarded. It is felt that water-cooling, if desired at this depth, is preferably effected by independent means, rather than by prolonging the depth of the interior water-cooled hearth segment, or plate, inside a steel-plate jacket. There are two reasons for this preference. Uneven expansion strains at the different depths below the tapping hole can be more adequately taken up by two superimposed jackets than by one of equivalent length; and stoppage of the water supply by plugging of a cast-in cooling pipe in a subjacket, or of a pipe embedded in the brickwork about the hearth bottom beneath the jacket, is not as liable to be immediately serious as a similar plugging of the pipe at the bottom of a deep hearth-jacket section or plate, as this involves the failure of cooling the hearth walls in a zone where continued and positive cooling is essential.

USE OF SUBJACKETS.

As mentioned above, subjackets are sometimes used to reinforce hearth bottoms. The subjackets used are of four types. One type consists of a steel-plate subjacket, 1½ inches thick and 4 feet high, riveted. These jackets may be set directly beneath the hearth jacket or outside, with the top 2 to 6 inches above the base line of the hearth jacket.

A second type is a cast-steel jacket, flanged and bolted. This is set similarly to the steel-plate jacket, or outside the line of the columns.

The third is a cast-iron jacket, made up of segments, with cooling pipe cast in. This is usually set with the top a little above the base line of the hearth jacket, and is a little larger in diameter than the jacket. Feed and discharge pipes are led down to it along the columns, as shown in figure 29. The disadvantage with these water-cooled subjackets is that the water connections sometimes break off by slight movements of surrounding brickwork or of the jacket, owing to expansion adjustments. Their advantage lies in the binding effect of the strong jacket on the inclosed brickwork, as the segments are held together by shrunk-on links.

In the fourth type the subjacket is replaced by massive steel bands. There may be as many as four bands, 12 to 15 inches wide and up to 2 inches thick. A bottom built from large shapes with a band inclosing each course is very strong.

All the types mentioned have given good results; the cast-steel type is least in favor. With the exception of the water-cooled subjacket, difficulty is found with any of them when used beneath a steel-plate jacket that is spray cooled and when the bottom of the water ditch about the jacket is 2 feet or more above its base line. It has repeatedly happened in such cases that the surrounding brickwork has become so hot that the subjacket is melted or cut and the iron has come through. It is clearly established that positive water-cooling must extend down to the bottom of the hearth jacket if the subjacket is to be of value. So many subjackets have been found cut from top to bottom that several plants cool the subjacket or bands by means of 2-inch extra-heavy pipes, set vertically about the outside of the jacket or band, on 10-inch centers. These pipes are welded or otherwise connected at the bottom to form a gooseneck circuit.

USE OF COOLING PIPES INSIDE THE HEARTH.

Probably the most courageous method of combating the penetration of iron into the bottom and the formation of a salamander is the placing of jamb pipes inside the hearth brickwork and extending from the top of the hearth jacket, between the hearth and

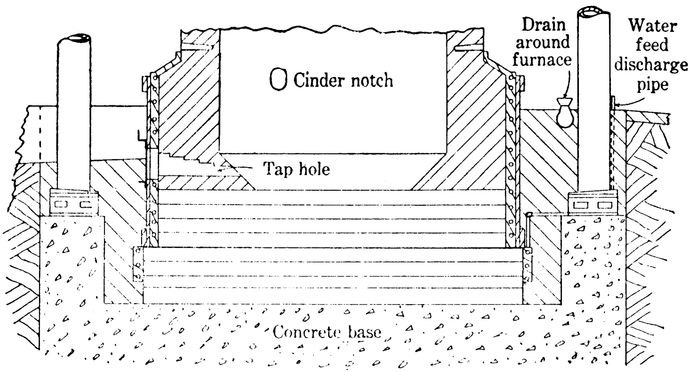

FIGURE 29.—Hearth bottom having cast-iron jacket with cooling pipes cast in.

tuyère jacket, diagonally downward to beneath the bottom of the hearth. Until this construction has been thoroughly tried out few furnace men will admit that any good can come of it.

LEAVING IN THE SALAMANDER ON RELINING.

On the basis of inquiries made, it seems that about 35 per cent of the furnaces in this country make the salamander the hearth bottom. The men in charge of these furnaces have come to the conclusion that regardless of the kind of brick or construction employed the bottom will disappear to a certain depth, and that if the iron should by any chance go any deeper no harm is done. The view has also been advanced that the iron eats to a certain depth at the first blast, then solidifies into a permanent block, which undergoes no change during the remaining life of the furnace. This solid mass of cast iron, it is claimed, is more effective than the best brickwork in preventing breakouts, because it is without cracks or joints and, from its high heat conductivity, will dissipate heat quickly and freeze any iron that may be lowering the bottom. In support of this view instances have been cited where, on blowing the furnace out and tearing out the brickwork between the jacket and salamander, a distinct and separate layer or skull of iron could be seen on top of the old salamander from a previous blast. This skull represented the new salamander, and goes to support the theory that once the lower part of the salamander formed on the first blast is solidified in any way the hearth temperature never after becomes high enough to remelt it.

Against this view may be cited the breakout described under example No. 10 (pp. 55, 56), which indicates unmistakably that the salamander had remelted and continued to work down, and also the breakout described under example No. 11, in which case the salamander had not been removed. Other objections are that on blowing in with an iron bottom, the bottom tends to work high for some time, inducing cold, high-sulphur iron, and causing difficulties with the tapping hole, that is, hard holes which may lead to hazardous conditions. However, if enough of the salamander is removed so that about 18 inches of brickwork can be laid on top of it, this danger disappears. Another disadvantage of having the salamander in is that the furnace is prone to work on a deep bottom in the course of a few months.

More serious is the trouble caused by the expansion of the salamander. When the salamander is left in, the hearth jacket is usually re-covered, the brick dug away, and enough of the salamander wedged or shot away to permit laying 30 to 40 inches of brickwork between the jacket and salamander on relining. If the salamander extends outward when uncovered in removing the brickwork, it is necessary to work to the bottom of the hearth jacket in splitting off the side, in order to put in an underpinning of brick beneath the base of the jacket and obtain the desired thickness of new wall. In some instances the brick foundation for the jacket, perhaps 9 or 13½ inches thick, is laid directly on top of the chilled salamander, which had worked to an unknown distance laterally and downward, as shown in figure 30. If no expansion space is left between the jacket and brick, or brick and salamander, it may easily happen, and has happened, that the salamander heats and expands after the furnace is blown in, so that the hearth jacket is cracked and crevices form in the hearth brickwork, which may result in a breakout. Column base plates have been cracked and columns displaced so that they get out of plumb. Such methods of rebuilding the hearth can not be said to be approved of by the majority of furnace men. Of statements made, about 70 per cent recommend removing the salamander at each or alternate relinings.

PROTECTION OF FURNACE COLUMNS.

The columns about the furnace are usually incased in fire brick or concrete from the base plate up to the cast-house pavement (see fig. 29). Often this reinforcement in the vicinity of the tapping hole and cinder notch is extended about 2 feet above the pavement. On most of the recently built furnaces the base plates of the columns rest on a concrete column or ring built about the hearth jacket and having its top 2 to 3 feet above the bottom of the jacket. With this construction any iron escaping through or beneath the jacket will be less likely to come in contact with and cut the column, thus undermining and weakening the foundations of the furnace. In the older furnace plants the columns stand on the concrete or brick foun-

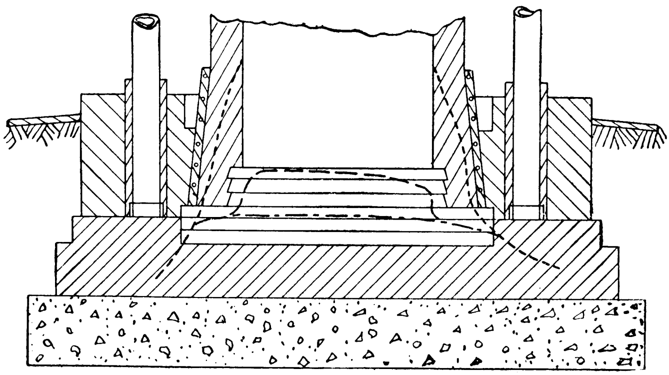

FIGURE 30.—Section showing method of repairing hearth bottom.

dation on which the hearth brick rests; their base may be at the same level or lower than the base of the hearth jacket. Several instances have occurred where molten iron penetrated the columns, which are usually hollow with 3-inch walls, and rose up inside the columns. The brick and concrete foundations inclosing the columns and base plates are usually held in against expansion of the brickwork and of the hearth by very heavy steel bands.

COOLING THE WALL ABOUT THE TAPPING HOLE.

With furnaces having steel-plate hearth jackets cooled by sprays, the weakest point is usually just above and below the tapping hole. A few have **Z**-bars riveted on over the iron notch which divert the spray water to one side. More often this part is not cooled, reliance being placed in a cooling plate about 3 feet above the tapping hole, set back 12 inches from the inside face of the lining, and the use of considerable amounts of clay in stopping the hole. This clay flattens against the wall and tends to build up and constantly renew the brick eroded by the blast. Frequently, beneath the tapping hole a brick pier is built against the jacket on which the skimmer trough is placed. This induces melting of the jacket and breakouts at this point. To take care of this difficulty in jackets relying on spray cooling, a small auxiliary trough is riveted or cast on; the skimmer trough is set in this and packed with loam to make a tight fit. The ditch is extended completely about the jacket and a spray introduced beneath the trough. A very serious accident was caused by the lack of such a trough; the iron at cast ate down between the jacket and skimmer trough, dropped into the water in the ditch, and caused an explosion.

IMPORTANCE OF FURNACE DESIGN AND CONSTRUCTION.

It may be thought that too much attention has been devoted in previous pages to details of construction. In contrast with nearly every other class of furnace accidents, breakouts are primarily dependent upon construction. If the bosh, tuyère breast, hearth walls and jacket, or hearth bottom lack strength or rigidity, or are insufficiently cooled, changes in practice or methods of work to avert breakouts are of little avail, and inasmuch as these accidents usually occur with appalling suddenness and frequently without warning, proper design of this part of the furnace is practically the only means of prevention.

NEED OF ATTENTION TO COOLING-WATER SUPPLY.

Several precautions and emergency measures may be taken to minimize the danger incident to breakouts. The bosh-cooling plates and also the plates about the tuyère breast should be flushed out regularly once a week with water under high pressure to prevent excessive accumulation of sediment. If this precaution is neglected failure of the plates is much more likely. In the lower part of the furnace, where the plates may come in contact with molten iron in the hearth, an explosion may result if the iron touches a plate insufficiently cooled because of water circulation being hindered by deposited mud.

The feed water for the cooling equipment should go through a double basket strainer with holes not larger than one-quarter inch. These baskets should be changed and cleaned at the beginning of each shift or oftener, and in times of flood water when leaves, chips, and other débris may be drawn in at the pumps, the strainer should be inspected more frequently. In addition to provision for high-pressure water, there should be a steam line into the cast house to blow obstructions out of cooling pipes cast into the hearth-jacket segments or plates. Steam at 130 to 150 pounds pressure will frequently open a plugged or slowly dribbling pipe that does not respond to high-water pressure.

The discharge pipes from hearth-cooling equipment should be carefully watched for signs of slackening flow or steamy water. As soon as such are seen the high-pressure water should be promptly turned on and kept on for several hours, or until the service water does not become unusually hot when turned on. An abnormally high temperature of the water is not necessarily, but is likely to be, an indication that the wall is becoming thin near that part of the jacket or that a crack is slowly opening. A larger volume of water circulated will help to stop the intrusion of molten iron by cooling the wall in that vicinity much faster. With spray-cooled plate or cast jackets, an additional short spray over any part that is becoming steamy is for the same reason an effective safeguard against failure of the jacket at that point.

CARE OF THE HEARTH DITCH.

If there is a ditch about the jacket, it should be kept clean. All débris, such as coke, slag, and dirt, should be cleaned out regularly and not permitted to accumulate. Before the furnace is started up, the bottom and sides of the ditch should be grouted with a neat Portland cement mortar so as to be absolutely tight and prevent water from seeping down about the hearth foundations. Whenever the furnace is shut down one or two days for repairs, as is the case once or twice a year, the spray should be shut off, the ditch cleaned out, and another coat of cement applied to close up any cracks developed by the expansion of the hearth and other brickwork.

The outlet of the ditch should not be raised to raise the level of the water. Cooling is more effectively done by a spray giving a rapid flow of water down the entire surface to the bottom than by a body of water flowing with relative slowness about the ditch. Another reason for not keeping the water in the ditch at a high level is that if the surface is higher than the bottom of the skimmer trough the water may, as has happened, work its way between the bottom of the trough and the brickwork of the pier upon which the trough rests, seep up between two sections into the trough, and cause an explosion. The need of such precaution is obvious when the ditch extends completely around the jacket, but is not so self-evident when the trough rests upon brickwork in front of the hearth jacket below the tapping hole. When that section of the spray-cooled jackets above the tapping hole becomes hot and water cooling is not feasible, it can be effectively cooled by directing a blast of cold air on its surface from one or more "rose-head" nozzles.

PRECAUTIONS AT BLOWING IN.

REGULATION OF COOLING WATER.

In blowing in it is customary to delay turning the cooling water on or into the hearth jacket until the first flush of cinder has appeared, in order to avoid any possible chilling of the hearth. After the first or second flush the water is started slowly and brought up to full head in the course of 48 hours, depending on the rate of blowing in and of obtaining the first cast. It is imperative that the water system be given a thorough try out before blowing in, for in event of any defect appearing immediately after the furnace is started there is good cause for apprehension, as water-cooling must be effective from the start in order to establish the working thickness of the walls.

Cooling-water discharges from the columns, if the columns require cooling, should be in plain sight of the furnace crew, and not led into the ditch beneath the ditch plates. Cooling should not be employed until the columns become quite warm to the touch, and even then they are probably as safe without as with interior cooling, for if iron should penetrate into a column filled with water, in all probability the resulting explosion will wreck the column. Water-cooling of columns was originally employed at furnaces where the column base was beneath the bottom of the hearth jacket and was useful in cooling the surrounding brickwork.

TYPES OF SLAGS AT BLOWING IN.

In blowing in, it is customary so to burden the furnace that the slag will be extremely limy, as a limy slag, particularly with the extremely hot iron made during the first 8 or 10 casts, is conducive to a heavy separation of graphite which may, to some extent, protect the hearth walls and bottom. Typical analyses of blowing-in slags are given herewith:

Results of analyses of limy slags from three plants.

Constituent.	Content in slag from—					
	Plant A.[a]		Plant B.[a]		Plant C.[a]	
	Theoretical.	Actual.	Theoretical.	Actual.	Theoretical.	Actual.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
SiO_2	30.53	34.34	24.35	29.10	28.98	30.23
Al_2O_3	11.76	16.42	19.39	19.88	16.58	16.04
CaO	40.91		50.11	46.40	47.58	47.33
MgO	12.23		4.15	2.56	2.53	2.07
Mn	1.54		.39	.15	.33	.81
S	3.03	3.14	1.55	1.71	2.19	1.45
Fe		.55		Trace.		.21

[a] Analyses by plant chemist.

The slag obtained at plant B gave trouble for several days, as in spite of high-silicon iron, high sulphur persisted and was not lowered until 500 pounds of gravel was added to the burden to decrease the alumina content. The theoretical analyses from plants B and C show needlessly limy or aluminous slag. The slag at plant A, although limy, was much more fluid on account of the high magnesia content. The slag at plant C was so limy that it slaked in the runners.

As is evident, liming the charge at blowing-in can be overdone very easily, and it is becoming the tendency to make the blowing slag as nearly normal as practicable with regard to the limitations of the constituents of the blowing-in burden, as the high silicon content of the iron causes graphite to separate regardless of the character of the slag. Examples of blowing-in slags from two plants, as analyzed by the plant chemist, which gave richly graphitic hot iron without being abnormally basic, are:

Results of analyses of slag from two plants.

Constituent.		Slag from plant D.	Slag from plant E.
SiO_2	per cent	32.80	35.39
Al_2O_3	do	17.20	15.03
CaO	do	45.30	44.05
MgO	do	1.36	3.28
Mn	do	.41	----
S	do	2.44	1.68
Fe	do	.22	----

All these slags were described as hot and gray. A few furnace managers fill the hearth below the tapping hole with clean, large lumps of converter cinder. This cinder carries from 8 to 15 per cent of manganese oxide, which is supposed to have a reducing action and impart a high manganese content to the pig iron collecting in the hearth previous to the first cast, and thus promote the separation of graphite, an action noted in furnaces producing ferromanganese. Inasmuch as, to be on the safe side, a furnace has to be blown in hot anyway, it is likely that neither an excessively limy burden nor one that will give high manganese iron is at all essential, and that graphite separation will take place in any case, whether helpful or not, at this stage of the run.

REGULARITY IN FLUSHING AND CASTING ESSENTIAL.

Regularity in the time of flushing and of casting is imperative. The higher the iron rises in the hearth, the greater the internal pressure and the danger of iron penetrating the walls and causing a breakout just before casting. While the interval between casts is governed somewhat by the rate of driving and the capacity of the hearth, there is nevertheless a considerable discrepancy between the tonnage per cast in furnaces of the same rated hearth capacity. This difference does not necessarily indicate that the furnace making the larger production is in a more hazardous condition, or that with the one making the smaller production the cast, in case of emergency, can be delayed until the hearth contains an amount of iron equivalent to the tonnage per cast of the faster driven furnace. This is because the tapping hole on the furnace making the larger tonnage is deeper and the hearth is deeper, so that the space between the bottom of the tapping hole and the center line of the cinder notch after cast—this distance representing the maximum capacity of the hearth for iron—is much greater than on a slower rate of driving. Figure 31 shows this condition. It is therefore dangerous to hold back the cast beyond the regular time, and there should be firm insistence that holding of casts be avoided.

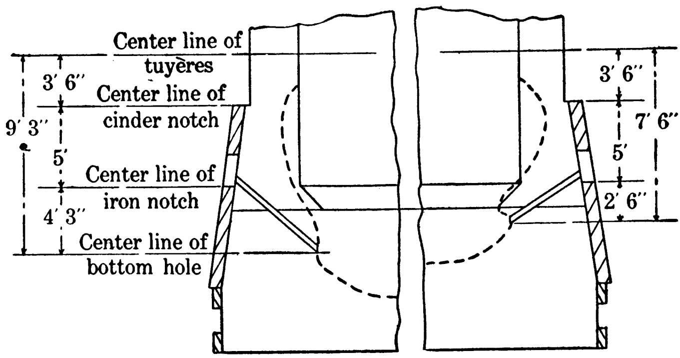

FIGURE 31.—Diagram showing hearth conditions of fast-driving furnace.

PRACTICE WHEN CASTING IS DELAYED.

METHODS OF OPENING HARD HOLES.

To avoid the probability of having to hold casts on account of hard or ironed-up holes, every plant should keep in stock at least a half dozen cylinders of compressed oxygen. By directing a jet of oxygen against the hot solid skull in the hole, or if the skull be cold against a handful of glowing kindling and aluminum powder placed against it, the hole can be opened very quickly.

Another method is to use an electric burner, consisting of a 3-inch carbon rod connected to the negative pole of a generator, the positive pole being applied to the hearth jacket. Such a burner takes care of mixtures of slag and iron that the oxygen jet may not eat through. The invention of these two appliances undoubtedly has prevented many breakouts, and they should be a part of the equipment at every furnace. The only objection ever urged against them is a singular one; it is stated that if permanent connections for an electric burner and a readily obtained resistance are provided, or if oxygen tanks are kept in readiness, the furnace crew becomes careless in the care of the tapping hole, and hard holes are more frequent, and that the men rapidly lose skill in sledging and become less resourceful. If these appliances are not used with some discretion by the foreman, such a state of affairs may exist. However, it has not been observed by the writer, and the objection is put forward only at plants where the management is inclined to be conservative.

Although a new tapping hole can usually be made, at the expense of some delay, by driving and drilling above the old tapping hole, or by driving a bar through the skull with sledges, rams, or dollies, it sometimes happens that the bar breaks off in the back of the hole when an attempt is made to withdraw it with the "Welshman," or freezes in the hole and can not be withdrawn, or the molten iron freezes in the hole, or the hole dribbles iron very slowly and the pricking rod can not be pushed in; then the fluid iron may cool, filling the tapping hole and trough with a solid mass of iron. Any of these mishaps leaves matters worse than before. Meanwhile the iron is rising higher and higher in the hearth, and if it rises above the line of safety it may run out, cut the "monkey" or cinder notch, and cause an explosion, or break through at some weak place in the hearth.

These misadventures and possible accidents can be avoided only by providing oxygen and electric burners. In the event of a "mucky" hole, one in which the iron is so pasty that it will not run freely but moves slowly up in the hole as it is burned out, neither type of burner is of much use; but this is about the only frequent serious condition that the burner can not overcome.

PRECAUTIONS TO PREVENT THE IRON RISING TOO HIGH.

In the event of an obstinate hole, or breakdown at the mixer or pig machine, delay in emptying the beds, or delay in spotting the ladles, care must be taken that the iron does not rise too high in the hearth. At some plants where the hearth walls are known to be weak, or the hearth bottom very low, the blast is taken off just as soon as any delay develops without promise of immediate correction. Other plants keep on full wind for not more than 40 minutes after the regular casting time. If the delay still persists the blast is reduced from a pressure of 15 to 9 pounds and thus to a pressure of 4 to 5 pounds. This low pressure is kept on not more than 20 to 30 minutes, as it may make the furnace stick; then the blast is taken off altogether and the furnace drafted back.

The furnace should be flushed more or less continually during such delays to keep the cinder away from the tuyères. Care should be taken not to let the iron come over the cinder notch, as it may cause an explosion, and especially not to keep the wind on until the iron is above the cinder notch and cinder at the tuyères, when the cinder can not be flushed without danger of cutting the "monkey" and cinder coolers nor the wind be taken off without the blowpipes filling.

ATTENTION TO SIGNS OF A BREAKOUT.

The cast-house crew should be instructed to pay particular attention to any indications or signs of breakouts. Although breakouts through the hearth jacket above the tapping-hole level are frequently sudden and without warning, nevertheless indications are not always lacking; the jacket may get unusually hot and steam heavily, or the water discharge from the cooling pipes set behind the jacket, or in plates or jacket segments, may start to steam and boil.

Impending breakouts beneath the tapping-hole level are indicated as follows: The pavement and brickwork about the jacket may become abnormally hot; the base itself, if not inclosed, may get unduly hot; the columns, if uncooled, may become too hot to touch, or if cooled, the discharge water becomes very steamy; steam or gas, the latter igniting and burning with a bluish flame, may issue from the cracks and joints in the pavement and in the brickwork about the columns and jacket.

PROCEDURE WHEN A FURNACE IS "LOSING" OR "HOLDING" ITS IRON.

"Losing the iron," and flames about the base, are unmistakable signs of lowering of the bottom, undue penetration of iron to moisture-impregnated brickwork, or a breakout. The significance of a furnace "losing the iron" has been described, but it should be mentioned that this condition is not to be confused with a furnace "holding the iron," the occasional failure of a furnace taking charges regularly to give anything like the normal amount of iron at cast. When a furnace loses its iron, there is usually a heavy run of cinder from the tap hole and a small cast or none, whereas if a furnace is holding up its iron, the tapping hole usually runs iron very slowly, with considerable blowing or blubbering, and the amount of cinder is somewhat scanty.

The best way of making sure that a furnace is holding iron and not losing it is that used at a large plant in the Pittsburgh district. In the event of an abnormally small cast, even with indications of holding up, the cast time is set forward 2 hours, and the next cast, instead of following 5½ hours later, as is the regular practice, is made 3 hours later. It is rarely found that the previous small cast indicates that the furnace is losing iron, the contrary is more frequently the case. Setting forward the casting time, besides developing the true state of affairs within the hearth, also obviates the possibility of an excessively high accumulation of iron being held in the hearth. The practice is one worth adopting at plants where it is not followed.

When a furnace is known to be losing its iron, or when gas generates and burns about the base, a breakout is indicated. There may simply be a lowering of the bottom, the iron may be seeping slowly into moist surroundings, or a very dangerous breakout may have started. Although the escaping iron may not cause damage or an explosion, the most careful plan is to flush the cinder, check the furnace, and cast immediately. The furnace should then be allowed to stand with the tuyères plugged for 24 or 48 hours, when more moderate driving and a more limy slag will enable the furnace to chill off in the bottom and effect its own repairs. It is also logical, if the brickwork about the base is inclosed with a filling of sand, brickbats, or other rubbish, to drill a number of holes down about the outside and insert long pipes attached to the water-supply mains to chill off the bottom. The water should be maintained under full head on or in the hearth jacket, subjacket, and cooling pipes. The plan more generally followed is simply to reduce the blast and make a limier slag. When this plan is followed, many advise against saturating the surroundings of the hearth brickwork with water, because of the danger of a destructive explosion if the iron eventually gets into the wet material. Whenever derangement of the hearth bottom is indicated and measures are being taken to overcome it, there is double need, until the indications mentioned have disappeared, of the blower and cast-house crew being on the alert for increasing emission of gas about the pavements or other signs of the breakout developing faster. Experience and knowledge of the construction and behavior of the particular furnace are the only safe guides when these conditions develop, but it may be said that it is better to err on the safe side when the signs become pronounced and to cast and take the blast off at once, or even, if the signs become especially alarming, to take the blast off without casting and simply flush the cinder. The crew should be dismissed from the cast house, all approaches to the cast house guarded, and the furnace left standing until either a breakout actually occurs or the signs quiet down. If in about four hours no breakout has occurred, the crew can with comparative safety return and take such measures to bank down or resume work as the superintendent decides.

PROCEDURE WHEN STEAM ISSUES FROM ABOUT THE FURNACE BASE.

Steam about the columns and other places in the floor adjacent to the hearth bottom may indicate, in case of wet filling about the hearth brickwork, that the base is becoming hotter, which is not without significance, or on the contrary may indicate only that water is penetrating into the fill, the hearth bottom surroundings being only normally hot. In either case, the appearance of steam indicates that a condition exists that may possibly cause an explosion should the hearth bottom be lowering, widening, or cracking, and the molten iron penetrate the wet material about the base. It should lead to prompt grouting of all ditches, both about the jacket and in the pavement about the cast-house wall, and such repairs to pavements as will eliminate pools of water and allow the water to run off quickly. Except at periods when, in the judgment of the superintendent, saturation of the already more or less wet fill about the hearth foundations with water is essential to prevent a breakout, these should be kept as nearly dry as possible. A breakout into dry sand, brickbats, or other material is harmless so far as possibilities of an explosion are concerned.

REPAIRING THE JACKET AND WALL AFTER A BREAKOUT.

In case a breakout above the tapping-hole level has cut the hearth jacket, the most effectual means of protecting the jacket and walls at this point against further failure is stated to be the chilling of the iron in the hole. If necessary the iron is cooled with an auxiliary spray during the remainder of the run, and its great relative heat conductivity makes it the most resistant part of the jacket. Chilling of the iron is frequently unfeasible. In this event, the hole is usually tightly rammed with clay and brickbats. Another method that has also been recommended is to drive an iron plug into the hole, if the latter is not too large, and wedge it in tightly. This serves in the same way as a chilled lump of iron left in from the breakout.

When the breakout is at the tapping-hole level or beneath it and comes into the ditch, the usual practice is to leave the solidified lump in, clean any cinder off the top of the lump, and raise the level of the water to cover the top. Such treatment of the hole cut is almost always efficient and prevents a repetition of the accident at that point.

When the ditch is provided with a lead plate, through which the iron melts and escapes before chilling against the tapping hole, or when the iron runs along the ditch beneath the water and escapes into the sewer, or when for any reason the iron does not chill in or against the hole, the latter is usually rammed full of crushed fire brick or clay, which is sometimes wet with tar. Large quantities are used and are packed by 6 to 12 men swinging a broad-faced "dollie" against the face as the material is thrown in. Sometimes hours are consumed at this task, but it is time well spent, as the emergency refractory wall must be tightly packed into the irregularities of the cut-out hole. The surface is, if necessary, faced with a thin brick wall and sprayed with water. Breakouts thus repaired, if not unusually and excessively large, prove as strong as the original wall. In one instance, where the hole was almost 2 feet in diameter and was cut near the cinder notch at the bottom of the ditch, a solid wall of concrete was built against the clay packing.

If cast-iron or steel jackets or vertical plates with cooling pipe cast in are used and there is no ditch, the furnace is usually allowed to make its own repairs, iron that has penetrated the jacket or between the segments being left. Any cooling pipe cut by the iron is disconnected, and the cooling-water feed pipes led across to the still available connections. A hole is sometimes drilled downward along the outside face of the jacket in the brickwork, and a half-inch pipe inserted for temporary water cooling.

When a destructive explosion within the cooling pipe blows out the jacket and surrounding brickwork, the hole made by the explosion is usually cleaned if possible, rammed full of refractory material, and the brickwork replaced about the jacket. No instance is known of an attempt to replace a jacket segment of a furnace in blast; in fact, this is unnecessary and practically impossible. Occasionally a space is cleared in front of the cut or blown-out section of the hearth jacket and concrete is poured in. When a breakout is in the depths of the furnace foundations, unless the base is uninclosed, and the hole is rammed with clay or other material, usually no effort is made to find the precise place and repair it, but after the breakout the furnace is allowed to stand with the wind off for 24 to 36 hours and its surroundings are thoroughly saturated with water to chill the runaway iron. A few plants have taken the opportunity, on relining, to dig out the sand or other filling surrounding the hearth foundations, and fill the entire space around and in front of the furnace with a monolithic mass of concrete. This, with elimination of the water-filled ditch about the hearth jacket, promises the greatest immunity from disastrous hearth breakouts.

TAPPING-HOLE BREAKOUTS.

FACTORS TENDING TO DESTROY THE IRON NOTCH.

With hearth jackets and hearth brickwork strongly constructed and copiously cooled, the weakest point is immediately over and at the tapping hole. The iron notch is expected to withstand the erosion of fluid iron forced out at high velocity, the slagging action of cinder, which begins to come out with the iron during the latter half of the cast, and the cutting of the gas or blast sweeping down from the tuyères when the iron sinks to a low level in the hearth near the end of the cast. To withstand this action there is provided simply a plug of fire clay, which fills the opening left in the hearth walls at lining, 6 inches by 24 inches by 36 inches in size.

Generally speaking, the limier and especially the richer in magnesia the slag is, the more severely is the clay in the tapping hole cut out and weakened. When the lime content becomes excessively high so that the slag is extremely mushy, the action is not pronounced, but the action of limy slags sufficiently fluid to work well is notably severe.

METHOD OF STOPPING THE HOLE AT BLOWING IN.

When the furnace is blown in the iron notch is rammed full of clay mixed with up to 33 per cent of coal or coke dust, the men working from the inside and outside of the furnace. The notch is sometimes left closed, but usually a 4-inch pipe is inserted in it when it is being clayed up. The pipe should project at least 6 inches inside of the brick lining, and clay be well packed about that part, so that the end will be well inside of any skull that chills on the walls. Holes are drilled in the outer end of the pipe, so that it may readily be withdrawn. Sometimes no pipe is put in, but the clay is packed about a tapered form 4 inches in diameter at one end, 6 inches at the other, and 6 feet long, which is withdrawn after the furnace is filled and ready to light. This is done to insure the hearth bottom being heated by the gas sweeping down through and out of the tapping hole, and also because on blowing in great difficulty is usually experienced in opening the tapping hole, if it is closed from the start, on account of the iron chilling against the cold walls, as frequently the first iron coming in contact with the hole seems to be cold and insufficiently carburized, so that it is very tough.

The bottom of the hole, which is put in horizontal or at a very slight angle, is usually at least 18 inches from the hearth bottom on the inside, so that the first slag collecting on top of the iron in the hearth either closes this opening in the iron notch or else, when it shows at the iron notch after 8 to 16 hours, the clay gun is swung around and one barrel of clay shot in. In either event, there should be only a skull of cinder to drill through when the first cast is made. An efficient method of keeping the hole shut when blowing in is by filling it, as shown in figure 32, page 81.

CARE OF TAPPING HOLE WHEN FURNACE IS IN BLAST.

The erosion of the tapping hole begins at the first cast. Usually the top and sides are worn away slightly by the iron, slag, and gas. When the hole is stopped with the clay gun at the end of the cast, more than enough clay to fill the hole is forced in, and the surplus tends to spread along the inside of the wall, on the top, sides, and bottom. The clay thus distributed, if it is of correct plasticity, tends to replace completely the burned-away wall.

With increasing production the bottom of the hole is made deeper and deeper as the hole is drilled, the angle of slope being increased until the desired capacity is reached. With higher blast and production the cutting effect is increased, until eventually as much as three handbarrow loads of clay are used to stop the hole. One barrowful, with the clay in the barrel of the gun, is more than enough to fill the hole, the two extra barrowfuls being used to insure that the walls and a substantial roof are built up. At this stage such excess clay, besides replacing the walls, tends to flatten out on the inside of the hearth wall and to thus form a key which locks the stopping clay in place within the hole and prevents it from being blown out by the internal pressure. The hole in a 36-inch hearth wall is frequently 5 feet long, but because of its slope does not project in as far as the length might indicate. It is desirable to keep the inner end of the hole away from the face of the hearth wall so as to protect the brickwork from the effects of the current of gas blowing down from the tuyères and out the hole. This may be overdone, however, and the hole have so long a roof built up that there will be danger of the roof breaking through while the men are at the drill.

USE OF COOLING PLATES OVER THE TAPPING HOLE.

To protect the walls over the tapping hole from being cut back to an unsafe thickness, a great many plants insert a bronze cooling plate in the brickwork about 2 to 3 feet above the hole. Another method, little used, is to place a cooling pipe in a pigeonhole in the hearth jacket over the tapping hole. To protect the sides and top of the tapping hole from being cut out, cooling boxes or plates have been placed in the brickwork about the hole. Such plates are very dangerous, for if the brickwork is cut back to the plate, as has happened repeatedly, the hot iron rushing past the plate, heats it until the plate wall melts. Then a terrific explosion that throws molten iron about the cast house is almost inevitable. These devices are used rarely and are condemned by 9 out of 10 furnace men.

TYPICAL TAPPING-HOLE BREAKOUTS.

EXAMPLE NO. 1.

After a cast the hole was stopped. The blast was turned on about 30 seconds after the gun was put in the hole and while the hole was still taking clay freely. The keeper removed the gun 20 minutes after stopping the hole. The helpers were working on the iron runners, "ridding up," and were in direct line with the hole. Three or four minutes after the gun had been swung away from the hole the clay plug blew out and a blast of hot coke, slag, and gas blew down the cast house, severely burning four of the helpers. It was stated that the furnace had been working with a short hole for several casts previously.

EXAMPLE NO. 2.

Six men were opening the hole with a churn drill. The hole was reported to be about 4 feet deep and rather flat. They were on the third spell and were probably close to the skull, when the tapping hole opened suddenly and blew a shower of iron and flame over the men, fatally burning the two nearest the hole. The accident is thought to have been due to molten iron breaking through the top of the hole, but as the keeper and helper were killed this fact could not be established.

EXAMPLE NO. 3.

The hole had been stopped with an unusual amount of clay, as it had been working short. About two hours after making the cast the clay blew out and the entire content of iron ran out into the ladles, which were standing where they had been spotted for the next cast. The hole was stopped again, but in less than an hour after the next cast the iron came through at the side of the tapping hole, cut the jacket to some extent, rapidly eroded the clay, and broke out again, although the blast was taken off immediately. No ladles had been spotted, and the mass of iron on the tracks had to be cleaned up.

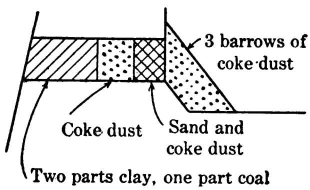

FIGURE 32.—Method of closing tapping hole when furnace is blown in.

Two hours later there was a similar breakout, the iron starting slowly but finally coming fast. This time the two tuyères over the tapping hole were plugged, and, as the hole was very wide, it was stopped by hand, two dollies being used to ram the clay in. Plugging the tuyères stopped the breakouts and enabled the wall adjacent and above the hole to build up. There was no cooling plate over the tapping hole. No one was injured.

EXAMPLE NO. 4.

A furnace was casting, and had run about half the cast. Pressure was still 16 pounds. The hole began to blow very hard, and almost immediately the entire stopping blew out, throwing a sheet of flame to the bottom of the cast house with a shower of coke, iron, and slag. At the same time a body or pool of iron, apparently held up in the furnace, broke out and overflowed the runners, sheeting the cast-house floor. Several men were severely burned.

EXAMPLE NO. 5.

The keeper and helper were engaged in ridding up the skimmer trough about an hour after a cast, when the clay blew out of the tapping hole. The clay gun had been swung back only a few minutes. Both of the men were killed.

EXAMPLE NO. 6.

At one plant the practice of allowing the furnace to blow at the tapping hole at the end of each cast was followed, the blast being kept at full pressure until the iron ran only in small dribbles; for about five minutes the blast would blow flame and coke the entire length of the cast house. This practice evidently had thinned the hearth walls and made the clay stopping virtually the sole means of holding in the iron over a wide and high area. A cooling plate over the tapping hole, 2 feet 10 inches in size, exploded and blew out just before casting time. It was thought that excessive blowing at the hole had thinned the walls until the cooling plate extended so far inside the hearth that it was unprotected by brickwork for a considerable depth, and, owing to stiff clay, melting of clay, or momentary severe scouring action, the protective covering over the plate failed and allowed the iron to cut through.

EXAMPLE NO. 7.

This furnace had two cast-iron cooling boxes, set 9 inches from the center line of the iron notch at each side. One of these exploded just as a brakeman entered the cast house. The concussion knocked him down the steps to the yard level, fracturing his back. Other men in the cast house were not injured.

EXAMPLE NO. 8.

A similar explosion occurred which threw molten iron and flame over two men and fatally burned them.

OTHER TAPPING-HOLE ACCIDENTS.

There have been in the past repeated instances of explosions at the tapping hole owing to cutting of the cooling blocks, but they are now a thing of the past.

A not infrequent type of accident, which is not regarded as a tapping-hole breakout, but is nevertheless essentially such, is when the men on the drill opening the hole are careless or uninformed as to the length of the hole, and break through the skull, or the skull opens suddenly when the tapping bar is driven through it. In any of these events there is a probability of the workmen being seriously burned.

PREVENTION OF TAPPING-HOLE BREAKOUTS.

PRECAUTIONS IN PREPARING AND LOADING THE CLAY.

Perhaps the chief difficulty in stopping the tapping hole is that the clay is likely, unless the gun is handled correctly and the clay mixed properly, to fill the hole straight ahead and not flatten out about the edges on the inside hearth walls or close up the uneven places and eroded channels in the hole itself, so that the stopping is neither safely keyed in nor firmly packed into the irregular contour of the tapping-hole surface. The clay is mixed to such plasticity that when squeezed in the hand it will flow between the fingers only slowly or with difficulty. As a rule a high grade of gray, weathered, flaky fire clay is used, because a red or yellow clay containing upward of 5 per cent of iron oxide may set too hard, although in certain districts yellow clay is used without difficulty.

When the hole does not take clay freely it is the custom to fill the gun barrel about half full of clay, then pour in half a pail of water, or loam and water, and force the clay and water into the hole. This thins the clay so that it fills the hole tightly. Many plants use water in the gun regularly. In this case the larger part of the first barrowful of clay, if two or more are used, is fed; then about half a pail of water is poured into the gun funnel after the barrel is well filled with clay, and the load shot into the hole. This procedure may be repeated a second and third time.

Another practice is to have a half-inch pipe with water connection directly over the funnel of the gun. After the first load of clay in the gun is pushed in and the gun is taking the clay, water is turned in continuously as the helper throws the clay into the funnel. This practice makes a very firm hole and one in which there is little probability of the iron working back and leaking through between the clay stopping and the walls.

There are two dangers in adding water to the gun charge. First, if water is used too quickly, before a large plug of relatively stiff clay has accumulated on the inside in front of the opening, the thin, watery clay may be shot into the hearth and, coming in contact with molten iron, cause an explosion. This has frequently happened with the result that a shower of slag and flame shot back through the hole, or has, in one instance, at least, fatally burned men engaged in changing tuyères. Second, the use of water may cause a "green" hole—one in which some part is not set thoroughly stiff, or even thoroughly dry, through which the drill may break and let the iron out before the men are expecting it and possibly cause a small explosion or shot inside the hole that will throw molten iron into the air.

OMISSION OF COOLING PLATES ABOUT THE NOTCH.

Water cooling about the iron notch is not necessary, and it should not be employed. It has rarely been found entirely satisfactory or safe in consequence of the inevitable, and occasionally severe, corrosion of the hole working back to the cooling plate. A disastrous explosion is invited by the employment of this device. It is entirely unnecessary, because careful stopping of the hole with the gun after every cast answers the purpose and is safe.

A GOOD PRACTICE IN STOPPING THE HOLE.

In stopping the hole, a good practice is to permit the nose of the gun to move back a couple of inches at a time as the hole becomes more nearly filled, in order to pack the clay firmly in that part of the hole nearest the jacket.

CLEANING THE HOLE.

At one plant the clay in the hole is dug out at least twice a week, or as much oftener as required, to a depth of 18 inches, and the sides and bottom are walled with 13½-inch by 4½-inch by 2½-inch bricks. The hole is then filled again with clay. This is to prevent cutting of the side walls where jamb pipes are inserted behind the jacket near the hole.

Another practice is to remove the clay to a depth of 18 inches and pack a stiff mixture of tar, clay, and crushed hearth-quality fire brick about a wooden form shaped like the nose of the gun. This method is employed where a cooling pipe, cast into the health jacket, bends about the iron notch at a radius of 12 to 18 inches from the center line of the notch.

USE OF A LONG PLUG OR STOPPING.

Most plants follow the practice of placing an unusually long stopping in the hole at the end of each shift. This is for three reasons: (1) So that there will be no possibility of danger to the oncoming crew from a short hole, which may break out unexpectedly; (2) to insure that the walls, which may be thinning unperceived, will build up, and (3) to assure a substantial roof or top thickness for the tapping hole. A commendable requirement followed at one plant is to have the keeper note after each cast the number of barrows of clay used in stopping, in order that the keeper on the following turn may know how the hole has been working and taking the clay, and thus proceed more safely in opening and stopping the hole.

BLOWING ON THE HOLE.

The practice of blowing on the hole for some minutes in finishing the cast, is becoming exceptional. It is admittedly poor practice, for it heats the furnace front, thins the walls, makes a safe stopping more difficult, and may lead to breakouts. It is, however, persisted in at a few plants. One reason is the rivalry between different shifts, each desiring to outdo the other in tonnage made, so the last particle of iron that can be obtained from the hearth is removed by prolonged blowing at the tapping hole. Recognition of the fact that the ultimate tonnage is governed both by conditions at the blowing room and stock house, and by watchful observance of the working conditions and adjustment of temperature, fluxing, tuyères, and other factors to meet the variations, and that an exceptionally large tonnage for a turn or a day means nothing, has led to sane treatment of the tapping hole at most furnaces, and probably will at all plants except those where other views prevail.

These views are as follows: Some furnace men still believe that the hearth should be blown absolutely dry, because any iron left in the hearth will begin to circulate, cut the walls, and cause a breakout. This condition, so they believe, is caused by currents of air from the blast finding their way down through the burden in some way, and starting a movement of the iron on the walls. As long as the iron can be prevented from moving, the walls will not be cut, and the best way to prevent this is to leave no iron in the crucible. Although this view may be held lightly by some, it is earnestly and seriously argued by older furnace men, which is the reason for recording it here. It is worthy of mention, however, that molten iron will necessarily accumulate in the hearth between casts, and that even after prolonged and heavy blowing a pool of liquid iron remains beneath the bottom of the tapping hole, which can not possibly be blown out. Nevertheless, their belief is strong enough to cause some furnace men to cling to their long-established practice. Another reason advanced is that the furnace is benefited by cleaning the hearth of "dead" iron and cinder. There are still other reasons which, for good and sufficient causes in the past, have established the practice. To dispute their validity is often hazardous, for, in spite of the advance in knowledge of conditions within the blast furnace, there are frequently actions within the furnace, or idiosyncrasies of individual furnaces, which are not comprised in the chemical-physical theories of their working. In regard to prolonged blowing at the tapping hole, the disadvantages and dangers arising from irregular working of the furnace and the tapping-hole difficulties have proved of greater weight than the benefits derived, and the practice is becoming obsolete except under abnormal working conditions.

ESPECIAL CARE NECESSARY WHEN CASTING IS DELAYED.

Especial care of the iron notch in stopping and precaution in working about the notch and in opening it are essential when the cast has had to be held for an hour or more. The load of iron in the furnace is higher and the interior pressure is more likely to blow the plug of clay out or to cause the iron to penetrate between the clay stopping and the walls or to break out suddenly when the hole is being drilled or the tapping bar is being driven in or removed. The high head of iron usually causes such rapid melting and erosion of the clay stopping that the hole quickly becomes double its ordinary or proper size and the carefully built roof of the tapping hole and interior wall of the hearth disappear. Similar results may be caused by high blast pressure, although in such a case checking the furnace at casting time has a more retarding effect.

Stopping the hole at such times is difficult. Cinder is nearly always lying in the hole and the nose of the gun does not fill the hole, and instead of the clay being forced into and beyond the interior face of the wall and packing against the face it sometimes escapes back about the nose, extends only partly into the hole, and fails to fill it completely; cinder or molten iron may escape and come back in the gun as the plunger is drawn back, necessitating a delay, the hole chills up, and no more clay can be forced in. These results may occur even with holes of normal size if the gun is not placed squarely in the hole, is not properly loaded, or if the operator is unskilled or unfamiliar with the method of operating the throttle lever. If a hole is short or hard, care must be used in drilling into it on the next cast to avoid a breakout if the drill goes through the skull unexpectedly.

STOPPING THE HOLE WITH THE BLAST ON.

To prevent the suction of the plunger and the interior pressure in the furnace displacing the clay in the hole and thus permitting cinder or iron to run into the barrel of the gun or burst out between the gun nose and the sides of the hole, one type of mud gun used at certain large furnaces has a single slide valve, worked by a hand lever, between the clay cylinder and the nozzle of the gun. The gun is placed in the tapping hole and the first load of clay driven into the hole. The slide valve is then jammed down and the plunger drawn back for recharging the clay barrel. The barrel being loaded, the valve is raised and a second load driven in, this process being repeated until one to three barrows of clay are placed in the hole.

With this type of gun the blast can be, and usually is, with a normal size of tapping hole, turned on immediately after the first load of clay is put in; but with the usual type of gun such action would occasionally be hazardous, for the reason mentioned in the preceding paragraph. It is therefore considered the safest practice not to turn the blast on full until the hole has ceased to take clay freely. However, it is desirable to have some pressure inside the furnace in order to flatten the clay on the inside of the walls within the hearth.

A typical practice, which has given minimum trouble with cinder or flame coming back and results in satisfactory keying of the stopping clay, is to drive in the first two barrels of clay with the blast off. The snort valve is then closed and the whistle signal for half pressure is blown. The pressure builds up slowly to 9 or 10 pounds, while the greater part of the second barrow of clay is forced in against this pressure, and the last two or three barrel loads of clay are pushed in with nearly full pressure on the furnace, the signal for full blast being given as the hole is almost stopped.

LEAVING THE GUN IN THE HOLE AFTER CASTING.

The gun should be left in the hole with the steam on for several minutes after the blast is fully on and the hole stopped, in order that the plunger shall hold the clay in the barrel firmly against the plug of clay in the hole and prevent it from blowing out. The gun should not be removed from the hole until the clay has set solid on the inside, which may require 10 or more minutes; 20 minutes allows a minimum factor of safety, and many plants require 30 to 40 minutes.

USE OF SPLASHER PLATE OR SHIELD.

A high, broad plate shield is sometimes provided to protect the men in case the stopping in the tapping hole breaks out violently. This is either placed over the skimmer, where it may be from 3 to 10 feet wide by 6 to 12 feet high, or is placed 10 to 15 feet farther down on the iron runners, on the skimmer side of the first junction. Many prefer the latter position, because the shield when placed over the skimmer makes difficult the use of pricking rods on the tapping hole. The skull was, of course, a necessity with the old sand skimmer, but is retained by several plants for its usefulness in protecting men from breakouts and also from coke blown down the cast house when the furnace is casting on a short hole.

MANIPULATION OF GUN.

The correct way of handling the gun, or, more specifically, the throttle lever, to meet any conditions at the tapping hole can not be given in detail. The experienced keeper or blower is guided by appearances about the nose of the gun, such as escape of gas or cinder, the "give" of the clay in the hole, the velocity or response of the plunger when the steam or air is thrown on, the sound of the steam exhaust, the way the iron has run, or the amount of blowing from the hole. By his knowledge of these and other obscure factors he is guided in the treatment of the hole at each cast, determining how much clay is required, and whether additions of water are necessary. An experienced keeper or an alert observant helper can and does handle the tapping hole so that accidents from any type of breakout are rare, whereas new crews or careless, unobservant, or unskilled keepers are in continual danger of poor holes.

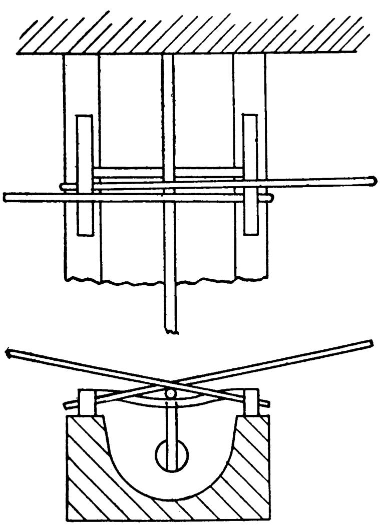
FIGURE 33.—Cross bars for holding the tapping bar.

PRECAUTIONS WITH SHORT HOLES.

A hole taking clay poorly, working short, or working high up indicates the necessity of a very deep stopping, extreme caution in drilling, and, if the trouble persists, inserting over the tapping hole a longer tuyère or one with a smaller nose. At times building up about the inside face is aided by temporarily plugging the tuyère for 24 hours. The opening of the tuyère will be easier if a bar hole is pierced through the clay to prevent it from ironing over. If the hole is very short or the wall over the hole is thin, a cold blast on the face of the clay helps to hold it between casts.

PRECAUTIONS IN OPENING THE HOLE.

In drilling up into the hole or driving the tapping bar through the skull, the splasher plate should always be placed to hold back any outburst of iron, slag, or flame and prevent it from flying over the men. On no account should any of the crew stand with their feet in the skimmer trough when holding the tapping bar. It can be held in line just as well by two pairs of tongs, one pair held by a man on each side, or more rigidly by a pair of cross bars. (See fig. 33.) There is no need or excuse for anyone getting into the trough near the hole in order to place the point of the tapping bar exactly in some particular spot unless the hole is hard, and there is no need of being there after the bar is placed. The blower should not permit such practices. The progress of the bar can be gaged by its drive when the crew are sledging it or by a chalk mark. Many plants have forbidden the practice of holding the bar by hand on account of the need of the men being near the tapping hole, where they may be caught if the iron breaks out.

Stopping is made much safer by dropping a shield in front of the splasher plate, as shown in figure 34. The use of this device is feasible at all plants. At a few of the plants where compressed air is used to blow the clay cuttings out of the hole, a plate is put over the skimmer trough and in front of the splasher, an angle iron being riveted on the front edge. This angle iron may be removable for convenience in using, if desired, a small stopping hook to clean the hole, or to observe its condition. (See fig. 35.)

This type of shield, though in use at comparatively few furnaces, has proved entirely satisfactory, whereas the solid plate has met with strenuous objection from many furnace crews who feel that they

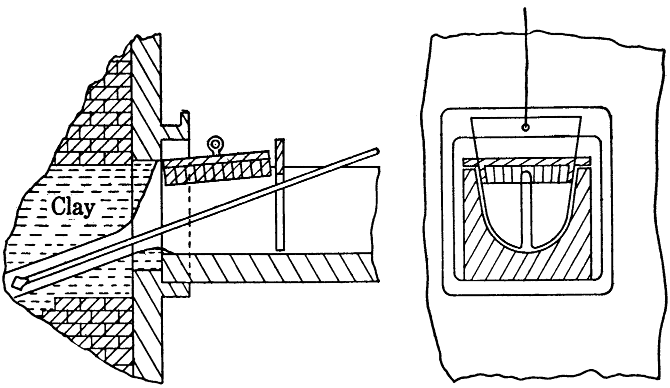

FIGURE 34.—Sections showing method of using shield.

must be able to see the progress of the hole. At many plants one or two sheets of corrugated iron are laid over the trough with their front ends resting on the splasher, a hole being punched through them for the drill and tapping bar. This arrangement is satisfactory, although the sheets wear out so rapidly that the crews at times are inclined to neglect prompt replacing of a worn-out sheet and to open the hole without using any shield. Hence a shield of $\frac{3}{16}$-inch or $\frac{1}{4}$-inch steel plate is preferable.

Shields should always be used with air and electric drills. When a drill or bit strikes the iron skull at the bottom of the hole the motor usually plugs itself or works so jerkily that an experienced crew knows the skull is reached, stops drilling immediately, and uses a tapping bar to drive through the skull. Nevertheless, occasionally the drill may bite through the skull, bringing the iron out with a rush. The latest method of safely opening the tapping hole is with a steam or air percussion drill, and was developed by the Republic Iron &

Steel Co. in the spring of 1915. Mechanical drilling is preferable to hand drilling because a smaller hole may be drilled in the clay. This limits cutting of the hole by slag considerably. A 2½-inch hole is large enough for a mechanical drill.

DEPTH AND ANGLE OF TAPPING HOLE.

A final factor in the care of the tapping hole having a bearing upon hearth breakouts is the depth or angle of the hole. Infrequently the tapping hole has an angle of 45° after the rate of driving and capacity of the furnace have become normal. As has been mentioned, the depth of the hearth is variable, depending on the height of the

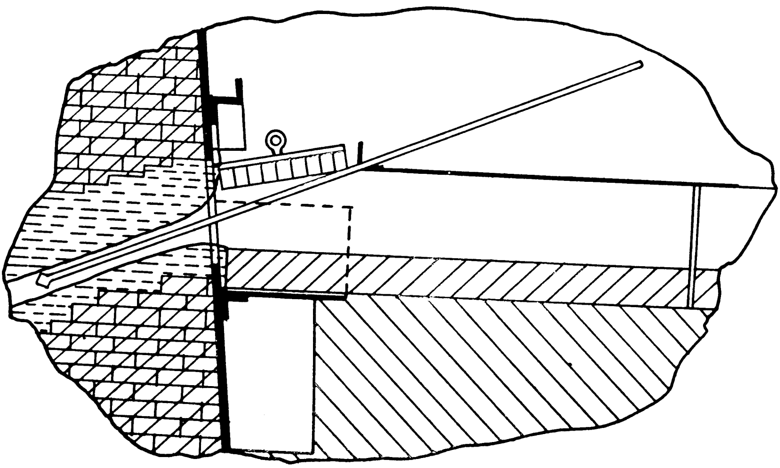

FIGURE 35.—Section of tapping hole, showing plate over skimmer trough.

bottom of the tapping hole, and it may be assumed that with the best constructed hearth brickwork the bottom of the hearth will be 3 to 6 feet below the bottom of the hole, the exact position of the hearth bottom being uncertain. On a 16-foot hearth, therefore, the tapping hole may with safety have a depth of, say, 2 feet 3 inches on a hearth jacket 4 feet 6 inches deep, but the same angle of tapping hole with a hearth jacket 3 feet deep, both jackets being water cooled to the bottom, would be hazardous. (See fig. 36.) The liability of a hearth breakout would certainly be greater in A than in B. Therefore the apparent advantages of a deep tapping hole in keeping the level of the iron in the hearth farther from the water-cooled cinder notch and hearth plates, giving cleaner casts and greater capacity, may conceivably give rise to an unperceived danger of breakouts. This danger should be kept in mind in endeavoring to get a production extremely large in proportion to the hearth area and depth and be given the same regard as the maintenance of the tapping hole at the proper angle with reference to the depth of the hearth jacket.

CINDER-NOTCH BREAKOUTS.

The cinder notch, as it is used to "flush" or drain the slag from the hearth previous to casting, being subject to erosion and attack of slag during 12 to 18 "flushes" a day, would last but a short time if it were simply built up and stopped with clay without the blast being taken off. In fact, a clay notch could not be used unless stopped in exactly the same way as the iron notch, and this would mean turning off the blast a prohibitive number of times. Consequently, in the cinder-notch arch or opening is placed a bronze cooler, similar to a tuyère cooler; within this bronze cooler and extending inside 6 to 12 inches is an intermediate cooler, and inside the intermediate cooler is the "monkey," also water-cooled, which projects in about 3 inches. The monkey has an opening 2 to 2½ inches in diameter, and is stopped by an iron "bot" or plug which chills the cinder inside the face of the monkey. The only danger of breakouts about the cinder cooler is escape of cinder between the large cooler and the brick walls, a rush of cinder when the intermediate cooler is changed, outbursts of slag and flame when the monkey is changed, or an explosion of the intermediate and the large cooler. If iron comes over the monkey by accident, it may cut the bronze and come in contact with the water inside, when all three coolers may be blown out of the furnace, and an outrush of furnace contents follow.

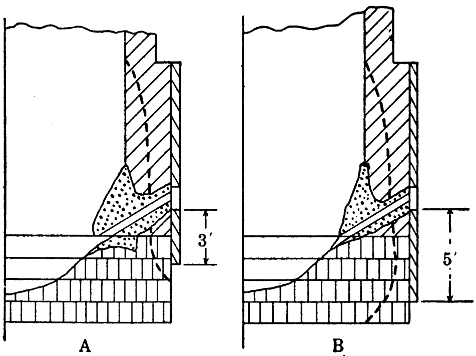

FIGURE 36.—Diagrams showing relation between depth of hearth jacket and slope of tapping hole as regards safety.

PACKING FOR CINDER-NOTCH COOLERS.

Breakouts about the cinder-notch cooler are minimized by painstaking care in setting and packing the cooler, which usually should be done after the kindling and scaffold have been placed in the hearth and bosh, and before the furnace is filled preparatory to blowing in.

The packing most generally used, and the firmest, is rope asbestos saturated with water, rammed in tightly all around from front and back with light blows of a sledge. Clay is usually plastered on the face of the brick before the cooler is inserted, and the asbestos rope is used to make a tight fit.

BREAKOUT FROM DEFECTIVE PACKING.

A serious breakout of this type happened at a furnace where the foreman packed the cooler in the brick arch with loam only. The cinder broke out beneath the cooler, cut a large hole in the hearth brickword, and ran over the cast-house floor and yard. No one was injured. The hole was filled with stiff clay and brickbats and the new cooler was packed with clay, tightly rammed in. No further trouble was encountered.

BREAKOUTS FROM CUTTING OF THE INTERMEDIATE COOLER.

Breakouts from cutting of the intermediate cooler are rare. The few known accidents of this type were caused by iron coming over on a flush or cutting the intermediate cooler from inside, which allowed the entire cooler to melt out and permitted the escape of cinder in uncontrollable quantity.

An instance of the intermediate cooler burning on the second flush through the monkey being cut illustrates a danger. Instead of waiting until casting time, 45 minutes later, or casting early, as could have been done if cinder showed at the tuyères, an attempt was made to change the intermediate bronze at once, the water being turned off and the cinder allowed to drain out. Owing to the small opening in the nose of the intermediate cooler the clay could not be placed effectively, and when a "puller" was set and the intermediate cooler jarred loose, slag burst out and severely burned the legs of a "cinder snapper." This happened in spite of the fact that the furnace had evidently been flushed dry, and shows how a furnace may hold its cinder.

Intermediate coolers should not be changed until after the furnace has been cast, unless they are cut on the first flush, and even then, depending on the hearth capacity, tonnage, slag volume, and working conditions, changing can be safely and profitably postponed to casting time.

BREAKOUTS FROM CHANGING THE MONKEY WITH THE BLAST ON.

Breakouts at the monkey are caused by trying to change a leaking monkey with the blast on. The change can frequently be made with impunity, but will almost inevitably lead to a serious accident sooner or later. Sometimes the skull of cinder which freezes on the face and sides of the monkey is stiff and thick enough to withstand the interior pressure, but it can not be relied on, however. In numerous instances where the monkey has been withdrawn with the blast on, the skull of cinder held for an instant, then bulged out, burst, and a stream of gas, slag, and coke spurted from the nose of the intermediate cooler over the men working in front. The monkey should not be changed unless the blast is completely off.

PACKING THE INTERMEDIATE AND LARGE COOLERS TO PREVENT CUTTING.

To prevent the intermediate and large coolers from being cut, clay is packed within the space inside them up to the monkey. The bot is withdrawn and the clay packed about a wooden form. This work may be performed without danger of a breakout, as the area of the skull face in front of the bot is only 3½ to 5 square inches, whereas when the monkey is withdrawn the unsupported area may be 40 or more square inches.

ARRANGEMENT OF COOLING SYSTEM.

The cooler system is held in the furnace by clamps, of which three types are shown in figure 37. Of these three, type C is least desirable. The feed and discharge pipes, in addition to having cocks near the cooler arch, should, rather than rising directly up to the supply pipe and trough, lead around the furnace at least one-third, or, better, one-half, of the circumference before being taken up, so that in event of cutting, burning, or a breakout at the cinder notch, the monkey boss can turn the water off, to avoid an explosion, without exposing himself to danger from escaping cinder, flame, or flying iron.

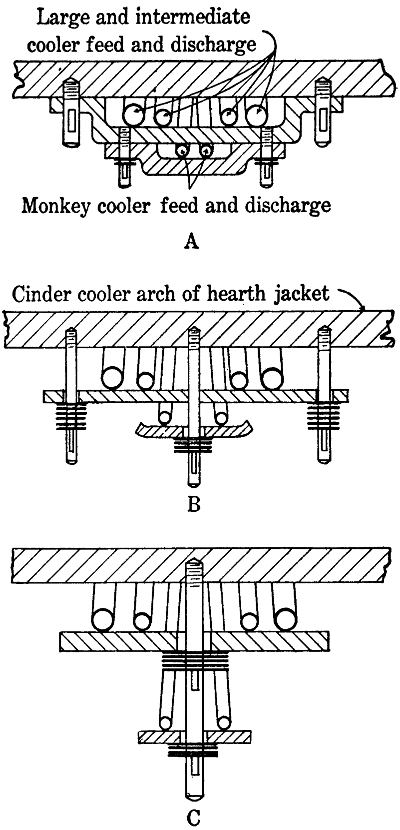

FIGURE 37.—Clamps for cinder cooler, intermediate, and monkey discharge pipes.

PART II.—GAS EXPLOSIONS AT BLAST FURNACES.

PURPOSE OF INVESTIGATION.

Explosions of gas at blast-furnace plants were in former years rather common and often disastrous to employees and to the equipment. Studies by the Bureau of Mines of the hazards in the metallurgical industries indicate that such explosions in themselves now constitute only an infrequent and inconsiderable hazard to employees. If explosions be considered with regard to damage to plant equipment, however, they assume decided significance. Gas explosions resulting disastrously are few, considering the number of furnaces in blast, but they do occur persistently.

A review of blast-furnace accidents during the past few years shows that the number of explosions is considerable. Few furnace men like to talk about them and there is virtually no mention or discussion of them in trade journals, possibly because there seems to be a feeling that such an accident reflects on the care and judgment of the men in charge. This view is warranted in some instances, but is wide of the mark in others. Attempts to contrast the proportion of explosions due to defective methods of handling gas with the proportion that is largely fortuitous are useless. It can be said that the number due to carelessness of the men in charge is extremely small, for probably nothing in the routine of furnace operation puts a man under a greater strain than his dread of a gas explosion when confronted with an unforeseen stop or the necessity of blowing in or blowing out. No matter how reliable the foreman or assistant may be, the superintendent is always present, if possible, when such jobs must be done, and the responsibility he must bear is always sufficient to insure his taking the greatest care. The uncertainty and unsatisfactoriness of attempts to state that a certain number of gas explosions are caused by unskillful handling of the gas lies in the fact that practically every furnace man has a particular way of handling the gas, each method differing radically or in some small detail from the others. These methods rest on personal experience and training and the exigencies of plant layout, or have been handed down from man to man; some of these methods provide sufficient safety in most cases, but have failed to provide for it when some abnormal factor was introduced. To illustrate:

Few furnace men will state that they can not handle furnace gas with practical immunity from explosions, yet few furnace men with an experience of 10 or more years have not had experience with a more or less serious explosion.

In undertaking to summarize and furnish useful information on the subject of explosions to those working about blast furnaces, it is believed that an investigation into the properties of blast-furnace gas, its ignition temperatures, the explosion limits of mixtures of gas and air, and the agencies accelerating and retarding explosions would be of less practical value than pointing out where the explosions occur, how they are caused and may be prevented, and giving a review of those methods of handling gas that promise greatest security. Although much work may be done on the explosive characteristics of blast-furnace gas, yet, even with the resulting information in hand, furnace men will be confronted from time to time with conditions necessitating possibly dangerous operations. At such emergencies a knowledge of the limits of explosibility would only serve to emphasize the danger, which is sufficiently well known, and would be of little practical use. On the other hand, the recognition and discussion of certain practices as being inherently hazardous not only separates them from careless or reckless methods or practices but places them definitely in the category of operations occasionally necessary but essentially dangerous. By recognizing them as such the incident difficulties can be met much more satisfactorily than by discussing certain conditions and dismissing them with the statement that under such circumstances gas may explode, and that therefore these circumstances are to be avoided. At times some circumstances can not be avoided, so the problem becomes one of so handling the gas that the least hazard is introduced.

For the above reasons it has seemed best to place emphasis on methods of practice, and that plan is followed in this report, with the exception of the following discussion of the theory of explosions.

THEORY OF GAS EXPLOSIONS.

Blast-furnace gas, which rarely contains more than 30 per cent of combustible gases, can not be classed as a dangerously explosive gas; and when the furnace is in normal operation the gas is easy to handle and the hazard from an explosion remote. In case the furnace has to be stopped for any reason, an explosion at some part of the equipment, either in taking the furnace off while the blast is off or in starting up again, is always possible if air gets into the furnace top or the gas mains. As a rule, such explosions, if they occur, are confined largely to small "top shots," "gas kicks," "puffs," or "cracks," and are usually harmless, although some are violent enough to lift gas-main explosion doors, knock burners off their stands, split dust catchers, and blow off the downcomers.

Blast-furnace gas varies in composition, but for the purpose in hand, may be assumed to contain 13 per cent carbon dioxide, 24 per cent carbon monoxide, 3.5 per cent hydrogen, and 59.5 per cent nitrogen. The reactions of the hydrogen and the carbon monoxide in an explosion are as follows:

$$2\,CO + O_2 = 2\,CO_2.$$
$$2\,H_2 + O_2 = 2\,H_2O.$$

Dixon, an English chemist, stated in 1880 that a mixture of carbon monoxide and oxygen will not explode or even burn unless a trace of moisture or of some gas containing hydrogen is present, the accelerating effect from moisture being at a maximum when the gas has a temperature of 45° C. and is saturated with moisture. Materials such as heated fire-clay surfaces, nickel, copper, and oxides of these and other metals also accelerate combustion or explosion. Carbon monoxide in air ignites at 644° to 658° C., but in contact with a hot fire-clay surface it will ignite at 500° C., or with copper oxide, at 300° C. This lowering of the ignition temperature is caused by "catalysis" or contact action, which is the increased activity of the gases from being absorbed and concentrated on the clay or metal surface. The catalytic power of all these materials is highly stimulated by long previous exposure to the combustible gas, and this increase of power is usually very lasting. It is probable that in the handling of furnace gas the heated walls, partly reduced oxides, deposited carbon, and other materials possessing catalytic properties, are important factors in causing combustion at low temperatures and thus starting explosions.

The ignition of a mixture of furnace gas and air does not necessarily result in an explosion. The velocity of propagation of a carbon monoxide flame is relatively slow compared to that of hydrocarbon gases, and, as in gas mains or furnace tops, there is rarely a perfect mixture, such as is found in gas-engine cylinders, the maximum theoretical generation of explosive power is probably seldom reached.

The mechanism of an explosion must be followed to understand the results observed when a mixture of gas and air is ignited. An explosion of gas and air consists of an "initial combustion," a "detonation," and a "retonation." To have these take place the explosion must occur within a closed vessel or cylinder such as a gas main. When an explosive mixture of air and a combustible gas is ignited it burns outward from the point of ignition and a compression wave starts, which travels ahead of the flame and more rapidly, with the velocity of sound, through the unburned gas. This compression wave upon reaching a barrier is reflected back in the direction from which it came, and on meeting the advancing flame, retards the latter. The reflected compression wave, however, continues to pass through the hot and probably still burning gases and an instant later reaches the flame traveling in a direction opposite to that of the other flame, accelerates it, and quickens the combustion. This flame continues to move forward with rapidly accelerating velocity until detonation is set up. Detonation is abrupt, and the union of the oxygen of the air with the combustible gas proceeds in the form of an explosion wave that generates an enormous force as it advances with great rapidity through the gaseous mixture. When detonation is taking place, the explosion wave is transmitted through the explosive mixture by each successive layer of the mixture, being instantaneously heated to the ignition point by the compression resulting from the accelerated velocity and the augmented temperature of the burning gas, both being induced by the compression wave.

At the point where detonation begins a "retonation wave" starts back through the still burning gas. Combustion is much slower than detonation, so that at the moment detonation starts combustion is still taking place in layers of gas some distance behind the flame front. The "retonation wave," in passing back through these burning gases, quickens their combustion, and when it arrives at the other flame front causes detonation there, provided that ignition has taken place at such a distance from the barrier that the flame front reaches it just as the "retonation" wave arrives. This setting up of reflected waves through "retonation" explains much of the shattering effect sometimes observed after a severe explosion of blast-furnace gas.

This process of initial combustion, detonation, and retonation takes place in an increditably short space of time. As compared with ordinary combustion, its characteristics are extreme rapidity of chemical action, abrupt attainment of maximum temperature and pressure, and subsequent rapid, almost instantaneous, cooling of the gaseous products of explosion. The velocity of an explosion wave, hence the violènce of a detonation, is independent of the shape of the inclosing walls, whether straight, circular, or zigzag, but is retarded by an inert gas. If hydrogen is added to an explosive mixture of carbon monoxide, its effect will be to increase the velocity of the explosion wave, as is illustrated by the propensity of furnace gas, rich in hydrogen, to "kick." Nitrogen, carbon dioxide, and oxygen retard the velocity. The velocity and violence of the explosion are greatest when the combustible gases, such as the carbon monoxide and hydrogen of blast-furnace gas, are present in slight excess of the amount theoretically required for complete combustion.

PRESSURE PRODUCED BY EXPLOSION.

The pressure produced by a gaseous explosion can be calculated. For instance, the calculated pressure of a blast-furnace gas analyzing 12 per cent CO_2, 26 per cent CO, 3 per cent H_2, and 59 per cent N_2, exploded in a closed vessel with the amount of air theoretically required for complete combustion, is 76 pounds gage. The pressure is generated entirely by the volume increase due to the high temperature of combustion, not by any increase in volume as the result of the reaction. Two volumes of carbon monoxide or hydrogen combined with one volume of oxygen give two volumes, not three or more. One cubic foot of the gas mentioned above burned with 0.7 cubic foot of air forms only 1.55 cubic feet of gaseous products, the explosion or combustion starting and ending at 60° F. and at atmospheric pressure. However, if the thermal capacity of the gas is divided by the specific heat of the gas the apparent theoretical temperature is 2972° F. At this temperature 1.55 cubic feet of products at constant volume would give a theoretical pressure of 76 pounds gage. Experimental explosions of a gas similar to the above have given gage pressures of 18 to 48 pounds; the larger the inclosing vessel the higher the observed pressure mounted. In a general way the maximum pressures observed in closed vessels are always less than the theoretical calculated values. This is because of the variation in specific heat with the temperature, not allowed for in the calculation, and because the calculation assumes that the whole heat of combustion is communicated without loss to the products, which is not true. It is safe to say that the maximum calculated pressures are rarely or never attained in explosions of blast-furnace gas in mains, just as in experimental observations, and chiefly for the same reasons:

EXPLOSIVE LIMITS OF BLAST-FURNACE GAS.

The results of an examination of the explosive limits of two samples of blast-furnace gas taken from the furnaces of the American Steel & Wire Co., at Pittsburgh, Pa., made by G. A. Burrell and A. W. Gauger, of the Bureau of Mines, are given below. These results do not cover a wide enough range of composition to be inclusive of all gases encountered with various practice, but are of interest in connection with the subject under discussion.

Composition of gas used in tests.

Constituent.	Sample 1.	Sample 2.	Average.
CO_2 ______ per cent__	9.97	10.01	9.99
O_2 ______ do____	.49	.49	.49
H_2 ______ do____	2.67	2.66	2.67
CO ______ do____	27.57	27.42	27.50
CH_4 ______ do____	.39	.29	.34
N_2 ______ do____	_____	_____	59.01

The explosion apparatus consisted of glass vessels, approximately 8½ inches long and of 900 c. c. capacity. Ignition was made at the center with an arc formed by breaking the contact of the electrodes while current was passing through them. The results of explosion tests with various percentages of gas in the mixture were as follows:

Results of explosion tests.

Gas in mixture. per cent.	Notes by observer.
20. 0	No ignition.
30. 0	No ignition. Small yellow flame played iintermittently about arc.
39.2	No ignition. Large flame about arc, about ¾ inch high at first.
44. 8	Slight puff heard when arc was first drawn. A ½-inch flame played about arc. No self-propagation through mixture.
44. 9	A small tongue of flame started at the arc (which broke immediately) and rose upward through the mixture. Flame did not fill bottle and combustion was incomplete.
45. 7	Ignited immediately; flame shot downward about 1 inch and then rolled upward in a ring. No other downward propagation noted.
46. 5	Ignited immediately and blew waxed paper off top of vessel.
50. 0	Immediate ignition. Flame traveled upwards, and more slowly downwards in rings.
56.2	Ignited immediately and blew paper off top of vessel.
57. 0	Do.
61. 0	Do.
62. 0	Ignited immediately; flame filled bottle.
64. 5	Did not ignite at first, but on drawing a wider arc the mixture ignited and blew off paper cover. Ignition was probably due to the mixture becoming diluted with air.
65. 0	Slight inflammation about arc; snapping sound. No self-propagation.
66. 0	No ignition.
67. 9	Do.
72. 0	Do.

The amount of air theoretically required for combustion in the first sample was 0.723 cubic foot per cubic foot of gas, and in the second sample it was 0.711 cubic foot per cubic foot of gas. These results being in close agreement, the average, 0.72 cubic foot of air per cubic foot of gas, may be taken as the theoretical amount of air required for complete combustion. This corresponds to a mixture of gas and air containing 58.1 per cent gas and 41.9 per cent air as being an ideal mixture for complete combustion.

These results show that the limits for complete inflammation of this gas lie between 46 and 62 per cent of gas or between 54 and 38 per cent of air in a gas-air mixture. The lower limit of explosibility is farther from the proportion theoretically required for complete combustion than is the high explosive limit, as shown below:

High limit (excess gas), 62 per cent gas, 38 per cent air.

Theoretical proportions for complete combustion, 58 per cent gas, 42 per cent air.

Low limit (excess air), 46 per cent gas, 54 per cent air.

This difference is of little significance as regards the possibilities of gas explosions about furnace plants, except that in the event of air entering a main and mixing with gas until the lower explosive limit, 38 per cent air, is reached, the possibility of explosion is not passed until a large excess of air has entered, the explosive range being 4 per cent less and 12 per cent more than the theoretical amount required for conditions most favorable for an explosion.

EXPLOSIONS AT HOT-BLAST STOVES.

That it is not always easy to burn blast-furnace gas instantly—that is, explosively—is demonstrated daily at blast-furnace stoves. The gas does not burn instantly but rather intermittently. As the air and gas mingle at the nose of the gas burner complete combustion does not take place immediately, even with approximately thorough mixing, as is shown by the length of the flame, the constant effort being to get a short flame. That it is possible to approach explosive conditions and set up "retonation waves" was demonstrated in 1913 at a plant in the Pittsburgh district, where a set of patented mixing burners were installed at a set of stoves using cleaned gas. From the minute the furnace was blown in and the gas turned into the stoves a deafening vibrating roar set up, and the burners had to be removed within 24 hours. A similar noise has been noted in carrying out explosion tests of blast-furnace gas in a 6-inch tube 21 feet long. When the gas inside the pipe was ignited the pipe vibrated and gave out a sound similar to that noted at the burners mentioned, though not as loud.

But as a rule, if the gas ignites promptly at the burner, there is no explosive tendency. The nearest approach to explosive combustion after the gas is lighted is seen when an excess of gas is turned in the stove, and for some reason—for instance, to see how the gas is burning—the stove tender opens an air or cleaning door. Under these circumstances the burning gas sometimes puffs from the door of the well, a hazard of stove tending that at times results in painful if not serious burns..

A similar condition is encountered when the stove checkers are more or less plugged up, or the stack draft is insufficient, and at times when cold washed gas is burning in a cold well. In the latter case, the presence of excess air causes the flame to be extinguished at the base of the stove well, a mixture of air and gas fills the well, ignites at the checkers, and travels down in the well with almost explosive violence, and bursts out of the air-inlet doors. At such times it is not safe to go within 8 or 10 feet of the doors. The only practical precaution against these conditions is to so adjust the gas and air on turning the gas on that as long a flame as possible is produced, and then slightly to reduce the length of the flame by admitting a slight excess of air. This is, of course, the method of experienced stove tenders, and the close regulation of the air is often a source of surprise to those undertaking to increase the efficiency of stoves by analyses of the stack gases. Shortening the flame may also be produced by a deficiency of air, but this error will, of course, result in the liability of an outrush of flame from the well.

More nearly allied to true explosions is the hazard of permitting gas and air to pass into a stove, when it is put on gas, without its lighting immediately. When a stove well is hot, the gas should ignite almost instantly, and it usually does, with perhaps a slight puff. However, gas turned in a cold stove, or into a run-down stove, in which the well is cold and the checkers hot, does not ignite quickly. In the latter case the gas and air may fill the combustion chamber, ignite at the top, and then flash down into the well and "kick" out about the burner with explosive violence, throwing hot dust and flame in the face of the stove tender should he be standing about the burner watching for the gas to ignite or about to pull the gas burner back. In the case of a cold stove, the danger lies in a stove tender allowing the stove to fill with gas and air before lighting the gas at the burner. In such event the same "kick" of burning gas is to be expected. Such practice is especially dangerous when gas from a furnace that has been shut down from a leaking tuyère or other leaky bronze is turned into a stove, or when gas from a newly blown-in furnace is being turned into the stoves. Several years ago a stove was entirely destroyed by an explosion caused by lighting the gas after the stove was full, and the stove tender was killed. There have been several injuries from this cause, and the precaution of having a good fire in the well or at the burner door is especially called for in turning "wild" gas into stoves. In fact, the elementary and only practical precaution to obviate all such explosions lies in providing a fire of burning waste, wood, coke, or coal at the gas-door inlet of cold stoves before the gas is turned on.

In the event of gas being turned into a run-down stove and failing to ignite immediately the gas should be turned off instantly and a pilot fire provided, as noted above. In turning the gas on, the stove tender should step away quickly from the burner after racking it into the burner door frame. Many burners are so badly designed that the stove tender in racking the burner into the door is compelled to stand within 2 to 4 feet of the opening, and must spring away as he racks the burner in; also if the gas does not ignite promptly, he is in some danger should it ignite while he is racking the burner back. Burners should be so designed—as several types are—that the stove tender can stand 6 to 10 feet from the burner door when turning the gas on. Stove cleaners should be warned of the danger of flame flaring out and burning them if the stove door of a well is opened with the gas turned on full. The gas should be turned off in part before a well-cleaning door is opened.

EXPLOSIONS OF GAS AT BLAST-FURNACE BOILERS.

The causes of explosions at the boiler house are in general the same as at stoves. An explosion in the combustion chamber takes place, as a rule, when the flow of gas is interrupted and air works back in the gas main through the boiler burners; or when the gas is shut off, on account of the furnace being stopped, and, on starting up, the gas, mixed with air, completely fills the boiler setting before it ignites or is lighted; or when gas is turned into the boiler on blowing in or after cleaning the tubes and setting. Aside from explosions due to air in the mains, which should probably be discussed under "Explosions in gas mains," explosions at the boiler setting can be avoided only by never allowing gas to enter the boiler setting, beyond the combustion chamber, unburned.

Except when the furnace is shut down for changing tuyères, or some similar cause, in which case the gas is drafted back through a stove, checking the flow of gas at the boiler (or stoves) is not a matter of much hazard even at an isolated furnace, as there is always an appreciable amount of gas coming over from the furnace at a casting stop. Even if this amount of gas is not sufficient to keep up combustion in all boilers, combustion chambers, variously called "dog houses," "Dutch ovens," or "fore chambers," are usually provided which present a large surface of incandescent brickwork, which ignites the gas the instant it is reintroduced into the boiler upon the furnace being put on blast again.

In addition to this automatic safety provision, it is almost the universal custom to keep a small coal or coke-dust fire going on the grates of gas-fired boilers, and especially when the flow of gas has been reduced for any reason. Also where more than one furnace is connected to the boiler-house gas main there is always enough gas from the other furnace or furnaces in operation to keep up a steady flow to the boilers, whereas at an isolated furnace, and usually at a group of furnaces, it is usually necessary to fire coal during even a short furnace shutdown in order to generate steam for the pumps, compressors, and electrical equipment. For these reasons interruption of gas current at the boilers and loss of gas are only exceedingly remote sources of explosions.

In lighting cold boilers the gas occasionally explodes or "kicks," especially when the gas is "wild" after a shutdown or on blowing in. Although it is the rule to provide a good coal fire, there have been instances where the gas did not light until it had filled the boiler setting, and upon ignition puffed out and burned men standing near the boiler burners and doors. Sometimes the gas is cold, wet, or difficult to burn, and in these cases may fail to ignite promptly. When gas is turned into a cold boiler, burning oily waste should always be placed at the nose of the burner, in addition to a blazing coal fire on the grates. If the gas does not light promptly the gas burner should be shut off and time allowed for the setting to clear before another attempt is made to light the gas. Serious injuries have been caused by the nonobservance of these elementary precautions. The fact that these accidents can and do occur should lead to the use of every precaution which will either minimize their possibility or surely prevent them.

The handling of gas at stoves and boilers at shutdowns, blowing in, or blowing out is discussed under these respective headings.

EXPLOSIONS AT GAS MAINS AND IN FURNACE TOPS.

GAS-SEAL EXPLOSIONS.

Explosions of gas at the furnace top, known as "top shots," and in the dust catcher, downcomer, and gas mains for the most part take place on stopping the furnace, practically the only exception being at skip-filled furnaces, where the doors on the gas seals are sometimes opened while the furnace is in operation, in order to inspect the bells or to dislodge material from the little bell, lumps or scrap sometimes lodging between the bell and the extension or lips of the receiving hopper. Occasionally when the gas-seal door is opened to inspect the bell the gas which fills the space above the large bell, under the gas seal or hood, ignites spontaneously and flashes out of the door onto the men who have just opened it. At some plants it is the practice, in cleaning the top, to open the gas-seal doors and shovel into the opening over the large bell the débris of coke and ore spilled from the skip. Men have been injured in doing this, the gas puffing out of the door in a sheet of flame while they were standing near. The explosions are slight, as regards violence, and have not been known to result in damage to the furnace itself. They are noteworthy only because of the occasional serious burns inflicted; three such accidents resulting in disability for periods ranging up to 10 weeks are known.

In opening gas-seal doors for any purpose, the little bell should be kept closed until the door is opened to prevent any air drafting in at the instant the door is opened. As soon as the door is opened the little bell may be lowered, thus drafting the gas out. As a rule, it is necessary to open more than one door, either for illumination or for access to the bells, but before the second door is opened some burning waste should be thrown in on the large bell to light the gas. This gas will usually puff when ignited, so it is essential to keep away from the door until the gas has lighted. In carrying on the work the gas should be kept lighted by throwing in burning waste from time to time, and the little bell should be kept open. At one plant where injuries from this cause have received especial attention, the possibility of explosion has been effectually removed by leading a $\frac{1}{2}$-inch steam line into the base of the gas seal, through which steam is blown, with the little bell open, for 10 minutes before the doors are opened. This displaces the gas entirely, and the only precaution necessary is to keep the gas lighted while the bell is being cleaned or other work is being done.

If the gas-seal doors are opened merely to examine the bell to see whether it is cleaning properly, or to inspect the distribution on the bell or the cleaning of the furnace top, the blast is not usually taken off the furnace, although sometimes it is checked. At a few plants, however, if it is necessary to open the gas seal, the water-seal valves at the dust catcher are closed in case the furnace is connected to another operating furnace through a common gas main, and steam is turned into the dust catcher, the bleeder is opened, the furnace shut down, and the gas drafted back through a stove. The doors on the gas seal are not opened until steam has appeared at the top of the bleeder pipe. When this is done there is little danger of a gas explosion in the gas seal on top while work is being carried on, provided care is taken to light the residual gas in the seal at the time the doors are first opened. These precautions are occasionally observed for work in which it is not even necessary to enter the gas seal. When it becomes necessary to enter the gas seal or receiving hopper, it is the almost universal practice to take the furnace off, and also to observe the precautions mentioned above. This rule is deviated from in some instances, as is known from accidents resulting thereby, but only infrequently with the open or tacit consent of the superintendent; more often a foreman or helper takes a chance of a slight " puff " or of being " gassed " in order to get the work done quickly. All work about gas seals should be done under the supervision and subject to the orders of the general foreman or boss blower, in order that the necessary precautions, the need of which may not be apparent to foremen and repair or labor gangs, may be taken.

TOP AND DOWNCOMER EXPLOSIONS.

EXPLOSIONS DURING EMERGENCY STOPS.

Probably the most dreaded emergency job about a blast furnace is that of repairing a broken water or steam main or encountering a similar misfortune that necessitates taking the furnace off instantly without any preparation or opportunity for consultation. At least one destructive explosion has occurred in such a stop, and there have been many explosions under similar circumstances which fortunately did not cause much or any damage. The trouble at such times is that the water is lost, the steam is lost, and the blast is either lost or has to be taken off as soon as it can be. In such event the assistance of water-seal valves in isolating an intricate gas-main system from the furnace and in isolating units of the gas main from each other is lacking, the use of steam in the gas mains is not possible, and the fact that the blast is off may make imperative such haste that the superintendent or foreman must delegate some detail of the work to some one else; confusion results, a blunder is made, or some hazardous expedient is resorted to, and the gas ignites and explodes. The usual result is only an extremely violent "crack" at the top of the furnace, but downcomers may be blown off and dust catchers wrecked, or the bell and hopper may be blown out of the furnace.

One practice in such emergencies is to shut all the gas burners at the stoves and boilers, shut down the fans or washers at the gas-cleaning plant, open the top bleeder, and let the furnace stand with two to four tuyères open. Every opening on the gas-main system, including burners, dust bells, explosion doors, and bleeders, is kept shut, and no attempt whatever is made to draft the gas out of the mains. The draft up through the furnace from the open tuyères generates sufficient gas to keep an appreciable stream passing out of the bleeder, and by partly closing the bleeder sufficient pressure can be maintained in the top of the furnace to prevent gas drafting up the downcomers and drawing air into the mains through leaky doors and burners. This method of meeting the emergency is costly because of the damage to uncooled plates, tuyères and tuyère coolers, the loss sometimes amounting to thousands of dollars, but it is sometimes preferred to the possibility of an even more expensive explosion.

Some plants prefer to draft back the gas through a stove. This procedure quickly stops any emission of gas on top, draws air in at the bleeder where it mixes with gas drifting from the gas mains up the downcomer, and may result in repeated sharp explosions in the top of the furnace. These "top shots" do little or no damage on top, and cease in the course of a half hour as the top of the furnace cools down, but are a source of alarm to the crew.

Another variation is to close all the burners along the gas main and to open a door at the end of the main. The top bleeder is then opened and the gas drafted out of the mains through the furnace top, the tuyères being plugged with clay. This procedure should displace all gas in the mains with air, the air as it is drafted in pushing the gas ahead of it. There is more or less mixing of air and gas, however, along the face and especially in the large space within whirlers and dust catchers. This mixture as it reaches the top of the furnace may cause a vigorous "top kick," which may sweep down the downcomer into the dust catcher and develop into a violent and costly explosion.

The most dangerous practice of all, and one probably seldom followed except by a blunder, is to have a burner or dust bell open near the furnace, in addition to having a burner or door open at the end of the gas line. Under these circumstances, with a current of gas moving toward the furnace top, air is drawn in with the gas, not behind it. This results in thorough mixing of gas and air, forming perhaps a very explosive mixture. These or similar methods or mistakes have caused very destructive explosions.

The method of action offering the least possibility of explosion at a shutdown, when the water, steam, and blast are lost simultaneously or in quick succession, is to close the cold-blast and hot-blast valves at the stoves and drop the blowpipes at once. The burners at the stoves and boilers should be shut at the same time. The tuyères can then be plugged with clay, the bleeder being opened sufficiently to afford partial relief to any tendency of gas blowing out at the tuyères, for, as the tuyères are usually burned at this time, the gas is apt to be "wild" and to blow out excessively. After the gas line has been inspected to make sure that all dust bells are tightly closed and the burners shut, the bells can be opened on top of the furnace. Although a few top shots may occur they are less likely to cause serious damage when a vent is provided for escape of pressure through the bells. The furnace can be allowed to stand in this condition indefinitely or after about four hours the farthermost burner, or door in the gas main, can be opened and the gas drafted out the furnace top through the bleeder.

The fact that explosions occur at the furnace top and in the downcomer at such times, when the temperature in the top immediately before stopping the furnace is only 350° to 550° C., may be explained by the assumption that the brickwork even at these temperatures may start combustion, and also from the fact that carbon, carried out of the stock by the gases, may have deposited in places on the walls. This carbon dust is highly pyrophoric, and in contact with air emits sparks or burns easily and may therefore ignite a mixture of air and gas at exceedingly low temperatures and thus initiate an explosion on top. The essential factor in preventing such top explosion obviously lies in not permitting any mixture of air and gas to draft up into the top of the furnace until sufficient time has been allowed for the top to cool. In view of the fact that there are innumerable small leaks along a gas main at burner doors, explosion doors, or at bleeders on dust catchers or ends of mains, and that gas in cooling from 450° to 200° F., contracts in volume approximately 30 per cent, and that with a bleeder or bells open on top the gas in the mains tends to drift up the furnace, there is every probability that, in case of shutdown, in the course of a few hours the mains will draw in a considerable amount of air and at a certain distance from the end be filled with air and gas in proportions closely approaching an explosive mixture. For this reason it is considered safest to draft out the mains rather than allow them to remain in such condition indefinitely, or even longer than is necessary for the top and downcomer lining to cool off.

On account of the uncertainty attending practice at these emergencies it is desirable to provide an easily closed valve, of the slide-gate or bell type, at each outlet from the dust catcher. These valves are most useful at routine shutdowns for repairs, or for temporarily isolating parts of the main, and should be supplemented by water-seal valves, as the mechanical type of valve is rarely gas tight, and in shutting down for repairs the prevention of gas leaks is essential. The use of the mechanical valve is largely to insure against high gas pressure blowing the water out of the water-seal valve, the latter taking care of any leakage of gas past the mechanical valve. This valve should therefore be inserted primarily with the idea of its supplementing the water-seal valve at ordinary shutdowns, and second, of being available in an emergency when the water-seal valve, steam pressure, and all routine auxiliaries are lacking. In order to fulfill these specifications the chief requisite of the valve is not necessarily tightness against gas leakage, but, rather, ability to be shut very quickly in order to isolate the furnace, downcomer, and dust catcher from the remaining cleaning and gas-main equipment. The ordinary goggle valve is an example of a type which does not conform to this requirement, as it is virtually useless in an emergency shutdown.

When such valves are provided, isolating the furnace from the gas mains is easy, the possibility of "top shots" or bad explosions becomes correspondingly remote, and the gas mains can easily be cleared by opening a burner at some point and drafting the gas out through a cold boiler or stove, a downleg at the other end of the main being opened to let air enter.

EXPLOSIONS AT SHUTDOWNS FOR REPAIRS.

Where the gas-main system is provided with water-seal valves or any type of mechanical valve it is easily isolated from the dust-catcher, and this is usually done when the furnace is shut down for repairs on top or at the mains. The possibility of an explosion is therefore practically eliminated, especially as steam may be used at such times as profusely as desired in drafting out the dust catcher and downcomer. Even at isolated furnaces where no valves are provided at the dust catcher and steam is not used, the chances of an explosion are remote. The work can be planned ahead, and performed deliberately, and aside from an occasional more or less vigorous "kick" on top, no trouble is encountered. As previously stated, three serious explosions within the past three years are known; in two of these instances the downcomers were split and in the third the stove burners were blown off the stands, no one being injured. In one of the cases where the downcomer was split, the explosion occurred several hours after the furnace had been taken off, and the furnace had been allowed to stand all night with the bleeder and bells shut, one gas burner open, and all dust bells shut. In the second case the explosion took place about half an hour after the furnace had been stopped, the bells had just been opened, and the gas was being drafted out through the top, but the gas on top had not been lighted.

PRACTICE DURING STOPS FOR REPAIRS TO TOP OR MAINS.

The following details of various practices at stops for repairs were furnished by the superintendents of a number of plants:

PROCEDURE AT PLANT 1.

In all shutdowns for repairs to the top or mains, the furnace is isolated from the other furnaces and the gas is lighted on top. The method of lighting the gas is as follows: The blast is thrown off the furnace, the tuyères are tightly plugged with clay, and the water valves are filled, sealing the gas off from other furnaces. The bleeder valve is opened and while the tuyères are being plugged the doors on the gas seal inclosing the hopper and the little bell are opened. After the foreman in charge has personally seen that this has been done, he opens the main bell. If after a certain time the gas has not lit, it is ignited by throwing a lighted piece of waste in, and a man is stationed on top whose sole duty is to see that the gas is kept lit. In order to have the top as open as possible, the explosion doors are also opened. In starting up after a stop, during which the gas was lit, the method of procedure is as follows: The bleeder valve and explosion doors on the top are closed. The explosion doors on the gas seal over the hopper are also closed, but the small bell is not closed until after the main bell is closed. After the foreman in charge finds everything safe, he closes the big bell and turns a low-pressure blast to the furnace. After the downcomer and dust catcher are filled with gas, as indicated by allowing gas to flow out of a dust pocket near the water-seal valve, the water valve is opened and gas allowed to flow over into the gas main.

PROCEDURE AT PLANT 2.

When possible, stops for repairs are always made directly after a cast. In taking the furnace off, when the first check is blown, the mixer valve is closed and water is turned into the water-seal valve with the idea of having it full at the end of the cast. As soon as the furnace is done casting and both water seals at the dust catcher are full both of the bells on the furnace and the dust-catcher bell are opened and gas allowed to draft up and out. The engines are kept turning over with the snort valve open, the mixer valve closed, the cold-blast valve closed, and the hot-blast valve and chimney valve open, thus drawing the gas away from the furnace. The blowpipes are then taken down, the tuyères plugged, and the engines stopped. In starting up, the blowing engine is started turning over with the snort and cold-blast valves open, the mixer valve shut, and the hot-blast valve closed. The blowpipes are put in place and the water-seal valves opened, permitting gas from other furnaces to flush the air out of the dust catchers and downcomer through the top of the furnace. When the dust catcher and furnace top are cleared of air the bells are closed, the starting signal blown in the engine room, and the hot-blast valve opened.

PROCEDURE AT PLANT 3.

In case men are required to go upon the large bell of the furnace, or into gas mains, or work about explosion doors or bleeders on top the procedure is as follows: The furnace is shut down and the bell valve at the dust catcher closed; the gas between the valve and the top of the furnace is expelled by steam. The openings of the dust catchers and downcomer between the valve and the top of the furnace are then opened, admitting air. While steam is being blown into the dust catcher the caps on the tuyère stocks are removed, the tuyères plugged with clay, and sufficient air blown through the hot-blast main to make a barely perceptible draft at the cap opening. The gas is then lighted under the bell and a small fire maintained by constantly feeding light wood down through the try-rod hole. The large bell is opened wide and the bleeder left open.

PROCEDURE AT PLANT 4.

In making short stops up to 24 hours in length the furnace is flushed and cast, the bleeder opened, and the mixer valve closed. The water-seal valves connecting the furnace dust catcher with the large general gas main and with the stoves are then closed, the large bell and small bell are opened, the blast-line snort valve opened, and the cold-blast valve in the stove closed. If, after a short interval, the gas in the furnace top does not ignite, it is lighted with flaming waste, after which several explosion doors are opened and the large and small bells blocked in their open position. The dust-catcher bell is locked closed to prevent anyone tampering with it, the blowpipes are taken down, and the blowing engines stopped. In starting up, the engines are started turning over against the open snort valve, the blowpipes are put up, the stoves opened, and a low-pressure blast turned into the furnace. As soon as gas appears on top, which is almost instantly, the large and then the small bell are closed, the bleeder being left open. The explosion doors are shut while the blowpipes are being put up. The dust-catcher bell is opened and when gas is escaping in quantity the water valves are opened, sending the gas over into the mains.

PROCEDURE AT PLANT 5.

When a stop of some length is made, precautions are first taken to see that the gas mains are sealed tightly at explosion doors and gas burners, in order that as little air as possible shall enter the mains with the gas, and to prevent accidental ignition of the gas. When the furnace is stopped the tuyères are plugged and the bleeder opened on top to draw off gas rising from the stock in the furnace. The gas mains are kept closed from the furnace top to the ends until the furnace is fairly cool. In case work is to be done on the gas mains, both bells are opened wide and the burners on the last boiler on the gas main are pushed in so that there is a suction through this boiler from the main. In starting up, the same boiler burners mentioned are opened so there will be a suction through to the end of the main.

SUMMARY OF METHODS AT THE FIVE PLANTS.

The chief points in the procedure at these plants may be summarized as follows:

1. Keep the engine turning over until the blowpipes are dropped.
2. Have the water seal or other valves closed at the end of the cast.
3. With gas valves shut, open the bleeder and draft gas back into the stoves.
4. Plug the tuyères and open the little bell and gas-seal doors.
5. Lower the large bell after the tuyères are plugged.
6. Light the gas on top if it does not ignite of itself, and keep it lighted.
7. Do not attempt to light the gas on top or open the large bell or draft out the downcomer while the tuyéres are being plugged, as a "top shot" may throw coke and flame over the men working about the tuyères.
8. In event of thère being no seals at the dust catcher, be sure that the gas main is tightly sealed. Block or lock the dust-catcher valve shut, open both bells on top, and open the farthermost burner on the gas main.
9. In starting up, open the valve at the dust catcher and permit gas from another furnace to displace the air in the dust catcher, downcomer, and furnace top before closing the bells.
10. At an isolated furnace open the burner, or, still better, the bleeder, at the end of the gas main to displace the air in the furnace top, downcomer, dust catcher, and main.

IMPORTANCE OF DESIGN OF GAS OFFTAKE AND BLEEDER.

There should be mentioned the importance of the relation of design of gas offtake and bleeder to the probability of top explosions. If the gas offtake and bleeder pipes are arranged in the "castle type," then the gas from the furnace, when it is off, will rise up through the bleeder pipe and mix in the upper part of this pipe with any air coming up the downcomer. If the offtake has its center line at about the bottom of the big bell, with the bleeder pipe placed at the end, over the downcomer, then the air rising up in the downcomer has a certain opportunity to draft down the offtake and mix with the gas under the bell and hopper by diffusion.

EXPLOSIONS AT SHUTDOWNS FOR CHANGING TUYÈRES OR COOLING PLATES.

The practice in an ordinary shutdown for changing tuyères, or other similar or minor repair work, varies considerably, considering that no wide range of options is possible.

The practices that give the greatest probability of an explosion are those which allow the gas in the mains to mix with air during a brief shutdown of 10 minutes to one hour. As this gas is often high in hydrogen it may explode violently on ignition. The mixing of air and gas in the pipes may be caused in one or both of two ways: (1) Air is drawn into the main by diffusion into open burners or dust legs and through leaky burner seats by cooling or explosion doors when the gas pressure falls to less than atmospheric; and (2) by opening the top air is forced into the main by the atmospheric pressure at the openings below being greater than the pressure of the hot gas inside the main which is open at the top. When the furnace is started and this mixture is forced into a heated stove or boiler, an explosion results, usually only a slight one if the flow of gas from the burner is of sufficient velocity, but sometimes making a considerable noise or throwing the burner off the stand if the gas drifts from the burner slowly. Occasionally the explosion extends into the gas main and develops sufficient violence to split or burst the main. Virtually every blast-furnace plant provides against this contingency by installing so-called "explosion doors" on the gas main, which are supposed to prevent escape of gas at working pressure, but will be lifted by a gas pressure of one-half pound, or 13 inches of water or more. The use of such doors is of questionable benefit and is in disrepute with some furnace men because the explosion doors frequently permit a great deal of air to leak into the gas main during a shutdown, and, owing to their inertia, will not at times respond quickly enough to a gas explosion to save the apparatus. In one instance the explosion door and frame was blown off the main, evidently before the door had time to open.

It is easy to ascribe too much importance to explosions of gas in the mains or at the burners at tuyère stops (stops for changing tuyères or plates). Many plants are not troubled with them at all;

at others months may pass without a single "kick," and this period be followed by one in which nearly every stop is accompanied by one or more "cracks," or explosions, at the burner or in the main; in the latter case an explosion door may be forced open and a cloud of flue dust blown out.

DIFFERENT PRACTICES IN SHUTTING DOWN TO CHANGE BRONZE.

Although such explosions seldom occur, the fact that they do occur is the reason for explaining practices in detail, and a description of practices followed at various plants will illustrate the possible hazards.

FIRST METHOD.

Operators at furnaces having relief valves in the hot-blast main may, and occasionally do, change tuyères without drafting the gas back through a stove. In making such a stop all burners are closed upon opening the snort valve; the cold-blast valve and, preferably, the hot-blast valve of the stove on blast are also closed. The pressure being thus relieved on the hot-blast main, the gas-relief valve drops, affording a vent to the atmosphere through which any excessive pressure of gas in the furnace or gas mains is relieved. Owing to the generation of gas in the stock column there is always some gas under slight pressure left in the gas mains if the explosion doors and bleeders are tight, but at the same time the back pressure is usually sufficiently relieved at the tuyères to enable work to proceed. With such a method chance of an accident during a short stop is small. There is danger, however, in making an unexpectedly long stop, when the gas in the mains and dust catcher may cool sufficiently to permit air being drawn into the gas system through loosely fitting burners, dust bells, or explosion doors. One hundred cubic feet of gas at 500° F. and atmospheric pressure will contract to 60 cubic feet at 100° F., and if the contraction in volume is replaced with air the resulting mixture will be explosive and may be ignited by a spark or red-hot material of any description. A possible disadvantage is that the gas in the hot-blast main may be drawn back in some quantity into the stove. Frequently, in addition to the relief valve being opened, the gas is drafted back into a stove.

SECOND METHOD.

The furnace being on the last check, all burners are closed except the burner at the extreme end of the boiler-house gas main and stove gas main. The furnace is taken off, the stove burner shut, and the top bell on the furnace opened. Upon starting up the furnace, the bell or bells on the furnace top are left open until the gas has displaced the air from the furnace top and is issuing from the top in large quantities. Then the top bell is closed and gas forced through the mains to the open burners at the end of the boiler-house line. This method has nothing but custom to recommend it, as large quantities of air may be drawn into the gas mains and into the top of the furnace. Should the air displace the gas bodily, there would be no particular danger. However, such opportunity is afforded for mixing of air and gas, in drafting air through the mains when the furnace is stopped, and in displacing air from the mains with gas when the blast is turned on, that often sharp explosions, or "cracks" occur at the burners or furnace top when the air-gas mixture comes through; also red-hot material may ignite the mixture at some point inside the mains, dust catcher, or furnace top. There is seldom enough of this mixture to cause a violent explosion, but the frequent "cracks" at furnace top and at burners are sufficiently disquieting and demonstrate the possibilities of more serious explosions. There is at some plants a tendency to ignore apparently trivial dangers in handling gas and to regard minor "puffs" and "cracks" as incident to the method. Encouragement is afforded this attitude because certain practices which contain elements of danger may be followed with impunity for years, and some day the exact combination of gas mixture, confined space, and igniting medium required to cause an explosion is encountered, with the result that the plant is wrecked or damaged and men killed or injured.

THIRD METHOD.

A more common practice in changing tuyères is to close all the burners at the stoves and boilers, open the bleeder, and draft the gas back through a stove. Some furnace men keep the bleeder, bells, and burners shut, and draft back through the stove, using two stoves if the gas pressure is strong at the tuyères. Other furnace men open both of the furnace bells and the bleeder, and also the dust bell on the dust catcher, thus clearing the dust catcher and downcomers of gas, and may leave a stove or boiler burner open to draw the gas from the gas mains. Another practice is to simply open the bells to draw the gas away.

Opening the bells, or bells and bleeder, induces a draft of gas up the downcomer and air flows into the main at every crevice, with the result that after a prolonged stop the mains may have considerable air in them and the furnace men not know it, and upon starting up a sharp explosion at the burner may result. When relief from gas pressure is obtained by drafting back through a stove with the bells, bleeder, and burners closed, there may be a slight vacuum induced in the gas main sufficient to draw air in and mix it with the gas. In case a stop of unexpected duration is made and air is leaking in appreciable quantities into the gas main, the conditions in the gas mains and dust catcher, in drafting back through stoves with the burners closed, may be as dangerous as with them open.

In the latter case the sweep of air into the mains offers opportunity for mixing of air and gas only at the face of the gas and air volumes or in large spaces, like dust catchers, the explosive mixture is soon swept out, and only air follows. The mixture of gas and air may cause a "top shot" from time to time as it mixes with particularly hot gas coming from the stock, which usually is not of sufficient violence to do any damage. The danger lies in its being severe enough to blow gas out of the tuyère or other device about the bosh or jacket on which the men are working. With closed burners, the whole course of the mains and dust catcher may be filled with an explosive mixture as the result of air filtering in at several shortly separated points, and upon starting up the furnace and turning the gas into a stove the whole contents of the main may backfire. If these explosions are of sufficient violence to tear asunder riveted steel plate construction in mains, as they have been, it is useless to attempt to safeguard against them by providing explosion doors. Experience has proven that the doors do not always open in time to prevent the bursting of the apparatus.

USE OF STEAM IN GAS MAINS.

Inasmuch as possibilities of danger are presented with every variation and modification of method and use of apparatus in brief shutdowns, it is interesting to note one practice which is safe and in which few, if any, combinations of circumstances can introduce any possibility of danger. If steam is turned into the gas main at every shutdown of a longer duration than or differing in kind from a casting period, there can be no explosions of gas. The steam may be connected with the system at the dust catcher or at a point next to the water seal, goggle, or sand valve which separates the dry-cleaning apparatus from the rest of the gas-main system. The best way to make the connection is to have the steam inlet valve on the foundation level within reach or to have a hook hanging from the valve and within reach.

The use of steam prevents a vacuum in the gas system when drafting back through the stoves with the bells, bleeder, and burners closed, or when drafting through the top of the furnace with the burners open, because a blanket of steam is interposed between the gas and air; also any explosive mixture formed in drafting up the downcomer is saturated with steam and rendered inert. The use of steam may easily be made a regular part of the plant practice. The small cost and the brief time required for turning the steam in at shutdown are amply repaid by the assurance that there is no possibility of even small "cracks" at the burners or top, to say nothing of more serious explosions.

The use of steam in handling furnace gas was introduced and first given publicity in 1905 by J. W. Dougherty, who applied for and received a patent on its use. Some furnace men dispute his priority in this application of steam, but the writer has been unable to find any record of another claiming to have used it before this date. It is, however, claimed to have been used in gas flues of steel-works furnaces prior to 1905.

RELIEVING GAS PRESSURE IN THE MAINS.

In furnace plants consisting of two or more furnaces the gas pressure in the mains is always adequate, when only one furnace is off for short repairs, to prevent any air being drawn into the main. As a rule a number of boilers are taken off gas, and the stoves are taken off at the furnace on which the stop is necessary. The gas is then drafted back through a stove. Frequently on furnaces connected together there is a very high gas pressure at the tuyères, which is not relieved by drafting back through one, or even two, stoves. Where this pressure can not be relieved by the full use of available stove or boiler burners or bleeders on the other stacks, it is sometimes deemed necessary, in order to reduce the gas pressure so that the work can be done with the least danger to the furnace crew, to open the top by lowering the bells. If the gas pressure can not be sufficiently relieved by opening the bleeders at other furnaces so as to enable the bronze to be easily changed, the bells should be opened only in extreme need and closed at the first opportunity when the bronze is replaced. Opening the bells is in many cases a hazardous practice at best, and should not be resorted to when there are but two furnaces connected nor when, in the case of two or a larger number of furnaces, the furnace in question is located next to the main leading to the gas engine. In every case a man should be stationed to watch the gas on top, and in event of its becoming slack at the bells to order them closed.

The best method of all whenever a tuyère must be changed, whether at an isolated furnace or a group of furnaces, is to fill the water-seal valves at the dust catcher, flood the dust catcher with steam, draft back through a stove, and open the bleeder if gas is excessively rank at the tuyères. This procedure renders the possibility of even a small explosion remote or virtually impossible.

EXPLOSIONS DURING SHUTDOWNS AT CASTING TIME TO STOP TAPPING HOLE.

There is little or no excuse for explosions at casting time, when the blast is off, unless a gas-engine plant is pulling too hard on one or two furnaces.

At one isolated plant the following practice is followed, which may be taken as typical of safe practice: The furnace is provided with a gas pressure gage and also with a whistle for signaling the boiler house. As the furnace is checked, the stoves are taken off gas until there remains but one stove on the furnace at the time the last check is blown, all of the boilers being left on gas. Shortly before it is necessary, in the blower's judgment, to open the snort valve and take the furnace off, he signals the boiler house. The water tender or foreman thereupon shuts the gas off at all but two boilers at the end of the main farthest from the furnace. One of these is taken off in case the gas becomes weak, the necessity for this being judged by the appearance of the gas flame at the burners. There is always sufficient gas from the furnace to keep a good flame at one boiler. When the snort valve is opened, the stove tender takes the last stove off gas. When the blast is put back on the furnace he turns the gas into this stove as soon as the snorter is closed, and then turns on the remaining stoves in quick succession. In putting the boilers on gas, the blower signals the engine room for full blast, then signals the boiler-house crew to put the boilers back on gas, waits a half minute until the snort valve begins to roar, and then turns the blast into the furnace. The boilers are put on singly and in turn, not all at once, but without further instructions.

Where two furnaces comprise the plant, the stove burners are usually shut at the furnace being taken off and the boiler-house crew either permitted to use gas with no burners closed or signalled to slack off slightly. With three or more furnaces in blast on a common main, it is not usually necessary to shut off any of the boiler burners, unless the gas supply should be scant on account of a furnace sticking. Heavy demands on stoves or boilers result in one or the other being favored at such times, but this is aside from any consideration of possible "top shots" or "kicks." At shutdown for casting it is essential as a rule to close the bleeder on the furnace being taken off.

At the few plants where the engines are stopped, or where the butterfly valve is closed tightly in the cold-blast main, or where a relief valve is opened at casting, little or no air enters the furnace, and on that account very little gas is generated. In such a case it is necessary to choke back the gas burners to insure positive gas pressure inside the gas main, which is essential to safety.

ACCIDENTAL STOPPAGE OF GAS.

Where water seals are placed in the gas mains, care should be taken that they do not fill with water from a leaky water-inlet valve. Such a possibility is done away with by placing an open gate valve at a tee in the feed line next to the dust catcher. Occasionally, where there are water seals on the discharge end of scrubbers not cleaning the gas thoroughly or dry, the flow of gas may be stopped by the water seal filling with sludge or with moisture condensed from the gas. Such valves should be emptied or flushed out at the beginning of each shift.

CARE AND OPERATION OF ROTARY GAS WASHERS.

The addition of a gas-cleaning plant which includes some type of rotary washer introduces cause for special precautions. Such washers may create a vacuum on the suction side, and if, for some such cause as sticking and tightness of the furnace, or a furnace stop, the supply of gas is less than the washer's running capacity, air will be drawn into the supply main at any point where a perfect seal is not present, such as bells or explosion doors or open burners. If this air mixes with the gas, still being furnished in scanty amount, to make an explosive mixture, and this is sent over to the stoves or boilers where flame is present, the flame may flash back and explode the gaseous mixture in the mains. Most frequently, however, a rotary washer draws its gas from a main carrying partly cleaned gas (this main also supplying partly cleaned gas to the stoves or boilers, or both) and delivers the clean gas to gas engines. In this case, if the gas supply falls below the capacity of the washer, and the washer remains running, it will create a vacuum in the main which supplies gas to the washer and to the stoves or boilers. As this main is open to the air at its stove or boiler burner connections, air is drawn into the main and delivered through the gas-cleaning plant to the gas engines where, if back-firing occurs and the incoming charge is ignited, the gaseous air mixture filling the mains will be exploded.

TYPICAL ACCIDENTS.

An example of such an explosion is illustrated in the following description of an accident that occurred in 1909:

Two furnaces were in blast at the time of the accident. At 12.31 a. m. the blast was taken off the furnace nearest the Theisen scrubber, and as the other furnace did not furnish enough gas for the gas engine and boiler and stove burners, air was drawn into the gas-cleaning apparatus through some of the burners under the suctions of the Theisen apparatus. At 1 a. m. the ammeter at the gas engine began to fluctuate. The current gradually went down from 4,000 to 2,200 amperes at 1.30 a. m. It then went up again and reached nearly 5,000 amperes at 2.19 a. m., when an explosion took place in the gas main between engine and gas holder. The gas engine stopped. Three minutes later, at 2.22 a. m., a second explosion was heard which blew up the gas holder. Seven minutes later a third explosion occurred which wrecked the tower washers and dust catcher on the furnace side of the Theisen. The first two explosions were caused by flame blowing back through an inlet valve of the gas engine and igniting at the engine the mixture in the main leading from the engine to the gas holder. The ignition evidently traveled slowly in this main, as three minutes were required after the engine stopped at backfire until the gas holder blew up. Probably the ignition of gas in the main had attained a great velocity as it reached the gas holder and projected the flame with great speed into it axially, thus igniting a large quantity of gas-air mixture at once. The bell of the gas holder was blown up and landed on its side in the holder tank, and a part of the top of the bell was blown off and thrown several hundred feet. The third explosion was started at one of the burners of the stoves or boilers, the gaseous mixture formed at the nose of the burner by percolation of air into the stationary gas igniting and traveling back to the dust catcher near the tower washer. The roof of the dust catcher was blown off and the main from the dust catcher to the tower washer was lifted by the blown-off roof so that it was wrenched loose from the tower washer. The top of the tower washer was ripped open but not blown off in one case, and torn off completely in another case. The explosion extended to the inlet of the Theisen washer where it was evidently extinguished by the water.

In 1910 there occurred in Germany a somewhat similar explosion. A description by Dressler[a] is summarized below:

At the time of the explosion but one furnace was running. The gas from the furnace went through a dry-dust catcher and two tower washers, and the final cleaning took place either in a Theisen or in two fans. At the time of the explosion the two fans were running in series, the cleaned gas going in part to stoves and boilers and in part to gas blowers and a gas generator. There was no gas holder. The furnace was running regularly with the bell closed. This bell was a "single" bell with central tube gas offtake, the space between the bell and the tube being sealed with a water seal. The top fillers noticed that the water seal was suddenly emptied and immediately refilled it. This probably took at least a minute. Following this, the gas blowers stopped and the gas generator began to run more slowly. As soon as the gas blowers were seen to be stopping the steam blowers were

[a] Dressler, H., Eine unerklärte Horhofen Explosion: Stahl und Eisen, Jahrg. 31, 1911, p. 270.

set in motion, but immediately upon the stopping of the gas blowers a violent explosion took place in the clean-gas main between the engines and the gas-cleaning house, traveling as far back as the Theisen, which was not working but was connected with the clean-gas main. The explosion was so violent that the front of the Theisen was destroyed and hurled a distance of several feet. The explosion did not make itself felt in the gas main leading to the furnace, nor to the boilers and stoves, nor at the fans. Accordingly, it is evident that only a comparatively small amount of explosive gas was present in the clean-gas main and that the scrubbers as well as the uncleaned gas pipe was filled again with the normal furnace gas, the aspirated air and gas at the furnace top having pushed itself like a cushion in front of the following normal gas, so that the inflammable zone had passed the gas-cleaning station and filled the clean-gas main from the Theisen washer to the gas engine. That it did not pass into the main to the boilers and stoves can be explained only by assuming that there was a balancing of pressure between the chimney stacks and the aspirating of the gas engine.

The explosion in this case, as in the preceding example, was due to back-firing or premature ignition in the gas inlet of the gas-engine generator. Whenever the normal working of a four-cycle gas engine is disturbed, either by an excessively high hydrogen content of the gas or a sudden lowering of thermal value, the ignition recoils into the mixing chamber, as the inlet valve, and also the gas valve, is open during suction. When back-firing takes place under normal working conditions, the line being filled with gas only, and the flame shoots into the gas pipe, such premature ignition has no serious consequences. Should the gas piping be filled with a gas-air mixture, then the ignition obviously travels back into the gas main where it may develop into an explosion.

ESSENTIAL PRECAUTIONS IN HANDLING GAS.

These accidents show that one of the most important details in the supervision of gas cleaning is to prevent, by suitable regulation, the formation of a vacuum in the gas mains at any point between the furnace and the rotary scrubber, as the rotary scrubbers of the type used in this country can usually give a vacuum, on the suction side, of 3 or 4 inches of water, and a discharge pressure about 8 inches higher than the pressure on the suction side. This requirement is adequately met at all gas-engine and gas-cleaning plants by means varying from very elaborate to exceedingly simple systems. These consist of a series of gages indicating and recording the pressure in the gas mains, automatic alarm bells which ring when the gas pressure falls below a certain predetermined danger point, whistle signals, telephones, circuit breakers on the gas engines that break automatically or are tripped from the gas-cleaning house, and valves that close or open automatically in the gas mains with varying pressure, but chiefly dependence is placed in personal supervision by a responsible employee at the cleaning house.

The point of danger in the gas-main system is essentially the main supplying gas to the rotary washer. If the pressure in this main is never permitted to drop below a certain water pressure—one-half inch, for instance—it follows that gas will always be delivered to the engines in sufficient quantity and at a satisfactory pressure, and that as there is a positive pressure in the mains leading to and from the washer, air can not be drawn in. Although the supply main is the one watched with the greatest vigilance, gages are attached to other parts of the gas system. Examples of various systems follow. The placing of the gages is given in the order of their importance:

1. Gas (*a*) to boilers and primary tower washer; (*b*) from primary washer to stoves and secondary washer; (*c*) from secondary washer to gas engines. Gages placed at *b*, *a*, and *c*.

2. Gas (*a*) to primary tower washer and boiler; (*b*) from primary washer to fan; (*c*) from fan to stoves and Theisen washer; (*d*) from Theisen to gas engine. Gages at *c*, *a*, *d*, and *b*.

3. Gas (*a*) to primary tower washer; (*b*) from primary tower washer to stoves, boilers, and Theisen; (*c*) from Theisen to gas engine. Gages at *b*, *a*, and *c*.

4. Gas (*a*) to boilers, stoves, and tower washer; (*b*) from tower washer to rotary cleaner; (*c*) from rotary cleaner to engine. Gages at *a*, *c*, and *b*.

METHOD OF HANDLING GAS AT A LARGE PLANT.

A detailed report of the system of handling gas at a large plant is given here in abridged form, as it conveys an exceptionally good idea of the methods used and conditions encountered.

GAS CONSUMPTION AT FURNACE PLANT.

The blast-furnace plant consists of one 500-ton and three 450-ton furnaces, each having four hot-blast stoves. In addition to these stoves the furnaces supply gas to the following:

8 batteries of Stirling boilers	horsepower	4,800
4 batteries of Cahill boilers	do	4,000
4 gas electric engines	do	7,200
1 gas electric engine	do	4,000
2 ladle dry houses.		

DESCRIPTION OF GAS-CLEANING PLANT.

The gas-cleaning plant consists of two parts—the preliminary cleaners and the purifying plant.

The preliminary cleaners are situated at the furnace and clean all the gas. The cleaners at each of the four furnaces differ in many respects as to form and arrangement, but they are nearly alike in principle.

At furnace "A" the gas leaves through the downcomers and passes through a 30-foot common dry dust catcher, a 21-foot tangential dry dust catcher, and a 26-foot 3-inch Mullin or impinging washer. The gas leaves the Mullin and passes through a Crawford valve and then into the 6-foot common furnace main. Off the end of this main a 30-inch main leads to the ladle dry house. This common 6-foot main passes through the Stirling boiler house, and from this main a 6-foot main leads to the Cahill boilers.

At furnace "B" the arrangement is identical to that at furnace "A," except that there is one 5-foot main leaving the Mullin washer, which leads into the 5-foot main behind furnaces "B" and "C."

At furnace "C" the gas passes through one 30-foot, common dust catcher, one 26-foot tangential dust catcher, and one primary and one secondary "baffle washer." The gas leaving the washer passes into the upper 5-foot main behind furnaces "B" and "C." This main feeds gas to the boilers and to the primary 6-foot main connecting the gas mains from all the furnaces. The stoves of both furnaces "B" and "C" receive gas from this 6-foot main.

At furnace "D" the gas coming down from the top is conducted through four downcomers into two pipes leading to a common dry dust catcher 30 feet in diameter, thence through a series of three centrifugal dry dust catchers, and from there through a primary and a secondary washer identical to those at furnace "C." The gas leaving the washers is passed into the upper 5-foot main, which feeds the "D" furnace stoves and also connects with the common 6-foot main connecting all the furnaces.

Goggle and Crawford valves are so situated in the gas mains that any furnace, boiler house, or engine house can be shut down or disconnected without interfering with the operation of any of the others.

A 5-foot gas main connecting with the "D" furnace end of the common 6-foot main leads to the purifying plant. Between No. 8 and No. 9 stoves a 5-foot main connects with the common 5-foot main and leads along the trestle to the purifying plant, thus forming two gas supply mains to the purifying plant.

The purifying plant consists of three separate units in parallel. Two of these are identical, each having one baffle, one Zschockke and one Theisen washer in series. The third consists of only one Theisen washer.

From the Theisens the gas passes through a water separator into a common 5-foot main which leads to the gas holder. A regulating butterfly valve is placed in the main ahead of the gas holder. A 5-foot main leaves the gas holder and divides into two 5-foot mains, one leading to the gas electric engines, the other to the gas blowing engines.

The gas holder is 55 feet in diameter and has a lift of 14 feet, thus having a capacity of 33,000 cubic feet, and requires a pressure of 7¼ inches of water to raise the bell. A 5-foot by-pass has been connected to the mains entering and leaving the holder so that in case of emergency the holder can be cut out by turning three goggle valves.

A butterfly valve has been placed in each of the engine-house gas mains, which is regulated by a small gas meter 5 feet in diameter connected to the gas main by a 4-inch pipe. With this gas meter the pressure of gas can be regulated at the engines. At present this pressure is set at 3½ to 5 inches of water.

As the pressure in our gas mains at "B," "C," and "D" furnaces is much larger than at "A," owing to the smaller main, it is obvious that as we have all of our boilers between these conditions, and a ladle dry house on the opposite side of "A," gas very seldom reaches the gas engines from "A" furnace, the exception being in the case of a shutdown or furnace out of blast at "B," "C," and "D." The method of operation under these conditions is referred to later.

SAFETY OF THE PLANT.[a]

The only danger which exists for the safety of the installation has its source in the lack of sufficient gas supply.

The principal part of the gas-cleaning plant is the so-called purifying plant, the object of which is to refine the gas for use in the gas engines. As mentioned heretofore, this part of the plant contains the Theisen washers, and these are so constructed that there is a suction fan on the end of the gas supply and a discharge fan on the other end. Because of this construction, they are able to suck gas or air through the mains and discharge it under pressure. The tendency of the washers is to deliver gas to the gas holder at a pressure 8 to 12 inches higher than the pressure on the suction side, and the object of the gas holder is to act as a reservoir, and it maintains a constant pressure of about 7¼ inches.

It is evident that if for any reason the gas supply to the holder should fail or continue to be pumped in after the holder has reached its uppermost position, there would be danger of a wreck; in the first case due to the suction from the engines on the empty holder, and in the second, to high internal pressure, as the butterfly valve is not gas-tight.

In mentioning the gas supply to the holder, we will have to consider air, because should the Theisen washer continue to operate when the gas had failed, air would be pumped into the main by way of the stove and boiler burners, bleeder and any similar openings in the supply main. If such were the case there would be no danger of a collapse, but an infinitely more serious one would be presented and in the nature of an explosion. The engines would receive a mixture of gas and air, and this change of mixture would cause the engines to "back-fire" into the main, and as the explosive mixture might extend all of the way back through the main, an explosion would be possible, wrecking the entire installation.

FURNACE OPERATION AS REGARDS GAS SUPPLY.

As the requirements of our gas-engine power house are practically the same regardless of the number of furnaces in blast, it is evident that there are times when it becomes very much of a problem as to how we can keep the engines running and take care of a brief "shutdown," owing to accidents at the furnaces, such as the burning of a blow pipe, or to make necessary changes. When the latter is the case we try to take the blast off at meal hours, when the load is the lightest and when we can shut down all but one gas engine and all of the engines at the steam power house. We then take care of the plant load by running the motor-generator set from the gas engine, and thereby economize on the gas consumption.

The worst condition which we can have and attempt to satisfy all of the requirements is that of only two furnaces in blast, and any rules of methods of operation are based on that condition. In case a shutdown is to occur, the general foreman or blower, if it be an accident, notifies by means of the telephone the office and Theisen washer operator. He then sends word to the boiler tender to make a fire, and to the stove tenders to be ready to operate the water-

[a] All pressures mentioned are in inches of water.

seal valves in the gas main to the furnace in question. If all furnaces are in blast, he also communicates with the men in charge so that everyone in control of the gas supply can assist in maintaining an excess.

If two furnaces only are in blast, he pulls back the stove burners on both furnaces before the blast is entirely off, and also opens the bleeder on top of the furnace so that the water-seal valve can be entirely filled while there is still a small supply of gas.

Having complied with these methods of operation, the furnace man has not eliminated the dangers, but he has done all in his power to put the supply on a safe basis, and, as is explained later, the responsibility has been passed on to others and he is free to hurry his various operations on the furnace. In the case of a premeditated shutdown, everything can be carried on deliberately, and possibly in the case of an accident, but if not, the dangers are taken care of partly by automatic means and partly by operators.

The furnace man has a pressure gage on the trough supplying the cooling water to the furnace and he maintains a pressure such that it will be lower than that of the blast, thereby reducing the possibility of hydrogen in the gas supply to the engines. He is also provided with a set of instructions and signals such as are applicable to the other parts of the system.

GENERAL SAFETY PRECAUTIONS.

The general features which have been installed for the purpose of avoiding accidents are as follows:

(A) A plant telephone system which connects the gas-electric engine house, blowing-engine houses, steam-power house, Theisen washers, furnaces, and offices, a telephone connecting the gas-engine power house and the steel works, also a telephone on the outside exchange. Where there is danger of operators not hearing the bell, a steam whistle is installed.

(B) Steam whistles electrically operated from the Theisen washers are located at each house and one between "C" and "D" furnaces. They are used in the case of "low gas" and can be heard at all of the furnaces and boilers, and, in fact, very distinctly from any part of the plant. They have a distinct tone of their own and can not be easily mistaken for others, so that they serve to keep posted all who are concerned with existing conditions.

In order to avoid the danger previously mentioned of pumping air or gas into the gas holder after it has reached its uppermost position, a butterfly valve is arranged in the main between the Theisen washers and the holder, and is operated by the holder bell in such a manner that when the bill is in its highest position or full, the valve shuts off the gas supply. The valve then is opened automatically as the bell descends and maintains a position which varies for each position of the bell.

In the case of an accident at this part of the plant, it is understood that a long blast on the "low-gas" whistle, located at the boiler houses and furnaces, will serve to notify the entire works.

Whistles are installed at the washers and at the gas-engine power house and serve as a means of communication in addition to the telephones. They are used in starting up and in stopping the engines and washers. The code of signals as posted and used is as follows:

SIGNALS AND GAGES FOR THEISEN WASHER.

To gas blowers from Theisen washer.—One blast, "Gas supply failing"; two blasts, "Gas supply O. K." (test at 6 a. m.).

To gas-electric engines from Theisen washer.—One blast, "Shut down engines"; two blasts, "Gas supply O. K."

To Theisen washer from gas-electric engines.—One blast, "Shut off gas supply"; two blasts, "Send over gas."

General signals from Theisen washer.—One blast (long or short), "Trouble, help wanted"; one long and two short blasts, "Pull stove burners back"; two blasts, "Pull boiler burners back"; three blasts, "Light boiler burners"; four blasts, "Gas supply O. K." (test 6 p. m.).

General signals from gas-blowing engines.—Any number over four blasts, "Gas engine failing"; four blasts, "Gas supply O. K." (test at 6 a. m.).

This code, in addition to being posted in a frame at the washer, is also posted at the gas-engine house, furnaces, boiler houses, and office.

The operators at the gas-blowing engine house upon receiving one blast from the Theisen will immediately put themselves in position to familiarize themselves with the gas situation, and, if they find that there is not enough supply to keep the engines running, they will advise the furnaces by blowing more than four blasts. When it is found that the engines must be shut down, the ignition will be cut off as quickly as possible.

At the furnace the stove tenders must be acquainted with the meaning of the whistles so that they will not wait for orders, but will pull their stove burners back immediately and make all preparation to take the furnace off as soon as possible if found necessary. The blowers upon hearing the whistle will get to their pressure gages as soon as possible and from them determine the course to be pursued. If the gage pressure does not indicate that the blast has failed entirely, it of course will mean that the condition has recovered to such an extent that the engines were not forced down, or that probably the blast is being supplied by speeding up the split steam engine that happens to be in operation.

At the steam-blowing engine house the operators will be prepared as soon as possible to put a steam engine into service on the furnace where the gas engine has failed. When they are ready the furnace can be advised by means of the telephone, in which case they will prepare to put the blast on again.

In the case of the stove burners, it is quite probable that if five or more whistles are blown "low-gas" signals will have been blown previously and that burners will already be back. The case may arise, however, where this may not be so, and it will be necessary that special precautions are taken in advising the men in charge of the stoves.

In case a furnace is shut down for any purpose, the furnace foreman will have an understanding with the stove tender that after the regular operations have been performed in taking the furnace off, he will also see that steam has been turned on, and not only turned on but **actually going into the dust catchers.** He will also take charge of the Crawford valve, shutting off the furnace in question, and see that it is operating in perfect condition. The stove tender is to do these things, and nothing else, while the furnace is off blast.

The following notices are placed in conspicuous places, the first being inside and the second on the outside, near the door of the clearing plant.

(1) "Smoking and the use of matches or open flames of any kind is strictly prohibited in this building."

(2) "Keep out except on business. Do not smoke or use red-hot metal or flames of any kind on or near these washers. Employees failing to comply with the above will subject themselves to discharge."

Similar signs are placed in and about all other parts of the gas-engine system and building.

It has been shown that the failure of gas supply is the most common danger which exists; therefore it is essential that some means be devised whereby this danger is guarded against. As has been shown, the furnace man does all in his power in the matter of warning, and the responsibility for the safety of the installation devolves upon the Theisen-washer operator, as he is in control of the train of mains and piping which conducts the gas to the engines. In order to assist him and to serve as a means of warning in case the gas gets "low" for any unforeseen reason or at casting time, a system of manometer tubes and recording pressure gages are installed.

The low-pressure signal consists of a manometer tube made of steel pipe and of sufficient length to hold the water for any pressure which may exist on the furnace side of the Theisen.

A copper float supporting a brass rod, on the end of which is a copper washer, is in the atmospheric end of the tube. The washer is set at such a point that when the pressure has been reduced to 2 inches, it will complete an electrical circuit and cause a whistle to be blown. After thus receiving his warning, the operator watches his glass tube and gage for critical conditions, as they are connected in the same line with the steel tube and on the supply side of the Theisen.

If the pressure falls below 2 inches, the whistle calling for the stove burners to be pulled back is blown, and the furnace man quickly responds. If this does not increase the supply to the engines, the signal for the boilers is blown. If the pressure does not resolve into a vacuum before the supply is increased, by pulling back the burners or the unusual conditions of supply readjusted, the operation is not changed. But should a vacuum occur, a gate valve which is placed between the holder and the Theisen washer is closed and the Theisen shut down in order to prevent air from being pumped into the mains and holders. The operator then watches his tank, also for a return of his supply pressure, and in case the tank gets beyond a marked position before the pressure returns, he signals the engine house to shut down, and his orders are imperative in so far as the engineers are concerned. In case it becomes necessary to stop the gas-power engines quickly, due to the sudden failure of gas, the Theisen-washer man has control of the ignition system on engines, which he immediately cuts out. The operator can of course vary his operation to suit conditions, such as allowing the tank to go lower when only one engine is pulling on the reserve gas supply.

One of the other glass tubes and the remaining pressure gage are connected to the main on the holder side of the butterfly valve, and indicate the pressure carried there. Under normal operation it is obvious that the pen of the gage should not vary from one position. If it does, it shows improper working of the butterfly valve or a shutdown at the engines and gas supply cut off. This recording gage has since been placed in the gas-blowing engine house.

The remaining glass tube indicates the pressure between the butterfly valve and Theisen washer. It has little or no effect on operating conditions, but shows the pressure which is built up by the Theisen.

The following list of duties is framed and hung up in the Theisen-washer building:

1. Change chart on 24-hours' pressure at 6 p. m.

2. Test automatic "low-gas" signal each day while 12-hour chart is off and when necessary to fill with water so that whistle blows at 2-inch gas pressure.

3. Test signal whistle at gas-engine house every 12 hours and boiler house at 6 p. m.

4. Drain water from gas main at tunnel and downlegs of by-pass valves each 12 hours.

5. Clean Crawford valve each 12 hours.

6. On closing down washers for any length of time, drain all water pipes, etc., to prevent freezing.

7. When starting washer after a long shutdown, let gas pass through system out of bleeder for 15 minutes before allowing engines to use it.

8. Do not give O. K. signal to start gas engines until engineer in power house has called up on telephone to say that bleeders are closed.

9. When we have "low gas" at gas washer and the electric engines are to be shut down, they are to be shut down by pulling out ignition switch.

Considering the system as a whole, changes will doubtless be made from time to time as their necessity becomes apparent, in order to decrease the possibilities of accidents, but as it now stands, those concerned in the control and maintenance of the gas supply appear to work harmoniously and to handle the "low-gas proposition" satisfactorily and intelligently.

METHOD USED AT ANOTHER PLANT.

Another method is described in brief by Freyn,[a] in the Transactions of the American Society of Mechanical Engineers, as follows:

The power house, gas-washing plant, and blast-furnace office were connected by two independent telephone lines, and recording instruments, in addition to ordinary U-tubes, were installed in the washer building and at the blast-furnace office, so that not only may the gas pressure be observed at any time but it is automatically recorded for each period of 24 hours. Moreover, an automatic alarm was installed at the blast-furnace office, which rings a bell as soon as the gas pressure in the raw gas descends below a certain danger point, and whistle signals operated by solenoids from the blast-furnace office were provided in the boiler house to inform the head fireman of the number of boilers to be "taken off" or put on gas. In addition an automatic bell was placed in this boiler house, calling the operators' attention to any drop below normal in the gas pressure.

Independently of the blast-furnace department, the gas-cleaning-plant operators were also carefully watching the gas pressure. The position of the gas-holder bell was made visible at any time by a system of incandescent lamps in the washer house, and strict orders regarding the use of the gas were issued by the blast-furnace superintendent, instructing the men to favor the gas engines under any circumstances, as it was fully recognized that, having taken care of the requirements of the hot-blast stoves, the remaining gas could not possibly be more efficiently utilized than in the gas engines. The practice was to shut off the gas immediately at a certain number of gas-fired boilers, as soon as the pressure in the overhead gas flue dropped below a predetermined point. Additional boilers were taken off if the gas pressure did not recover, so that sometimes as many as 24 boilers were being fired by coal exclusively. If this did not have the desired result, stoves were taken off for short periods to increase the gas pressure above the danger point. At last, if all the steps did not improve the situation, one or more gas engines were shut down. Fortunately in the majority of cases the blast-furnace operators know in advance if the gas supply is likely to fail, and communication could easily be established to warn the departments concerned of the impending gas shortage.

The system of close observation and of cooperation among the departments concerned worked to perfection, but nevertheless conditions existed at times

[a] Freyn, H. J., Operating experiences with a blast-furnace power plant: Trans. Am Soc. Mech. Eng., vol. 32, 1910, pp. 368.

which with all due optimism had to be called dangerous. It was frequently necessary to keep several gas engines running, with the gas pressure dropping below the danger point momentarily or even for periods of a few minutes. This was unavoidable if the operation of certain departments dependent upon a supply of electric power was to be maintained with any regularity. If the gas engines had been shut down every time a momentary drop in pressure occurred, it would often have meant an endless amount of shutting down and starting of engines, altogether too frequent for satisfactory operation of the mills and physically impossible for the gas-engine operators.

AUTOMATIC APPLIANCES TO REGULATE THE FLOW OF GAS.

The exclusive use of automatic appliances to regulate gas is unsatisfactory for several reasons. Such devices are never fool proof, and from various causes may work at unexpected times or may fail to work at a critical moment when dependence has been placed on them. Among the various types in use are automatic circuit breakers that stop the washer and at the same time break the ignition circuit on engines, butterfly valves on the mains that automatically open and close with varying gas pressure, and check valves to prevent back flow in downlegs to gas burners or in gas mains. The employment of a responsible man at each shift who through experience knows whether any pressure drop in the mains will be only incidental and brief, being caused, for instance, by casting, or from the characteristic fluctuations of the gas flow from the furnaces, is much safer and incomparably more satisfactory than depending entirely on automatic safety appliances. In case of occasional or somewhat frequent drops in the gas pressure the working of these safety appliances might shut down the engines so frequently that it would be physically impossible for the engine crew to keep them running; also, the automatic closing of butterfly valves might cause very serious accidents at the stoves or boilers when the valves again opened, if a rush of gas should arrive at the burners before sufficient time had elapsed for the men to assume control of putting the gas on again. Similarly, strict operation of the boilers, according to signals automatically operated by gas pressure, would be impossible under many conditions of furnace operation. Such signals are chiefly useful as warnings and indicating the need of watchfulness. Placing control of gas at the burners under a responsible person who can judge whether shutdowns are necessary is in the end most satisfactory, as stove tenders and the boiler-house crew will follow instructions and recognize the necessity of compliance with signals coming from a competent gage man, whereas repeated and annoying signals and interruptions from automatic valves, bells, or whistles will be frequently disregarded, only to result disastrously some day when compliance with the signal is essential to avoid accident.

Where the cleaning plant consists of tower or impinging washers alone, no rotary cleaner or fan being used, the putting on and taking off of boilers and stoves is usually controlled by the furnace blower, who can be provided with a pressure gage and signal whistle to the boiler house at a place convenient to the engine-room whistle switch and snort-valve lever or wheel. The control of gas with this type of washer is not greatly different from control of gas direct to stoves and boilers from the dust catcher.

BLOWING IN.

CAUSES OF EXPLOSIONS AT BLOWING IN.

There have been several explosions of gas at blast-furnace plants on blowing in. The critical point in this operation lies in the necessity of bringing the gases down from the furnace top to the gas burners. This operation is made comparatively simple at plants having one or more furnaces already in operation, as gas from the mains can be sent up through the dust catcher and downcomer to the furnace top, displacing the air, and when a good flow of gas is coming off at the top bleeders the bleeders may be closed, forcing the gas from the furnace just blown in down into the mains.

SPONTANEOUS EXPLOSION OF GAS MIXTURES.

At isolated furnaces, however, the problem is not as simple and the work of bringing the gas down causes much anxiety, owing to the dread of an explosion. Some furnace men believe that furnace gas and air will ignite or explode spontaneously at such times, that is, explode in the direct absence of fire or other igniting medium. Three explosions at blowing in occurring within recent years have already been mentioned, in which the circumstances and the testimony of witnesses pointed to spontaneous combustion as the cause. It is realized that persons at fault in these cases may have omitted to mention to their superintendent contributing causes, but the writer, at least, regardless of whether spontaneous or catalytic ignition of gas mixtures can or can not take place, is unable to offer any explanation other than spontaneous ignition.

In two of the accidents mentioned the gas upon being brought down into the dust catcher exploded within it, in one case breaking the dust-bell lever and in the other doing no damage. In the latter case it is stated a bleeder at the end of the gas main at the boiler was open, no burners were open, there was no fire near the mains, and gas had not appeared at the gas-line bleeder. The explosion occurred within a minute of closing the bleeders on top and opening the bleeder at the end of the boiler gas mains. The other case occurred in almost exactly the same manner, except that steam had been turned into the dust catcher at the instant of bringing the gas down.

The third explosion mentioned resulted in splitting the furnace jacket above the stock line. The gas had just been turned into the boilers and the men were about to turn it into a stove.

As a rule, the men who believe such explosions result spontaneously belong to the older school of furnace men, with a few converts to the theory among the younger group, conversion having been effected by experience or direct testimony. One furnace man who had an unexplainable gas explosion of this type years ago now follows the practice of blowing a considerable volume of cold air through the furnace after it is filled and before it is lighted in order to blow out any loose dust and fine ore which otherwise would presumably be blown out when the furnace is lighted and the blast put on. He attributes this type of explosion to the presence of these fine dusts. This is cited as an illustration of the very real belief in these explosions being caused by spontaneous combustion.

BRINGING GAS DOWN WITH BELLS OPEN.

A second cause of such explosions is found in taking the gas down to the burner and having the bells on top open, either inadvertently or by design. Two accidents have been noted which occurred in this manner, one resulting in blowing up the dust catcher and the other in bursting a gas main. In these cases the draft in the stove-chimney stack was sufficient to draw air in about the bell, where it mixed with gas, and the mixture, on arriving at the burners, back-fired and exploded.

BRINGING GAS DIRECT TO STOVES OR BOILERS CONTAINING A FIRE.

A third cause is in taking the gas down from the furnace top directly to boilers or stoves in which there is a fire burning. A somewhat recent explosion resulted in this manner. In this instance steam was turned into the dust catcher, the bells and bleeder on top shut simultaneously, a boiler burner opened over a lively coal fire on the grates, and the gas led in. The burner back-fired and the resulting explosion blew up a small auxiliary dust catcher about 100 feet from the burner. Repairs were effected, the blast was again put in the furnace, the same procedure followed, and the dust catcher was again blown up. The third time steam was led into the dust catcher several minutes before gas was brought down, and when steam appeared at the bleeder the gas was brought down to the burner without difficulty. It is to be emphasized that the use of steam in itself may not prevent accident, because, at 48° C., gas saturated with water vapor or steam (not entrained moisture) is at a maximum of explosibility. Steam should rather be used with the idea of interposing a blanket or cushion of steam between the air and the gas. An accident resulting from the same practice—that is, leading gas directly into a boiler having a fire in it—occurred several years ago, with disastrous consequences, gas mains and dust catchers being blown to pieces and a spectator killed.

This practice is followed quite widely, and rests on the assumption that the gas sweeps the air bodily out of the mains, and that there is no mingling of air and gas except at the face of the gas and air. It is probable that there is no sharp line of demarkation between the gas and air currents, and that at times the gas pushes ahead, owing to its higher temperature and tendency to travel along the top of the gas main, while the cold air, being of heavier density, tends to travel along the bottom, to say nothing of the opportunity afforded for mixing of air and gas in the dust catcher. Obviously, the greater the velocity of the gas current at this time the more completely is the air swept out. For this reason it is the practice at some plants to turn the blast at nearly full pressure into the furnace just before and while the gas is being brought down, in order to get a good sweep of gas. Such a method, however, does not offer the best possibility of immunity from explosion, and it is better to allow the gas to escape from the far end of the gas main through a bleeder, explosion door, or manhole door, or cold boiler, until gas is coming in good volume rather than immediately leading it over a fire.

BUILDING FIRES IN GAS MAINS.

A method of taking the gas down followed at a few plants where the gas is conveyed to boilers and stoves by an underground gas main is to build a large wood fire in this main, under the manhole nearest the gas downtake to the underground main. This fire is left burning strongly and the gas is brought down into the main, over the fire, and thence to the burners. At one plant where this practice is followed there is a belief that cold damp air in the main when mixed with gas will explode spontaneously. The essential idea of the fire is probably not to heat the main, but to push up a current of inert gases, CO_2 and N_2, into the mains from the underground main to the furnace top, so that inflammable furnace gas, when brought down, will arrive at the fire unmixed with air. It is observed that the gas extinguishes the fire, and a sheet of flame sweeps up the main ahead of the gas, burning out the air in the main, until it finally arrives at the burners. In one instance a violent explosion, probably caused from an inadequate fire or too much air being admitted to the fire and mixing with the gas, occurred and blew up the underground main along half its length. A variation of this method is to build up a large bed of burning coals, then close all manholes and wait about 30 minutes before bringing the gas down. Both of these methods are too hazardous to be undertaken by any except men having previous experience with the details of time intervals and practice.

SHUTTING OFF THE BLAST.

An infrequent source of explosions is when, shortly after the gas has been brought down and is at the burners, the blast has to be taken off in consequence of some mishap. If more than one furnace is on the gas line no danger is introduced, if care is taken to keep the gas pressure up, but if only one furnace is in operation an explosion may occur unless stringent precautions are taken to prevent air entering the main. In one instance where a furnace was taken off suddenly about two hours after the gas had been turned into the boilers and stoves and while the men were on the bustle pipe repairing the water supply, the dust catcher exploded, throwing them from the pipe to the cast-house floor. It is not known how the explosion was started as the gas temperatures were low, but as one burner was left open and the furnace bell was opened, the mixing of air and gas is apparent, the point being that air should not at such times be admitted to the mains or furnace top. The blast should be kept on at all cost and a positive gas pressure maintained.

METHODS OF BLOWING IN PRACTICED AT 18 PLANTS.

The point has been expressed by several furnace men that, in view of the variation in methods of blowing in furnaces, the Bureau of Mines could be of service by compiling and publishing a number of methods of blowing in. Accordingly there are tabulated herewith 18 methods of operation:

PLANT 1.

As soon as a furnace is filled and ready to be lit we light all the tuyères and leave the sight caps open and also the relief valve on the bustle pipe. One engine (84 by 60 inches) is put on at 14 revolutions and is kept on until all the wood is burned, which takes about two hours; the sight caps and relief valve are then closed. The bells are left open for about 10 hours and the bleeder for about 24 hours. The gas is turned into the flues after 24 hours.

PLANT 2.

If a single furnace and not connected to another furnace, have the top bells and bleeders open. Have all openings on the gas mains or flues closed except at the end of the main, and allow no gas to boilers or stoves until you are ready for it. Be sure that all valves are made tight by sand or some other sure way if you do not have water valves. When ready to light the furnace have the engine going, turn the blast on the furnace, and light by means of hot rods. After a good flow of gas is coming out of the top, close the bells; this will force gas out of the bleeders, throughout the mains, and out the end of mains to the air. Allow this to continue for sufficient time to clear all mains of air, then light the gas at a stove or boiler farthest away. Be sure to keep gas away from the fire until satisfied everything is O. K. If the furnace is connected to a group of furnaces, when ready to light the furnace open a gas-seal valve and allow gas from other furnaces to drive all air out of mains and out of top and through the stock in the furnace, the top being open. When satisfied the air is driven out, open the blast valve from the engine and ignite the furnace with hot rods through the peep holes. After the furnace is lighted for a short time and gas permitted to escape from the top into the air, close the top and go ahead, using gas at stoves and boilers.

PLANT 3.

The furnace is filled, according to standard methods, with coke to cinder-notch level, scaffold to top of coolers, kindling wood under scaffold, and about three tiers of cordwood on top of scaffold; then about 100 tons of coke is put in before any ore is used. The first ore charge consists of about 1 part ore to 2 parts coke; then we put in six charges at a ratio of about 1 to 1 and finish filling with a burden having a ratio of 1.25 parts ore to 1 part coke.

We usually blow in on 5-inch tuyères, of which half are open and the rest banked, and start up on about 15,000 cubic feet of air per minute, and this volume is blown for about 15 minutes, or long enough to get the furnace started nicely, when the volume is reduced to 10,000 cubic feet per minute, which is increased by 1,000 cubic feet every three hours until 18,000 cubic feet is reached.

The tapping hole is left open and blown through until coke appears, which is usually in about six hours. The bleeders and explosion doors on the offtake are left open, and the valves to the gas line are closed, and when we are ready to turn gas down to the stoves all valves but one are opened, all explosion doors except one are closed, all dust pocket bells are opened slightly to allow any air to escape, and a good wood fire is burning in the stoves.

After these preliminary preparations are arranged and the pressure of gas on top of the furnace is sufficient the last valve is slowly opened, driving all air ahead, and gas ignites at stove burner, when the remaining explosion door on top is closed, and the other stoves are put on gas as soon as the gas pressure will permit.

The gas is then turned down to boilers in the same manner, care being taken that the number of boilers is not too great for the quantity of gas produced.

PLANT 4.

When the furnace is dry and cool a wooden scaffold is built in the furnace, composed of upright posts made of 6 by 8 inch timbers, and a platform on top of posts is made of 3 by 12 inch plank spaced about 3 inches apart. The distance from the top of the scaffold to the center line of the tuyères. is 15 inches.

A manhole 3 feet wide by 4 feet long is left in the center of scaffold to pass wood up through. On top of the scaffold, around each tuyère, is built a box 24 inches wide, 30 inches high, and 36 inches long, made of seven 2 by 2 inch strips. These boxes are filled with shavings. A wooden plug 5 feet long, 5 inches thick, and tapered down to 2½ inches is placed in the tapping hole and packed around with clay to form the tapping hole. Two feet of cinder is placed on bottom of the hearth and the hearth filled in with coke to the level of the cinder notch.

Fine wood is piled on the scaffold to about 6 inches above the top of the coolers; above this cordwood is piled three tiers high, standing the wood on end, and the manhole closed with heavy pieces of wood. The bottom underneath the scaffold is filled with fine wood. The cooler, small cooler, and "monkey" are placed in the cinder notch.

The furnace is filled with 30 skips of coke and no limestone, then 4 skips of coke and 2,500 pounds of limestone 10 times. Then about 20 per cent burden is used for about 10 charges, and the ore gradually increased about every 10 charges to full weight, although the full burden is never on the furnace before 12 to 14 days after lighting furnace.

When blowing in a very light wind is used until wood is burning good in the furnace. This is accomplished by running the engines very slow and with the snort valve wide open. In about three hours 13,000 cubic feet of air is on the furnace with the snort valve shut. The blast is increased about 700 cubic feet per hour to about 80 per cent of the full volume, depending on the size of the furnace. Our system is to light the furnaces about 4 to 5 p. m. and turn gas into main on the next morning.

PLANT 5.

After the furnace lining is dried out as well as possible a wood scaffold is built in the furnace about 2 feet 6 inches above the center line of the tuyère. This consists of a double thickness of 2 by 6 inch maple on four cross girders of 8 by 8 inch pine, resting on sixteen 8 by 8 inch pine posts 8 feet 3 inches long. In the center of the scaffold an opening about 2 feet square is left through which to pass wood. On top of the scaffold are piled 4-foot lengths of dry pine in three tiers, and on end, making 12 feet of wood above the scaffold. The hearth below the scaffold is then filled with dry kindling wood, with shavings around the tuyères.

The preliminary charging of the furnace is then done, as follows:

30,000 pounds of coke, 600 pounds of "spiegel" cupola slag.
15,000 pounds of coke, 600 pounds of stone.
800 pounds of "spiegel" cupola slag, 15,000 pounds of coke.
150 pounds of limestone, 500 pounds of "spiegel" cupola slag.
15,000 pounds of coke, 800 pounds of limestone.
700 pounds of "spiegel" cupola slag, 15,000 pounds of coke.
400 pounds of limestone, 400 pounds of "spiegel" cupola slag.
15,000 pounds of coke, 900 pounds of limestone.

The furnace now stands ready to light, with 4½ by 12 inch tuyères in place, blowpipes down, bell shut, bleeder valve open, and downcomer valve shut.

The shavings at the tuyères are now soaked with oil and the torch applied at all tuyères, care being taken to have the burning uniform all around. In two or three hours the scaffold inside will fall and bright coke will show at the tuyères. Soon after this the blowpipes are put up and the furnace fanned lightly by running one blowing engine slowly with the snort valve open, producing only a few ounces blast pressure on the furnace. After standing under this light draft for about 12 hours the snort valve is closed and the furnace takes all the blast from the engine, which at the start is about 3,300 cubic feet per minute, or 10 per cent of the full blast. With the other furnace in blast when blowing in, the initial blast temperature at the tuyères will be about 800° F.

When one furnace is already in blast all the gas from the furnace blowing in passes out of the bleeder until after the first cast, when the downcomer valve is opened, allowing the gas to enter the underground gas flue and mix with the gas from the other furnace. When one furnace remains out of blast the gas from the furnace blowing in is sent out of the bleeder until the wood gas is gone and rich coke gas appears at the bleeder. All gas outlets in the underground flue are closed except to the boiler at the extreme end of the flue. The downcomer valve is then opened and the gas is lighted under the farthest boiler. When this is burning safely gas is turned into the other boilers and then into the stoves.

The cold-air mixer valve is kept shut while blowing in. The bell is kept shut and no charging is done from the time the furnace is lighted to the time the snort valve is closed and the blast is put on the furnace.

Immediately after the blast is put on charging is resumed and the burden is gradually increased, full burden being reached about five days after the furnace is lighted. After the blast is put on the volume is increased about 600 cubic feet every two hours up to 9,200 cubic feet and then increased 300 cubic feet after each cast up to full blast.

It is aimed to bring the furnace in hot and limy. No. 1 furnace was blown in as per the above schedule and it was a successful "blow-in" in every way.

PLANT 6.

After cordwood is placed and coke and limestone are charged, the stock line is about 40 feet down. Both the large and the small bell are blocked open; the water-seal valves on each side of the dust catcher are closed and the dust-catcher bell valve left open; the blowing engine started turning over 14 revolutions per minute, bleeder and snort valve open, cold-blast, hot-blast, and mixer valves closed; cinder-notch cooler and intermediate cooler in place, with the monkey out; tuyères placed, blowpipes up, and caps off; the tapping hole is left open, and sheet iron covered with sand is placed over the iron runner from the tapping hole to the first spout. The furnace is lighted by inserting hot iron bars in all tuyères. From three to four hours after lighting, ore charging is started, and when the stock line is 20 feet down, the caps are placed on the penstock, the snort valve half closed, the mixer valve opened, and the dust-catcher bell valve is closed. As soon as the gas coming from the tapping hole will burn it is lighted and permitted to burn until the hole is closed. The bells are closed about 10 hours after lighting. When incandescent coke appears at all the tuyères the snort valve is closed, usually about 24 hours after lighting, and the speed of the engine is increased 1 revolution per hour until the engine is running at 21 revolutions per minute. One revolution per minute is equal to about 740 cubic feet of air.

From two to three hours after closing the snort valve the water-seal valves are opened and gas allowed to go to the stoves and boilers. The gas is first lighted at the stove and boiler farthest from the furnace. The bleeder is closed.

When cinder appears at the tapping hole the snort valve is opened and the hole is closed, usually about 40 hours after lighting. We try for cinder 50 to 52 hours after lighting and, depending upon the amount of cinder flushed, we time the first cast.

PLANT 7.

The scaffoid is built in the furnace in the usual way, and four tiers of cordwood placed on it. The preliminary charges of coke, limestone, and slag are put in, and the furnace is lighted with the tuyères in place and the blowpipes down. The wood is permitted to burn until the scaffold falls, when the blowpipes are put in place and the blast put on the furnace with the snort valve partly closed. Twelve hours after the scaffold has fallen the snort valve is closed and the blast is increased at regular periods. Before the furnace is lighted all bleeders are closed, with the exception of those on top of the furnace, which are left open, together with both bells. Steam is turned into the large dust catcher and kept on until the gas is led into the common gas main, which occurs when the blast pressure on the furnace is between 3 and 4 pounds. When the gas can be turned into the main system, the bleeders are closed on top and the water valve opened, and after the gas has entered the main the steam on the dust catcher is turned off. No charges are put into the furnace while the blowpipes are down.

PLANT 8.

The scaffold is built 18 inches above the tuyères, a 6-inch space being left between each two planks. Three tiers of 4-foot cordwood, placed on end, are then built upon the scaffold. After the cordwood is all in the furnace, small pieces of wood and a generous quantity of kindling are placed underneath the scaffold and the iron notches. After the wood is all in the furnace, the following blanks of coke, limestone, and furnace slag are charged:

Initial furnace charge.

Blanks of coke.	Coke.	Limestone.	Slag.
	Pounds.	*Pounds.*	*Pounds.*
12	100,800		
4	67,200	10,480	
4	33,600	5,240	4,800
4	33,600	5,240	9,600
	235,200	20,960	14,400

Before the furnace is lighted the goosenecks are keyed up tight. The tuyères are put in place and securely braced by wedging 2 by 4 inch timbers between them and the goosenecks. This precaution is observed in order to minimize the danger of hot coke being ejected in event of a gas explosion. Kerosene is injected at each tuyère opening and the cinder and iron notches. The furnace is then lighted by means of flambeau torches through each of these openings. Both bells and all bleeders on top of the furnace are opened before lighting.

About an hour after the furnace is lighted and the scaffold begins to fall, the first regular round of coke, stone, and ore is charged. Each successive charge of coke, stone, and ore follows at intervals of one hour until the stock is up to 20 feet.

As soon as red-hot coke appears at the tuyères, the openings are plugged with clay and a 3-inch opening left, and the furnace permitted to burn under natural draft for about 36 hours. Clay at the tuyères is partly removed from time to time to ascertain if the furnace is burning properly. Both bells and all the bleeders are left open between the charges of coke, stone, and ore. Whistle signals are blown from the cast house before a charge is lowered into the furnace to warn all workmen to stand clear. At the end of 36 hours or thereabouts the blowpipes are put up and the blast, at 600° F., is put on at the rate of 10,980 cubic feet per minute and increased at the rate of one revolution per hour until 28 is reached, then one every 24 hours up to 50. This volume is maintained for about two months. Gas is brought down to the stoves and boilers two to three hours after the blast is put on. Before the water seal is emptied the bells are opened. The seal is then emptied and the large bell is closed very carefully. When a series of dry-dust catchers is used our practice has been to inject steam into these cleaners, a vent being provided at the top of each before the gas is brought down.

PLANT 9.

After the furnace has been filled preparatory to lighting, which is to be done so as to handle the gas on the day shift, the water-seal valve is filled and allowed to overflow, then the goggle valves are opened and left open. The steam is then turned on before the furnace is lighted at the tuyères by means of red-hot rods put through the tuyère stocks and blowpipes (which are in place) and into oiled waste and shavings.

If the lining has not been thoroughly dried, or if for any reason it is desired to heat the brickwork very slowly, the furnace is allowed to start up on natural draft, if possible, by leaving the eyesight plugs out or the caps open, with the bells and furnace bleeders still open.

All openings from the top of the furnace to the water-seal valve are kept closed. If the furnace does not light on natural draft, a very light blast is put on by closing the openings in the stocks and closing the snort valve. After the furnace is lighted and a good volume of gas coming off, the bells are closed and the gas permitted to escape out of the furnace bleeders. (This applies to one furnace only, as the others are short of bleeder capacity, and on these the bells are left open until the gas is "pulled down.")

When the furnace has been on long enough to form a good coke gas, the water-seal valve is opened and the gas in the common main beyond, the pressure in which has been built up by closing the necessary burners, is forced up through the dust catchers and downcomers, driving the steam ahead of it. When a good flow of gas out of the furnace top has been established, the bells are closed and the furnace then operated as usual.

In case the gas produced by the furnace may affect the gas engines, the operation of "pulling down" is delayed until better gas is formed. In any case one or two of the furnace bleeders are left open for some time, so as to permit part of the furnace gases to escape.

PLANT 10.

We build a heavy scaffold with 2-inch plank floor 18 inches above the tuyères, a 2-inch space being left between floor planks; fill bottom to cinder notch with cordwood placed on end; put two tiers of cordwood on end on scaffold, fill from cinder notch to scaffold with kindling, with space in front of each tuyère for shavings; block the tuyère coolers until ready to light the furnace; and then fill the furnace.

Our furnaces are entirely separate, and stoves on one furnace can not be heated with gas from another furnace.

The furnace is filled to within 20 feet of the top. The distribution inside the furnace is examined.

All gas burners at stoves and boilers are racked back, and the whole gas-main system is shut up tight from the top of furnace to the ends of the mains, We have no water seal or spectacle valves at either furnace. We are particularly careful to prevent gas coming in contact with fire until we are ready. On stoves we seal burner door from the time furnace is lighted until we are ready to turn gas into the stoves. At No. 2 boiler house, blanks are put in the main; at No. 1 boiler house the mushroom valves are closed. In addition the openings in boiler fronts are bricked up, and sheet iron placed over end of burners.

All bleeders, explosion doors on top, and both bells are opened. Steam through 2-inch line is turned into dust catcher and allowed to fill the mains, dust catcher, and downcomer.

Oily shavings are put inside at each tuyère, the blowpipes are put up, the iron hole left open, the cinder notch closed, a very light blast put on, and the furnace lighted at each tuyère. After one hour the snort valve is closed, the cold-air valve of stove on furnace is opened one-half, with one engine running at the minimum number of revolutions, or blowing 13,000 cubic feet per minute.

We blow in with 5-inch tuyères on each furnace, increasing these gradually to 6 inches on No. 1 furnace, and to 7 inches on No. 2 furnace, when the full blast is on. Seven hours after lighting, by which time the wood gas is practically gone, we close the large bell and enough other openings on top to give 3 inches of water pressure in mains. We then open the doors in the ends of the mains and the pockets at gas legs, let gas and steam escape freely, care being taken to insure there is no chance of ignition, and also drain all the pockets at the gas legs. We then turn off steam and repeat above with gas alone.

We turn gas into the stove nearest furnace, being sure of 3 inches of gas pressure at this time, and then into the other two stoves. After this, as fast as the gas supply increases, we give it to the boilers. The iron hole is stopped with the blast on about five hours after lighting. In case we do not feel it necessary to examine distribution, we leave blowpipes down and fill only to within 35 feet of top. After lighting at tuyères, we let furnace burn with natural draft for 18 hours, if we can keep all tuyères burning evenly. In this case we pile three tiers of cordwood on and above the scaffold. At the end of 18 hours we bring gas down to stoves and boilers as described above. The volume of blast, burden, and other furnace data are shown below:

Data on blowing in furnace.

Hour.	Volume of blast, cubic feet per minute.	Engine speed, revolutions per minute.	Blast pressure, pounds per square inch.	Hour.	Volume of blast, cubic feet per minute.	Engine speed, revolutions per minute.	Blast pressure, pounds per square inch.
1	(a)	(a)	0	12		20	1
2	(b)	(b)	0	13		20	1
3	13,000	17	½	14		20	1
4		18	½	15		20	1
5		18	½	16		21	1½
6	15,200	20	½	17		21	1½
7		20	½	18		22	1½
8		20	½	19		22	2
9		20	½	20		23	2½
10		20	½	21		23	2½
11		20	½	22		24	3

a Snort valve open, cold-air valve slightly opened.
b Snort valve closed, cold-air valve half open.

On the last blow-in the first flush was obtained in 26½ hours, the second flush in 28 hours, and the first iron in 31 hours, 12½ tons of iron containing 3.68 per cent silicon and 0.021 per cent sulphur being obtained. Filling subsequent to that given in the table was as follows: Ten rounds (25 per cent Mesabi ore), with a burden ratio of ¾ to 1; seven rounds (50 per cent Mesabi ore) with a burden ratio of 1 to 1; seven rounds (50 per cent Mesabi ore) with a burden ratio of 1.25 to 1; seven rounds (50 per cent Mesabi ore) with a burden ratio of 1.30 to 1; the ratio was increased 5 per cent each seven rounds until a ratio of 1.75 to 1 was reached, which was 58 hours after lighting furnace with 25.000 cubic feet of air blowing and with 6-inch tuyères.

PLANT 11.

A wooden scaffold is built just above the tuyères and three tiers of wood placed on top of this scaffold, then the bottom of the furnace is filled with wood. We then start filling. When sufficient number of blanks of coke and first few charges of ore are in, we light the furnace (all blowpipes and tuyères being in place and tapping hole closed) by turning the blast on through a hot stove. Engine is kept turning over slowly, and the amount of blast regulated with the snort valve. During all this time the water seal is filled to keep the gases from the balance of the system from coming back and mixing with those of the furnace going on. The bleeders are kept open (both bells closed) until gas can be lighted on top of the bleeders (which requires 6 to 10 hours), then the gas from the furnace being blown in is turned into the system. During all this time a jet of steam is kept in the first dust catcher and gas main. Blowing in is done with tuyères and blowpipes in place, which eliminates any danger of men being burned when scaffold falls.

PLANT 12.

The furnace is filled as follows: First, fine kindling wood is laid on the bottom of the hearth to a depth of 3 or 4 feet. This wood is piled vertically, commencing against the walls at four equidistant points. When these piles are built out to within about 2 feet of each other the cross-shaped space between them is filled with kindling laid flat. One of the ends of this cross is directly in front of the tapping hole. On top of this kindling dry cordwood is piled on end to a height of 4 to 6 feet above the tuyères. No scaffold is built in the furnace. Coke and limestone are charged on top of the cordwood. The furnace is filled to the stock line. The last few charges contain a small and gradually increasing amount of ore, which in the last charge filled does not much exceed half the weight of coke. All dust-catcher and gas-washer bells and doors are closed, and the water seal connecting the furnace with the gas main is filled. No openings in the path of the gas from the top of the furnace are permitted. The bleeders or explosion doors on top of the furnace and both bells remain open, so as to give all the vent possible for gas at the top of the furnace after lighting.

The furnace is lighted at the tapping hole with a coal-oil torch made of waste wrapped around the end of a bar or by hot blast with no other ignition. Where hot blast is available its use for lighting is preferred. The air blown is delivered by one engine turning over as slowly as possible. The amount delivered to the furnace is at first a mere breath, the greater part going out the snort valve. The blast heat used at this time is not above 900° F. Coke will appear at the tuyères within two or three hours. after lighting. The amount of blast is gradually increased by closing the snort valve, so that it is entirely closed in about 15 to 18 hours after the furnace has been lighted, the volume of air being then about 9,000 cubic feet per minute. This amount is not increased until after the bells have been closed, which is done 24 to 28 hours after the furnace has been lighted. The bells are always closed on the afternoon of the day after the one on which the furnace was lighted. The practice of lighting the gas on top of the furnace before closing the bells by lighted waste carried up by the skip car is followed. This is an old practice, intended to see whether the gas will ignite. We have never known it to fail to do so, even when the bells were closed within a few hours after lighting the furnace, and it is questionable whether there is any benefit derived from the practice. The method of handling the gas depends upon whether other furnaces at the plant are in blast and making gas. If so, the gas from the other furnaces is under pressure at the water seal of the furnace blowing in. A 3-inch steam line is connected into the furnace for several minutes to exhaust the air from the dust catchers and large gas containers between the water seal and the top of furnace. The gas on top having been lighted in the meantime, the water seal is broken and the gas from the other furnace goes to the top of the one blowing in. The steam is shut off as soon as the water seal is broken. As soon as it is certain that the gas from the main is coming out of the furnace top the main bell is closed and the gas from the new furnace turned into the main, after which the bleeders are closed and charging commenced. No charging is done from the time the furnace is lighted until the bells are closed, and the furnace will usually be about 16 feet below stock line at this time.

If there are no other furnaces in blast at the time of blowing a furnace in, it is necessary to close the bells and fill the gas system connected to the furnace with gas forced downward from the top. In this case all openings along the gas main are closed, excepting a stove at either end and an outlet at the water seal. We have never blown in a furnace under these conditions since the use of steam was commenced at this plant. In order to derive any benefit from its use in the dust catchers of the furnace blowing in it is necessary to close the bell and force the gas downward immediately after breaking the water seal. This is always done with or without steam.

Our practice, then, after lighting the gas on top is to fill the dust catchers with steam, break the water seals, and close the bells as nearly simultaneously as possible, force the gas to all ends of the main, providing a relief to prevent dead ends. As soon as this is done the gas is lighted and burned at convenient points along the main.

PLANT 13.

A layer of coke, extending from the hearth bottom up to the bottom of the iron notch, is put in by hand through the cooler. Cordwood is then put in on end, bringing the layer up to the bottom of the tuyère cooler. A layer of fine kindling is then put in, extending from the bottom of the nose of the cooler to the top, and at each tuyère is placed a bag of shavings with a ball of oily waste right at the nose of the tuyère. Cordwood is then placed in the iron notch on the bottom and the notch plugged with clay. The monkey is plugged with cinder "bot." From 150,000 pounds of coke for a 60-foot furnace to 300,000 pounds for a 100-foot furnace is then filled on top of the wood by dumping it in from the top. A burden of slag, coke, and ore is then filled in, starting with an 0.5 to 1 burden and aiming at a 1 to 1 burden when furnace is full. The amount of slag used on a 60-foot furnace is 88,000 pounds and on a 100-foot furnace 24,000 pounds.

When the furnace is full a careful inspection is made of all valves, cleaning doors, and dust legs to see that all are in proper condition for manipulation. A barrel of oil is distributed in the tuyères, the bleeder is opened up, the explosion doors on top, if any, are opened, all other openings are closed, and if the furnace is connected by gas mains with other furnaces the water or dry valves are closed, isolating the furnace to be blown in.

The blowing engine is now turned on, with the snort valve adjusted to give 5,000 cubic feet for a 60-foot furnace and 11,000 cubic feet for a 100-foot furnace. The stove next the furnace, which has previously been heated up with wood or gas from another furnace, is now opened up, the hot-blast valve being opened first, and then the cold-blast valve. When the cold-blast valve is opened hot rods are put in through the face plates and into oily waste at the nose of each tuyère. When the tuyères show light the rods are pulled out and the tuyère caps closed. The gas is lit at the iron notch and let burn until the hole plugs itself.

After the first movement of the furnace burden, which takes place generally in about two hours, the volume of air is increased at about 800 cubic feet per hour on a 100-foot furnace and 300 cubic feet on a 60-foot furnace.

In about 5 hours the bleeders and explosion doors on top are closed. In about 45 minutes the cleaning door at the base of the leg to the stove farthest from furnace is opened slightly and the gas permitted to escape. At this time the cleaning door or other opening on the extreme end of the main to the boiler house is also opened and gas allowed to escape until there is a certainty that all air has been expelled from the mains.

The blast is then increased about 2,400 cubic feet for a 100-foot furnace and about 300 cubic feet for a 60-foot furnace, and the gas is racked into the boiler and stoves on the end of the line. The volume of air is now increased 800 cubic feet on a 100-foot and 300 cubic feet on a 60-foot furnace per hour until the first flush of cinder, or about 18 hours after blowing in, when it is adjusted according to the amount of cinder. The furnace is allowed to move 6 or 8 feet before filling, and in the meantime the remaining stoves and boilers are lighted.

If the furnace is connected by a gas main to other furnaces, the water or dry valve is now opened and the furnace is put on the line. In drilling for the first cast the tapping hole is started just above the 2-inch pipe in the iron notch, which generally burns out on first cast, giving a chance for a good stop on the iron notch after the cast is made.

PLANT 14.

After the brickwork and top is complete a gas fire is allowed to burn in the hearth for a period of about two weeks, which insures thorough drying of the furnace, after which time all foreign material is taken from the hearth. If the hearth is built on an old salamander, then asbestos pads, placed on 10 brick piers 10 inches high, are distributed equally over the bottom. On top of these pads are placed posts 9 feet long by 8 inches square.

On top of these posts is built a strong but loosely laid platform of 2¾-inch boarding. About 24,000 pounds of coke is then scattered on the hearth, bringing the filling up to the level of the cinder notch. A hole is then left in the scaffold floor and 4-foot lengths of coarse wood are laid loosely, so as to give plenty of air space. On top of the coarse wood on the scaffold a coke blank is filled in with the hoisting apparatus, as follows: Coke 120,000 pounds, limestone 1,800 pounds; coke, 72,000 pounds, limestone 1,800 pounds; coke 48,000 pounds, limestone 1,800 pounds; coke 48,000 pounds, limestone 1,800 pounds, making 288,000 pounds of coke and 7,200 pounds of limestone.

After all the coke blank is in, a short period is allowed to elapse in order to examine all the appliances.

In the meantime we have had an engine turning over slowly in the engine rooms. The blast is now up to the cold-blast valves on the stoves. If possible, gas has been turned into the stove mains on the previous day from another furnace, and after the gas is ignited by a wood fire in the wells of the stoves of the furnace to be blown in the heat on the stoves is raised as fast as consistent with good practice. The stove at the end of the gas line receives its gas first.

The furnace is now lighted through the tuyères, cinder notch, and tapping hole with the aid of long poking rods which have been dipped into a ladle of hot slag, care being taken to see that the furnace is lighted all the way round. Before lighting, the bells and bleeders are propped open. In about four or five minutes after lighting smoke will commence to appear at the furnace top; the fire in the furnace is allowed to burn with air it will draw in.

When we are certain that the furnace is burning nicely all around, the burden is started. Approximately 50 per cent Mesabi ore with a heavy ratio is used.

Burden used in filling a furnace to be blown in.

Number of rounds filled.	Ore.			Coke.	Stone.	Ratio of bases to acids.
	Mesabi.	Old range.	Siliceous.			
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	
10	6,720	1,920	960	12,000	3,950	1.29:1.00
10	7,290	2,100	1,020	12,000	4,140	
10	7,890	2,280	1,020	12,000	4,200	
5	8,460	2,460	1,080	12,000	4,380	
5	9,030	2,640	1,110	12,000	4,620	
5	9,630	2,820	1,170	12,000	4,800	
5	10,200	3,000	1,200	12,000	4,980	1.33:1.00.
5	10,890	3,810	1,290	12,000	5,220	
5	11,610	3,990	1,410	12,000	5,520	
5	12,300	4,500	1,500	12,000	5,700	
5	12,900	5,010	1,590	12,000	6,000	
5	13,000	710	5,490	12,000	6,240	
(a)	14,400	6,000	1,800	12,000	6,480	1.32:1.00

a Full burden.

The coke blank and approximately 20 rounds on the schedule fills the furnace up. After the furnace is filled it is allowed to stand until the scaffold has fallen.

In the meantime the tapping hole has been closed, and after the scaffold has fallen caps are put on the tuyère stocks and the cinder notch is closed. The furnace is now closed up and the stove blast valve is opened. The snort valve on the pipe from the engine room is also closed. The engines are now running at approximately 12,000 cubic feet per minute. Then the blast is raised every two hours approximately 500 cubic feet per minute until 30,000 cubic feet per minute is reached. At this point the furnace is generally held for some time. The heat from the stove during this period will be approximately 800° or 900° F. The stoves are changed in rotation, one every hour.

As a rule, the first cinder flush will occur after 50 rounds of burden, or in about 36 hours after lighting. The first cast is usually made after about 54 rounds of filling, or about 39 or 40 hours' time after lighting.

In the meantime, as soon as the gas burns on the top of the furnace, all bells are closed and the gas is allowed to discharge through the bleeder stack. After the first cast is made the pressure on the gage will possibly be about 8 or 9 pounds. This will give a sufficient gas pressure on top to equalize that in the mains, at which time, after all air is expelled from dust catcher, mains, etc., the water valves on both the stove and the boiler-house lines are opened and the bleeder on top of the furnace is closed. After a certain period the burden on the furnace is changed to the regular allotment used at these works.

PLANT 15.

The furnace is always dried out with hot blast for by using this method the stoves, tuyère stocks, and everything pertaining to regular operation has been operated and the furnace man is left free to pay all of his attention to the furnace itself because he knows that everything else will work properly.

The hearth of the furnace is either filled with loose, small wood up to about a foot above the tuyères or a platform is built up to the same height with loose wood underneath. On top of this about four rows of cordwood are placed, which will reach nearly to the mantle. Then a large coke blank is placed on top of the wood and on top of this blank the burden is started with about one-half pound of ore per pound of coke, and the ore content increased so that when the furnace is full the ratio will be about 1 pound of ore per pound of coke. I always find it is a good practice not to fill a furnace as full as it is filled during the regular operation. In front of each tuyère light shavings or oily waste is placed and when the furnace is ready to be blown in this waste is saturated with kerosene. A hot stove is put in the furnace, with a light blast, and hot poking rods are inserted into the eyesight holes. During all this time the bells are necessarily lowered, as well as the bleeders being open, the gas cut-off valve being always closed. The tuyères are watched and a short time after good incandescent coke shows at the tuyères and the gas on the top of furnace looks right, the gas from the other furnaces, provided there is more than one furnace, is sent through the gas cut-off valve, which may be a Crawford seal or any other type, and allowed to fill the dust catchers and downcomers of the furnace being blown in, and as soon as sufficient pressure shows on top of the furnace through the open bells the large bell is closed and the furnace is in blast. The downcomers, dust catchers, and all gas piping up to the cut-off valve are kept filled with steam so as to exclude the air.

PLANT 16.

The furnace is dried out thoroughly, either by hot blast, or, if this is not available, by a wood and coke fire built in the crucible. In the latter case, combustion may be promoted by bulkheading all cooler, cinder, and iron-notch openings and inserting draft pipes leading to the bottom of the crucible, thus bringing an induced draft direct to the fire.

A scaffold is built in the furnace above the tuyère coolers, and the crucible is filled with coke to the bottom of the tuyère coolers. Cordwood is loosely stacked on end, usually three lengths or more. Filling is then begun and carried to such point as judgment and experience indicate there will be a structure which admits of good natural draft.

The furnace is lighted with inflammable material at all tuyères and iron and cinder-notch openings. Precaution is taken to see that the bell is fastened open, as are also the bleeder valves on the downcomers. The furnace is allowed to burn on natural draft until the scaffold has fallen or burned and until coke is burning thoroughly at all tuyères, then the blow pipes are put up and the blast applied.

All gas mains, both overhead and underground, are filled with steam before gas is turned in, one or more boiler or stove gas-burner valves are opened at the ends of the mains, and in the case of underground flues a manhole cover of large area is removed to facilitate a rapid passage of all gases through the mains.

In turning gas into the mains all gas is allowed to escape from the top of the furnace and bleeders until it lights and burns with a clear and steady flame on contact with air. Precaution is taken to see that live steam is still entering the mains. At a given signal the main sealing bell and all bleeder valves and other openings are quickly closed, and as soon as gas has lighted at the extreme end burner valves, the valves on the intermediate burners are opened. Lighted oily waste or a wood fire is always built at the burners on cold stoves or boilers so that gas is burned from the first, thus forestalling any possibility of an explosion in stoves or fire boxes.

Where water-seal valves are available, they are always kept closed so that no gas can get into dust catchers or mains not in use. It is considered essential that the blast pressure shall not be considerably slackened or taken off the furnace during the first few hours after turning gas in mains, as a rapid circulation well-nigh precludes any possibility of an explosion.

PLANT 17.

In preparing a furnace for blowing in, first a scaffold is constructed across the furnace at a point about 1 foot above the tuyères. Coke is thrown in at the tuyères, covering the furnace bottom to the top of the iron hole. About 8 cords of wood is placed on end on top of the scaffold and fine wood is filled in below the scaffold, with a pile of shavings in front of each tuyère.

The last blowing-in burden was as follows:

Number of rounds.	Material.	Weight, pounds.	Number of rounds.	Material.	Weight, pounds.
5	Coke	5,700	12	Mesabi A	2,775
5	....do.	5,700		Mesabi B	925
	Blast-furnace slag	2,100		Old range	1,850
8	Coke	5,700		Siliceous	300
	Blast-furnace slag	1,400		Total ore	5,850
	Limestone	800		Limestone	1,900
6	Coke	5,700		Blast-furnace slag	1,400
	Blast-furnace slag	4,200		Coke	5,700
	Limestone	1,000	4 [a]	Ore	[b] 6,300
				Limestone	2,000
				Coke	5,700

[a] Furnace full. [b] Proportioned as above.

Both the explosion doors and the bleeder were fastened open and orders given to keep the charging bell closed until permission was given to start filling. A 3-inch opening was left to burn gas through iron hole. Alternate tuyères were plugged with clay, leaving five 6 by 12 inch tuyère openings, through each of which 6 gallons of torch oil was poured. The furnace was lighted with shavings partly burned in the hot-blast stove before blast was turned into it at 8.50 a. m. Data on the method of furnace operation follow:

Data on furnace operation at blowing in.

Time of day.	Time elapsed.	Volume of air per minute.	Blast temperature.	Number of charges.	General remarks.
a. m.	*Hours.*	*Cu. feet.*	*° F.*		
8.50	....	7,000	450	....	Lighted furnace.
9.20	$\frac{1}{2}$	....	....	....	Hot coke showing at tuyères.
p. m.					
12.50	4	....	....	....	Gas brought down.
2.10	$5\frac{1}{2}$	....	500	....	Plugged iron hole.
3.00	$6\frac{1}{6}$	8,400	....	....	Started to fill.
4.50	8	....	535	11	Stock line, 14 feet.
6.00	$9\frac{1}{6}$	9,800	550	12	Stove every hour.
6.50	10	10,500	585	14	
8.20	$11\frac{1}{2}$	11,900	625	16	
8.50	12	13,300	675	17	
9.30	$12\frac{2}{3}$	14,000	....	19	
10.00	$13\frac{1}{3}$	....	725	21	First cinder flush (A).
a. m.					
12.05	$15\frac{1}{4}$	....	775	25	Second cinder flush (B).
2.00	$17\frac{1}{6}$	....	800	29	Third cinder flush (C).
4.00	$19\frac{1}{6}$	....	850	33	Fourth cinder flush (D).
5.30	$20\frac{2}{3}$	12,200	....	37	First cast (E), 6 tons of iron.
10.10	$25\frac{1}{3}$	....	950	40	Second cast (F), 11 tons of iron.
12.00	$27\frac{1}{6}$	14,000	960	44	
p. m.					
1.00	$28\frac{1}{6}$	14,700	990	46	
2.00	$29\frac{1}{6}$	15,400	1,020	49	
3.20	$30\frac{1}{2}$	....	1,040	53	Third cast (G), 20 tons.

Composition of iron and cinder.

Sample.	Silica.	Alumina.	Iron oxide.	Lime.	Magnesia.	Manganese.	Sulphur.	Silicon.
Cinder:								
A	34.40	15.33	0.51	44.50	3.49	.13	1.84	....
B	34.43	15.78	.51	44.00	3.40	.13	1.75	....
C	35.07	15.42	.38	44.20	3.04	.10	1.79	....
D	35.03	15.68	.32	44.30	2.80	.10	1.77	....
Iron:								
E	....	....	....	....	....	....	.105	3.95
F	....	....	....	....	....	....	.039	4.37
G	....	....	....	....	....	....	.037	3.46

General data on furnace operation during first week of run.

Day.	Volume of air per minute.	Blast temperature.	Blast pressure (per square inch.)	Tuyères.		Ratio of ore to coke (coke=1).	Iron produced.		
				Number.	Size.		Tons.	Silicon content.	Sulphur content.
	Cu. feet.	*° F.*	*Pounds.*		*Inches.*			*Per cent.*	*Per cent.*
First	10,080	670	3.1	5	6 by 12	1.28	6	3.95	0.105
Second	15,190	840	5.8	5	6 by 12	1.51	98	4.30	.023
Third	20,475	940	10.5	5	6 by 12	1.90	208	2.44	.015
Fourth	22,120	980	11.8	7	6 by 12	1.94	330	.97	.071
Fifth	27,090	1,000	13.4	8	6 by 12	1.97	323	1.28	.032
Sixth	28,630	1,010	13.2	4	6 by 12	2.00	406	1.26	.028
Seventh	29,960	1,000	13.5	5 5 5	$6\frac{3}{4}$ by 9 6 by 12 $6\frac{3}{4}$ by 9	2.03	419	1.20	.028

Gas was permitted to escape through the explosion doors and bleeder until after wood had been consumed and furnace had heated up sufficiently and ore descended far enough to produce more nearly normal gas. Up to this time all openings on gas flues and dust catchers had been kept closed. It should be noted that one furnace was in operation and that its gas was sealed off by the Crawford water-seal gas valve. The stove gas burners are supplied through bootlegs. At the base of these pipes, and also on the bootlegs supporting the boiler gas flue, cleaning doors are provided for the removal of flue dust. These doors are now fastened slightly open, leaving about the equivalent of a 1-inch hole, all other valves remaining closed. One of the explosion doors is then slowly closed with a set of blocks until the gas starts to force air through the openings just provided. It may be necessary to partly close the second explosion door before the air is forced out, but in any case the explosion doors are closed slowly and only far enough to cause sufficient pressure to start the flow of air, where they remain until the gas has forced out all the air. The explosion doors are closed far enough to give appreciable pressure to the gas when a wood fire is started in the stoves and the burners carefully opened. After the gas is lighted in the stoves the bootleg openings are closed and the water in the Crawford valve is released, uniting the gas from the two furnaces. Gas is permitted to blow through the iron hole until cinder starts out, when the hole is plugged.

If one furnace had not been in operation it would have been necessary, in bringing the gas down, to force the air out of the gas flues in the boiler houses. The procedure would then be as described, except that the Crawford valve would contain no water, and would have its water connections and bell closed. All boiler gas burners would be closed, except one at the end of the underground flue, which would be pulled slightly beyond the closed position, permitting the air to be forced out in front of the burner. The cleaning doors would be opened the same as at the stoves. The same system would be used for either furnace, the idea being to keep all flues tight except small openings on every dead end.

PLANT 18.

First we build in the hearth a scaffold of about 6 by 8 inch timber, the top of which is above the tuyères. Uprights are placed between every other tuyère opening, the top of the scaffold being boarded loosely. The hearth is then filled with clean coke to the level of the cinder notch. Cordwood, or any heavy wood, such as split ties, slabs, etc., is then taken into the cinder notch and piled on end on top of the scaffold. Two tiers of such material, or sufficient to reach about the fifth row of plates, are then placed in the furnace, the men working from the outside to the center. The center opening of the scaffold is then bridged across and wood placed in position by building down from the top of the wood to the original scaffold at the tuyère level. Split kindling wood is then filled into the opening formed between the coke in the hearth and the scaffold. Two bags of shavings are put in front of each tuyère. When the hearth is finally filled in in this manner the cinder-notch coolers and "monkey" are placed in position, and the furnace is filled as follows:

Burden used in blowing in furnace.

Material charged.	Pounds.
Ten rounds:	
4 buckets coke (3,800 pounds each)	13, 200
1 bucket limestone	2, 800
Eight rounds:	
4 buckets coke	13, 200
1 bucket limestone	3, 000
1 bucket blast-furnace slag	4, 000

Material charged.	Pounds.
Four rounds:	
4 buckets coke	13,200
1 bucket limestone	4,200
Old range	6,000
Mesabi	6,000
Blast-furnace slag	2,000
Until filled (24 rounds):	
4 buckets coke (3,800 pounds each)	13,200
1 bucket limestone	5,700
Old range	6,000
Mesabi A	10,000
Mesabi B	6,000
Blast-furnace slag	1,000

After the furnace is filled, care is taken that no fire or sparks can come in contact with the hearth. In case we are building on a hot salamander, we may put several feet of sand on the bottom and place the wooden scaffold uprights on brick piers to protect them from the heat. We generally aim to turn on the cooling water before the furnace is filled so that the men can inspect the plates and coolers and determine if any are leaking before the furnace is finally lighted. The mushroom valves on the dust catcher, as well as the water seals, are closed; all doors on gas mains are closed and sealed, the bleeder and two explosion doors opened. The furnace is now in position to be lit. The stoves are fired up three or four days beforehand by means of gas, coal, and wood. The stove nearest the furnace is filled with a wood fire and allowed to burn, so as to form a large body of embers. About 2 bucketfuls of carbon oil is injected in each tuyère, thus saturating the shavings, and the caps are then closed. The main bell and the small bell are also closed. While these preparations are being made, the engines have been started and are running at about 25 or 30 revolutions with the snort valve open. When the bells have been closed and everything around the bottom of the furnace made tight, the stove is then closed, the hot-blast valves and cold-blast valves are opened, and the blast turned into the furnace in the usual manner. Sparks are carried over from the stove and ignite the oil-saturated shavings, and in a few seconds gas is issuing from the bleeder and explosion doors. The tapping hole is left open and the gas issuing from it is ignited, as well as all gas which is leaking around the tuyères and plates. After the furnace is well ignited, the speed of the blowing engine is reduced to about 22 revolutions, and from this point is gradually increased as furnace conditions demand; in about 15 or 20 minutes coke appears at the tuyères and the furnace starts to take stock. If there is no reason for taking the gas off a furnace, the gas may be permitted to escape at the bleeder until the first flush of cinder is taken out, which is possibly 12 hours after lighting. Then the gas valves between the other furnaces and the one just blown in are opened, allowing the gas to mix. In case anything should happen to require a stop on the newly blown-in furnace, gas from the other furnaces is allowed to go over so as to maintain a constant gas pressure under the bell and in the mains. It is always our aim to keep a constant outward pressure at all points, the mains generally leaking slightly. After blowing air through the tapping hole for four or five hours, the gun is placed in position and the hole stopped up. After an hour or so from the time of blowing in, the explosion doors are closed and the bleeder is allowed to carry all the gas. This depends altogether, however, on the quantity of gas produced, care always being taken that we have sufficient pressure to keep the mains full. When the gas is taken to the boilers, it is drawn to the end of the line and into the farthest boiler, where it is allowed to ignite, and the boilers are put on in rotation from this end. This cleans out the main completely and does not allow any trap there.

METHOD IN USE AT ANOTHER PLANT.

One method not mentioned previously is as follows: When everything is ready for lighting the furnace, close the bells, bleeder, and mains, open a burner at the extreme end of the main into a boiler setting in which a hot fire is kept burning. The furnace is then lighted with the wind on and the top and mains full of air. No wood is used in the furnace, charcoal being placed at the tuyères. This method has been followed for several years by one operator, the gas lighting quickly at the burner within 10 minutes. But one explosion has resulted and this was due to the bell opening by accident as the gas was being taken down. This illustrates a possible hazard from this method; that is, some part of the machinery going wrong at the early stage of blowing.

PRECAUTIONS IN BLOWING IN.

The chief danger in blowing in furnaces is the danger of gas explosions. Other possible sources of danger and damage exist and are discussed in this report, but as in blowing out many details of practice must vary with circumstances and plant layout and only the general operations are noted here. The most important points to be watched in blowing in are as follows:

1. Drying the furnace is preferably done by hot blast when gas from another furnace is available. This enables the furnace man to assure himself that stoves, valves, stocks, and other equipment are in working condition and eliminates some chances for accident due to the unforeseen necessity of taking the blast off and allows him to devote his attention to the working of the furnace.

2. In case the hearth bottom, or the top of the salamander, is excessively hot it is advisable to place a 12-inch brick pier with asbestos padding on top beneath the scaffold uprights and to place about 20 inches of crushed slag on the hearth bottom before putting wood or coke in the hearth. It is also a good plan to turn the water into the tuyères coolers, etc., before the furnace is filled to see that all connections are water-tight and not stopped; the bronze should be inspected for leaks from the inside.

3. In placing wood or charcoal in the hearth and bosh, the use of electric lights should be compulsory, accident being invited by the use of candles, torches, or open lights, or by allowing men to smoke. All men not required for the work should be kept away, such as visitors and spectators.

4. Before lighting the furnace the foreman in charge should, by personal inspection, assure himself that all gas burners are sealed;

burner doors closed; openings on mains, dust catchers, and downcomers tightly closed; the bells, bleeders, and explosion doors on top fastened open; and the water seal or other valves in good condition, special attention being given to see that all mechanical valves are tight and the water connections open, and that the burners are tight; if necessary, some clay or dust should be put on the burner slides to act as a seal.

5. If the blast is put on immediately when the furnace is lit, the chances of men being burned by coke or flame shooting from the tuyères when the scaffold falls or from a "crack" of gas at the top are eliminated. If the furnace should be lit and allowed to burn on natural draft for a period of 6 to 36 hours, the following precautions are suggested:

(*a*) If the blowpipes are up and the caps off or the eyesights open, the foreman should be sure that the hot-blast valves are securely seated so that no draft will be induced into the blast main.

(*b*) If the blowpipes are not up, but the tuyères are placed, the tuyères should be blocked in place with a 2 by 4 inch timber against the stock, the latter being held by the bridle.

(*c*) The foreman should keep everyone away from the tuyères and stocks until he is satisfied that the scaffold has fallen, and should not start to put up blowpipes until this has happened. In drafting in, the scaffold will usually fall in three to five hours if care is taken that the furnace is nicely lit all the way around and it burns evenly at all the tuyères.

6. The method of handling gas depends upon whether other furnaces at the plant are in blast and are making gas, but if it be assumed that no other furnace is in blast the following notes are typical of safe practice:

(*a*) The gas pressure should be kept up at all cost after the gas has been brought down into the mains, 3 inches of water pressure being regarded as the minimum. Accidental lowering of the bell or bells so as to leave the top open after the gas is brought down should be guarded against.

(*b*) The foreman should be sure the gas is all right, clear of wood smoke and gas, before bringing it down. The first hour after lighting produces the most explosive gas, so time should be allowed for the ore to get into action before the gas is used. The time of taking the gas down varies much, ranging from immediately to 36 hours after the blast is on. A safe rule to follow is to wait eight hours after the scaffold has fallen, and then, after the furnace is filled and the coke is bright at the tuyères and the blast pressure amounts to 4 pounds, proceed to bring the gas down. This period of time will assure the smooth working of the bell and there will be less chance of some unforeseen difficulty preventing the bells from closing or opening. There is certain to be ample gas pressure in the mains, and the gas, though very explosive when mixed with air, is not markedly more so than later.

(*c*) The essential idea is to clear all mains, dust-catcher systems, etc., of air, being positive that none is trapped in any space or dead end before the gas is lighted, the aim being to constantly keep a positive outward pressure. To this end it is requisite that the blast shall not be taken off the furnace during the first few hours after turning the gas into the mains, or, if the blast is considerably slackened, that enough burners be closed to maintain 3 inches of water pressure in the gas mains.

(*d*) After personal inspection to see that all burners and burner doors are shut, the valve, if any, between the stoves and dust catchers is opened, and the bells closed if still open, at as nearly the same time as possible. The bell will usually have been shut previously, however. Before the gas is brought over into the main, the air should be expelled from the dust catcher through the dust bell and bleeder, if a bleeder is provided on the dust catcher. After making sure there is no fire near the gas mains and that the burner doors are shut, then the bleeder at the extreme end of the gas main, or the cleaning door at the base of the down leg to the stove or boiler farthest from the furnace should be opened. When sufficient time has elapsed to make sure that all the air has escaped from the mains the cleaning door may be shut, the burner door opened, and the gas lighted in the stove. Unless the stove is incandescent at the bottom, a large bunch of oily waste or a wood fire at the gas inlet should be used to insure instantaneous lighting. It is dangerous to permit gas of this nature to pass into a stove without lighting it immediately, as, if the well fills with an explosive mixture of gas and air, an explosion or a "crack" of sufficient violence to throw many types of burners off their seats may result. Such damage is especially serious and fraught with danger at this stage of blowing in, because a shutdown may be necessitated, and more serious explosions are possible.

(*e*) Similar methods are followed at the boilers, the exception being that instead of allowing the gas to escape into the boiler house when no bleeder is provided at the end of the line, it is preferable to have the boiler at the end of the line cold, and draft the boiler-house main through this boiler until the gas is coming strong, when it may be lighted at an adjacent boiler.

(*f*) In lighting stoves and boilers, the danger, after successful lighting of the first one, lies in putting too many on. It is better to have too few lighted than too many; the gas pressure should be maintained at at least 3 inches. In lighting gas from a furnace newly blown in, additional supervision, both at boilers and stoves, is advisable, and this step should never be undertaken without the supervision of the furnace foreman or blower.

(*g*) In case a shutdown becomes necessary on an isolated furnace, it is better not to draft back. Shut all the burners and keep the bells and bleeders closed before taking the blast off. This insures a positive pressure under the bell and avoids an updraft through the bleeder, and if the pressure is too strong at the tuyères a few caps can be knocked off to afford relief. When a furnace is started up after a stop of this nature it is best, in lighting the gas, to observe all precautions taken in first bringing the gas down.

(*h*) If a steam line is connected to the dust-catcher system, the system should be filled with steam prior to shutting down, and the steam kept on until the blast is put on again. Steam is a valuable auxiliary in blowing in, and if a connection is provided steam should be turned into the dust catchers shortly before the furnace is lit, and kept on until the gas has been brought down and is passing out of the mains through the bleeder.

7. If one or more furnaces are in blast, connecting them with the gas mains of the furnace being blown in simplifies taking the gas down, as one is always assured of ample gas pressure in the mains.

(*a*) If gas from another furnace is available, the gas is usually being burned in the stoves of the new furnace at the time it is being blown in. If not it is a simple matter to bring the gas up to the valve separating the dust catcher from the main of the new furnace, clearing the downlegs of the stove burners of this furnace. At the determined time, which may be earlier than with an isolated furnace but not before the scaffold has fallen, with bright coke showing at the tuyères and the snort valves shut, the stoves along the line should be closed temporarily to be sure that the gas pressure in the mains is greater than that at the top of the furnace being blown in, the dust-catcher valve opened, and, the furnace bleeder and bells being open, the gas from the other furnace is permitted to pass through the dust catcher and up the downtake, driving the air out through the furnace top.

(*b*) When the air is displaced, the bells and bleeder may be shut and the stove and boilers put on, care being taken to clear all dead ends in the gas mains, and observe the usual precautions with regard to lighting gas.

(*c*) If there is a steam connection to the dust-catcher system, it may be turned on prior to admitting gas from the other furnace; indeed, it is the safest practice to keep steam in the dust catcher from the time the furnace is lit until gas has been brought over from the adjoining furnace.

(*d*) The old practice of keeping a coke fire burning on top has much to recommend it and may be adapted to modern closed-top furnaces by putting a large bunch of burning waste on the skip, hoisting and dumping it into the hopper, the bells being open. Upon the gas lighting, the bells may be closed and gas led off from the bleeder. This takes more time and trouble than many consider necessary, but it is a practice which is followed by several men and warmly believed in.

(*e*) In case of an accidental shutdown, gas may be brought over from the other operation to the furnace being blown in, and the air having been displaced, the bells and bleeders can be closed prior to shutting down or taking the blast off. This insures a positive pressure at the furnace top under the bell and in the gas-main system.

BLOWING OUT.

CAUSES OF EXPLOSIONS IN BLOWING OUT.

One hazard in blowing out lies in letting the top of the stock column get too low with too high a blast pressure, so that air containing oxygen channels through the coke and forms an explosive mixture with the carbon monoxide and hydrogen of the gas in the furnace stack. The writer personally does not know of any explosion that has been caused in this way, although the possibility of such an explosion is frequently spoken of by furnace men. The enforced use of water, sprayed in at the top of the furnace, keeps the temperature down as the stock descends, and generates a large volume of steam which should tend to prevent such explosions. This dampening effect is, however, counteracted by the decomposition of water by the incandescent carbon in the charge, forming a large amount of hydrogen, which, with the excessive amount of carbon monoxide, makes a very explosive gas.

The composition of a typical "blowing-out" gas, as analyzed by the plant chemist, is as follows:

Results of sampling blowing-out gas.

Hour.	Temperature at down-comer.	Proportion in gas.					
		CO_2.	O_2.	H_2.	CO.	CH_4.	N_2.
	°*F.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1st	320	12.30	....	2.60	26.73	0.17	58.20
2d	365	9.40	....	2.58	30.58	.12	57.32
3d	585	7.80	....	4.60	31.20	.40	56.00
4th	560	6.90	....	2.46	31.20	.20	58.84
5th	550	4.30	0.10	2.68	30.48	.72	61.72
6th	535	3.30	....	3.62	32.82	.18	60.08
7th	600	3.50	....	5.28	31.82	.18	59.22
8th	615	2.80	....	4.98	32.58	.22	59.42
9th	575	2.70	....	5.60	32.26	.14	59.30
10th	660	4.10	0.10	6.22	29.96	.04	59.50
11th	670	4.90	....	7.94	28.74	.06	59.36
12th	720	3.20	....	7.96	31.60	.00	57.24
13th	550	4.30	....	6.80	29.34	.06	59.50

The temperatures of blast-furnace gases, from observations by the writer, are unusually low, and it is to be mentioned that temperatures taken at the furnace top were from 100° to 415° F. higher than those observed at the downcomer.

The composition of another "blowing-out" gas, as determined by the plant chemist, was as follows:

Composition of gas from furnace being blown out.

[Furnace blow-out started at 10 a. m.; analysis started at 3 p. m. and continued hourly.]

CO_2.	H_2.	CO.	N_2.
Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
5.1	5.1	28.8	61.0
5.5	5.5	34.5	57.5
3.4	3.4	33.6	59.07
3.2	3.2	33.8	59.4
2.6	2.6	33.3	59.4
3.1	3.1	32.5	59.7
5.9	5.9	29.7	59.0

DANGER FROM ACCUMULATIONS OF WATER.

In one instance a gas sample taken by accident just as a furnace made a slip in blowing out contained 20 per cent hydrogen. This points out a second danger in blowing out, that if the stock wedges and hangs, and water is continuously sprayed in, the hanging part may become excessively saturated with water, possibly a pool collecting on top of the stock. When the slip occurs, this water is precipitated into the incandescent coke and walls beneath, and the generation of steam and water gas may result in an explosion. In one case, where two rings of the furnace shell were split in a "blowing-out" explosion, the evidence indicates that this had occurred.

In addition to this danger is the one encountered when the large bell hopper on top fills with water and the bell is dropped or opened at the end of blowing the furnace out. Two instances of this kind are known to have occurred within the past few years. In one of these the bell and hopper were sealed with flue dust and the bell to keep it cool was being sprayed. It was supposed that the seal was insufficient to retain water on the bell, but the unexpected happened. The hopper became full of water, and when the bell was lowered at the end of the last cast, the water dropped into the furnace, in which the red-hot stock was at a little below the mantle and the walls presumably were red-hot. The resulting explosion blew the bell and hopper out of the top and wrecked the top rigging. Several explosion doors on the gas offtakes did not, apparently, relieve the pressure. In the other case the hopper was filled with water by design, in order to keep the bell and hopper from warping, and it was opened by mistake with a less serious explosion.

ACCIDENT FROM DRAFTING GAS FROM DOWNCOMER.

The final danger lies at the end of blowing out, when an attempt is sometimes made to draft gas out of the downcomer and dust catchers. The following description is typical of the manner in which such accidents occur:

After the cast was made the furnace was drafted back until all blowpipes were dropped, when the engines were stopped. Eight tuyères had been pulled and men were working on the ninth when a violent explosion of gas took place in the dust catcher and downcomer, which forced a sheet of flame and red-hot coke out of each tuyère opening. The condition of the gas-main system was: Bleeder on top of the furnace open, little bell open, large bell closed, bleeder on the dust catcher open, and bleeder at the end of the gas line open. The explosion took place between 15 and 20 minutes after the blast was taken off the furnace. Inasmuch as the downcomer, dust catcher, and mains were full of gas, the draft induced by the open bleeder on top caused air to be drawn in at the dust-catcher and gas-line bleeders. Whatever air entered through the dust-catcher bleeder was intimately mixed with the current of gas moving into the dust catcher by virtue of the open bleeder at the end of the gas main. From the high top temperature obtained in blowing out, the brickwork in the top of the furnace was at better than a bright-red temperature, and thus ignited and exploded the intimate mixture of gas and air. From the point of view of plant damage, the most destructive effect of the explosion was in the bleeder, downcomer, and dust catcher. The ejection of hot coke and flame at the tuyère caused the death or severe injury of several men.

This explosion was directly caused by opening the dust-catcher bleeder. Had only the bleeder at the end of the main been opened, the effect of the draft would have been to exhaust all the combustible gas from the system, as the gas, being followed by air from the end bleeder, would not have had as great a chance for mixing with the air. It would probably have been still better not to draft out the mains until the furnace had partly cooled at the top.

METHODS OF BLOWING OUT PRACTICED AT THE 18 PLANTS.

The methods of blowing out followed at the 18 plants for which the proceduce in blowing in has been described (see pp. 130 to 146) are summarized in the following:

PLANT 1.

We use water through the test holes, watching the temperature of the gases, and as the temperature rises we increase the water, and after about six hours' time we drop from one to two revolutions per hour, according to our gas temperature. It takes about 20 to 24 hours to get all the material out above the tuyères. As soon as we find that all the material has been consumed, before taking off the blast we close the main gas valve and open the bleeder. The bells are allowed to remain closed, and also the relief valve on the bustle pipe and the caps on the tuyères. The furnace is allowed to stand for several hours with water on the test holes, but when water is being put on the large bell to keep it cool care is taken that it does not accumulate, and it should be examined before opening the large bell, as a large amount of water being thrown into the furnace is liable to cause an explosion. Care should also be taken that the large bell is kept open before any work, such as taking down the tuyères or blow pipes, is attempted.

PLANT 2.

We see that we have a sure supply of water for blowing down and good pumps for same. The further preparation is to place ¾-inch water pipe in each try hole at the top and a 1-inch pipe in the receiving hopper. The bells are kept so as to not close tight, but to allow the water put on the bells to pass through. No stock is kept on the bells while blowing down.

While blowing out the furnace is checked every hour and the blast is reduced as the stock goes down. About 15 hours is needed to complete the work. The water is started to pump into the top about 1 to 1½ hours after we stop charging, and this is generally at a time when we can finish the "blow-out" in a day's time. In order to keep the top gas from getting too hot we put a regular charge of stock into the furnace every 2 to 2½ hours until about 4 hours of the furnace being out. We keep watch of the top heat, and if the temperature goes up to 700° to 800° F. we add water by the use of the skip, half a skip at a time. The pumps are so arranged that at casting time we can stop and open the valve, thus permitting all water to run out of the pipes three to five minutes before we take the blast off to close the iron hole. The gas while blowing out is used as much possible and the balance goes to waste. When the furnace is down close to the tuyères, which can be told by its appearance, the valve which cuts off the gas from the other furnace is closed. The water pump into the furnace is taken off and the bells, bleeders, and explosion doors opened before the blast is taken off. Dust catchers and gas mains are kept closed.

As soon as the blast is off we take down a couple of blowpipes, pull the tuyères, and pull coke to get a couple of good holes through the stock to burn all gas produced in the stock in the bottom. As soon as this is done, we take down all blowpipes, warn all men away from the blast furnace, and start the pump to drown out the furnace, all the openings in the top of the furnace being kept open. After 12 or 15 hours of pumping the furnace is in condition to dismantle.

PLANT 3.

A 2-inch water line is run to the top of the furnace with four connections to regulating valves on same and all controlled by a master valve at the bottom of the furnace, and three spray pipes are put into the gaging holes, one in each hole, with the holes in the pipes turned toward the center of the furnace.

In the big bell we place about 10,000 pounds of good coarse ore around the apex. The bell is clamped closed and all valves or dust catchers left in running position.

After the top is put in condition, as stated above, the blast is turned on and a small amount of water is sent through all four connections. As blowing out proceeds, the volume of air is reduced as conditions warrant and the quantity of water increased, so that the gas temperature approximates 900° C. or less. When the stock gages about the top of the bosh, the bleeders and explosion doors are opened, and shortly after that the valve at the dust catcher is closed, and all gas led out of the top of the furnace.

The furnace is now cast and blown as dry as possible, leaving about 3 feet of stock about the tuyères, the blast taken off, and the gas drafted back through the stoves, all explosion doors and bleeders on top of the furnace opened, and a full head of water turned in on top; and the furnace is let stand for 12 hours. Then the blowpipes are removed and the tuyères pulled, what little stock is left in the furnace is raked out, the furnace now being cold, and the big bell is lowered.

As a general proposition our big bells leak enough to permit all the water from the circle pipe at the apex of the bell to run into the furnace. If such is not the case, the bell is opened and closed against two pieces of ¼-inch round or square steel supported from the gas-sealing hood doors, so as to permit the water to run into the furnace, but this is a rare condition.

When the blast is taken off the furnace for casting, the water is shut off at the top until the blast is again put on.

PLANT 4.

Our procedure is as follows: Start about 10 a. m. Take 12 per cent of the weight off the furnace; take one-half the lime content off the burden every second charge for eight times. At 2 p. m. let the furnace work down slowly to about 32 feet; put in one charge about every half hour to keep the top cool. At 3 p. m. reduce the blast about 14 to 17 per cent. When furnace is down to about 32 feet, put in 20 skips of coke, then put 2,000 pounds Mesabi ore on the big bell. At the next cast hold the blast off the furnace to get spray on the small bell. The spray on the small bell is 1-inch pipe bent in a circle about 2 feet in diameter; the holes in the pipe are three-eighths inch in diameter and are 3 inches apart. Also put in two spray pipes, one on each side of furnace, in test holes; these sprays are made of 1-inch pipe, 11 feet long, one end of the pipe being plugged. The holes in these sprays are one-eighth inch in diameter and about 1 inch apart, and there are three rows of holes extending up 5 feet from the bottom end of the pipe. These sprays are connected by a 1-inch hose to a manifold placed on top between No. 1 and No. 2 stoves. There is a 2-inch pipe leading from a 150-pound pressure line to the manifold. This manifold has connection for spray on bleeder stack or for other sprays, if needed.

As soon as water is turned on, the bleeder is opened wide, and the 1¼-inch valve on the connecting sprays is opened two full turns of the wheels after the blast is turned on the furnace. The water is turned off in the sprays about three minutes before the blast is taken off at cast time; the furnace is then gaged with a long wire with a weight on to see how far down the stock is in the furnace.

After the blast is on the furnace the water is turned on in the sprays. When the stock is down about 2 feet below the mantle the last cast is taken from the furnace, the blowpipes taken down, and the tuyères plugged with clay; then the gas valves are closed, the large bell opened wide, and the bleeder is left open. The sprays are then taken off and a full head of water is turned on the furnace. The tuyères and coolers are left in the furnace until the gas has died out and water is running out of the tuyères and coolers. The tuyères and coolers are then removed.

PLANT 5.

After the last charge the stock is covered with about 10 tons of coke dust, and 1½-inch water pipes are placed in the four try holes in the top of the furnace to keep the top heat down. This water runs steadily up to 24 hours after the furnace is out. The bell is kept shut and is covered with wet ore to help keep it cool. The bleeder is kept shut until the top temperature gets high, when the bleeder is easily opened.

After the stock is covered with coke dust the wind is gradually cut by slacking the engines one revolution, or about 300 cubic feet every 20 minutes, down to half blast, which is reached in five or six hours. One engine alone then maintains this half blast until the furnace is out. It would be safer to keep two engines on, but they could not run slowly enough to deliver the small amount of air necessary.

Just before the last cast, when the stock level is at about the level of the tuyères, the iron runner is removed. The last cast is then taken out through a hole in the hearth jacket, 18 inches below the iron notch, for the purpose of reducing the size of the remaining salamander. After the last cast, and while the blast is still on the furnace, the bell is opened and is left open, and the downcomer valve is shut. The wind is now taken off the furnace, the blowpipes taken down, and the remaining blowing engine stopped. The door in the downcomer, just over the downcomer valve, and the valve in the bottom of the dust catcher are now opened, and any remaining gas passes up and out of the top of the furnace.

After blowing out, the furnace and stoves are roped off for at least 24 hours, to keep the men out of danger of possible explosion.

A furnace was blown out according to the above schedule. The gas was quiet; there were no puffs nor any explosions whatever. The stock level was blown to below the tuyères and a salamander about 8 inches thick was all that remained.

PLANT 6.

Perforated water pipes, 1-inch, placed in two of the test holes on opposite sides of the furnace, with valves controlling the flow at the bottom of furnace. The furnace is tested with a rod at intervals to make sure that the stock is descending regularly. When the top temperature reaches 900° to 1,000° F. water is turned on and allowed to spray into the top.

The air blown per minute is reduced as the stock descending and the condition of gas on top necessitates. When the stock level is in the neighborhood of the mantle, the water-seal valves on each side of the main dust catcher are closed and the bleeder opened. When the stock is level with the tuyères the last cast is made, and when the snort valve is opened, both bells are opened and the water shut off.

One man is sent around the furnace to loosen the caps on the penstocks and no one else goes near the furnace. After everyone is away from the furnace a large volume of water is turned in and the furnace is allowed to stand under these conditions for at least 18 hours.

PLANT 7.

The stock level is lowered and about a carload of boiler-house ashes put in. Chains or cables are hung from the lugs of the large bell hopper to keep the bell open, making it impossible for a large amount of water to collect on the bell. Perforated pipes are run down the try holes to wet the stock and keep the top cool. A pressure gage is put in the main water-feed line to insure against the stoppage of a sufficient flow of water. The blast is reduced as the top temperature rises, and it is the aim to keep this temperature below 800° F. When the gas gets in such a condition that it does not burn freely in the stoves, or trouble is experienced in the gas-engine room, the water seal between the furnace and the overhead main is filled and immediately steam is put into the dust catcher between the furnace and the water seal. All bleeders are closed with the exception of those on top of the furnace, and the gas is thereby driven up through the top of the furnace. After the furnace is cast, and before the blast is taken off, both bells are lowered. The blast is then taken off and the blowpipes are taken down one at a time by one gang of men, in order to minimize the danger. The furnace is then roped off for a period of 48 hours.

PLANT 8.

Water is introduced by means of spray pipes through the try holes as soon as possible after charging has stopped. The sprays are made from ¾-inch pipe with staggered holes punched over an area of about 10 feet of its length with the ends of the pipes closed. The sprays are connected with a high-pressure system, thus insuring adequate water at all times.

After the stock has settled to about 20 feet the blast is taken out and about 30 tons of coke dust thoroughly saturated with water is charged into the furnace with enough limestone to flux the ash. During the time the coke dust is being charged, no water is allowed to enter the top of the furnaces until the blast is again turned on. The furnace is gaged every hour or oftener, although if the contrary is found to be the case the blast is reduced and the furnace is slipped in the usual manner. The blast pressure is gradually lowered to meet existing conditions. Practically full blast is maintained during the "blow-out." As soon as the furnace shows signs of getting wild, the volume of blast is reduced.

The amount of water is increased to keep the top temperature as low as possible, and at no time is it allowed to get above 1,000° F. The gas is regulated at the stoves to meet conditions. The water seal is filled immediately after the final cast is finished and the tapping hole is left open. Before the blast is taken off, both bells and bleeders are opened. The blowpipes are taken down and the tuyères withdrawn right after the blast is taken off. The water is turned off at the top while this is being done. As soon as the tuyères are all removed, water is put at the tuyère arches and again turned on top of the furnace through try holes. The water is left on until the stock is thoroughly cooled.

As soon as the blowpipes are disconnected from the bustle pipe, engines are shut down.

PLANT 9.

When the blowing out of a furnace is not extemporaneous, it is planned to start operations at such a time as to allow their completion on an afternoon of a day turn. Plenty of time is taken to make each operation completely and carefully. The ore burden is decreased for 12 hours previous, depending upon the heat margin on which the furnace has been working.

The limestone burden is decreased 12 to 24 hours previous to putting in the last charge, 300 to 500 pounds, depending upon the size of the charge and the general working conditions of the furnace. In the case of a thin-lined furnace, the temperature in the water buckets would be allowed to increase to near the boiling point, but not to it. All steam lines to the dust catchers, etc., are thoroughly tried out previous to starting, to make sure that there will be a maximum flow of steam provided when required.

The last two or three charges are made up of ore alone, and for several previous to this about one-half of the limestone is taken off, or the stone is left off entirely for two or three charges. Shortly after the last filling has been put in, four 1¼-inch pipes about 10 feet long are inserted into the top of the furnace through the try-rod holes, the blast being taken off meanwhile. These pipes are drilled with ⅛-inch holes, and the holes pointed toward the center of the furnace. A gage is put in the water line at the bottom of the furnace so that an idea may be obtained from the pressures as to the relative amount of water being used. While these pipes are being put in the receiving hopper, all of the filling apparatus is examined to make sure that there is not an undue amount of material accumulated which may wash down later onto the large bell and seal the small opening between the bell and hopper, which will be made at this time by inserting ½-inch or ¾-inch flat bars between them and closing the bell.

Blowing down is then continued and the top heats kept under 800° F. by means of water through the spray pipes, and small amounts of water at short intervals, if necessary, through the opening between the bell and hopper, the water being conveyed to this point by means of the skip cars. The volume of blast is reduced meanwhile as the pressure falls off and is lowered if necessary to assist in reducing the top temperature. Only enough heat is supplied to the blast to keep the furnace from working cold. Two or three hours before blowing down is completed it is made sure that the dust catchers are all empty.

Steam is turned on for three or four hours before the blast is taken off, and when the quality and quantity of the gas is such as to affect any of the operating points materially the water-seal valves are filled and the mixture of gas and steam blown out through the furnace bleeders. After these valves have been filled, everything between them and the top of the furnace is kept closed.

When it is apparent that blowing down is practically complete (as shown by coke just above the tuyères) the blast is reduced slowly, and finally some of the air is permitted to escape through the snort valve. Then the bells are closed, after which the blast is taken off and the hot and cold blast valves closed.

One man is then assigned to open the caps on the tuyère stocks, after which the engines are shut down. All passageways to the cast house are then closed and kept closed until the morning of the second day following (about 36 hours), when the blowpipes are dropped and a few men put to raking out the coke, no other laborers being permitted around the furnace.

A noticeable quantity of steam will be kept coming out of the furnace top until enough coke has been raked out at the bottom to allow free burning of any gases formed. After this has been assured other labor will be permitted around the furnace.

PLANT 10.

When preparing to blow out, we lighten burden to a 1 to 1 ratio, and take off 25 per cent of the limestone during the last 10 rounds. Before the last four rounds are filled, we charge two rounds of coke only, and end by charging in the same way. We then shut down and put 1-inch spray pipes in the test-rod holes and around big bell. The spray pipes in test-rod holes are drilled with two rows of holes to direct the water toward the center of the furnace and keep it off the walls.

The blast is continued at the normal number of revolutions until top heat becomes 800° F., and then blow enough less air to keep the top heat at not over 800° F., with water going through spray pipes at a pressure of 75 to 100 pounds. Enough gas is wasted at bleeders to keep the gas pressure less than 8 inches of water. All air is cut off around the gas burner on the stove and less air than is needed to burn the gas is admitted through the blow-off doors, to keep the stoves from melting in the bottom.

We blow down to a point about halfway between the tuyères and mantle. After making the last cast, we drill in as low as we can in the iron hole to drain as well as possible.

As soon as the last cast is made, the blast is taken off the furnace, the blowpipes taken down, bleeders left open, all doors on gas main kept closed, and burners at stoves and boilers racked back tight. The water spraying is continued on top until it begins to show up on tuyères. Then the tuyères and cinder notch are pulled and the furnace raked out through the tuyères and cinder notch. The gas mains from the furnace top to the ends are kept closed until all material is out below the tuyère level and the furnace is fairly cool.

PLANT 11.

When ready to blow down, we have perforated water pipes in try holes. We aim to clean out coke pockets, and use the small coke with converter cinder to blow down on, or in other words this is the last material charged. All flue dust is drawn out of the dust catcher and all valves closed as tightly as possible. As the stock in the furnace keeps going down, we turn water (through the perforated pipes) into the top of the furnace and keep increasing the volume as the top temperature rises. When furnace gets below the reach of the test rod, a cable with a weight is used to find out how far down the stock is. This is done every hour. We analyze the gas when blowing a furnace down and when it is found that the gas is not usable, the furnace is cut off from the other gas systems by the water seal and its gas blows out of the bleeders. Steam is turned into the dust catcher and gas main at this time. When the stock is down nearly to the tuyères, the tapping hole is opened, the iron taken out, and the hole left open so all cinder possible may drain out. The blast is then taken off the furnace and both bells opened. After the blast has been off for one hour, the caps of three or four blowpipes are pulled back and water hose put into these blowpipes in order to drown the furnace. After three or four hours, the blowpipes and tuyères are removed, one at a time.

PLANT 12.

Before blowing out is commenced the furnace is shut down and sealed off, while the main bell is opened and four ¼-inch bent rods are introduced through doors on the seal and placed so as to hold the bell open ¾ inch when it is closed again. The hoppers above the bell are thoroughly cleaned out and two sprays made of 1-inch pipe bent nearly to a circle, and perforated so as to spray inward and downward, are placed so that one sprays upon the small bell and one upon the main bell. The last charge before shutting down generally carries some extra coke, more or less depending upon the condition of the furnace. Nothing is charged after the sprays are placed and no material is carried on either bell during the blowing out. The blast is slackened shortly after the charging is discontinued. The rate of blowing out is shown below:

Time after charging stopped, hours.	Volume of air, cubic feet per minute.
None (blast at usual rate)	40,500
1	30,000
3	26,250
6	18,750
7	16,875
8	16,500
14½	Blast off.

Enough water is used to keep the top of the furnace below 800° F., and the blast is reduced at any time when necessary to do this. The furnace is checked once an hour to make sure that it is moving. The gas from the furnace becomes wet; it goes into the gas main, however, until the blowout is completed. The bleeders on top of the furnace are often opened at the latter end of a blowout in order to reduce the amount of wet gas going into the main. The furnace is gaged by hand by means of a weight on a long wire clothesline. It has been our practice to blow partly down the bosh but not to attempt to blow completely down to the tuyères, partly because of the possibility of blowing uncombined air into the gas main and partly because a little pressure in the furnace enables some iron to be blown out on the last cast and the level of the salamander lowered.

After the last cast is completed, the engine is slackened to the minimum rate and allowed to turn over against the snort valve; the water seal is closed.

PLANT 13.

The furnace is stopped and spray pipes put on all pipe work on top, where the brick is gone. Pipes are run down try-rod holes, two if possible, one being left open for gaging the furnace. A circular spray is put around the apex of the bell with the bell shut. Blast is put on the furnace and the water regulated according to supply needed to keep the exposed plate work wet and have bell spray going strong. One-inch pipe is used in the try hole, or 2-inch if possible. The engine speed is regulated to keep the top heat below 1,000° F. and the furnace is gaged every 30 to 45 minutes until about 70 feet is reached. Casting and flushing are continued, with an effort to have the furnace about empty when through with the last cast.

If the furnace does not move regularly, it is checked, and if serious hanging takes place, say for four hours, the blast is checked, but as a rule any "scabs" come off as the furnace empties. The last cast is made when the furnace is judged to be about empty, and the iron notch is kept open until the stock gets down to the level of the tuyères. The blast is taken off and stoves and boiler-house burners closed. The bleeders are left open and the bell is left closed for at least six hours.

The gas is drawn back through the stove, the blowpipes are taken down, four coolers taken out, and the stock raked out. Water is left running into the try-rod holes and onto the bell for about six hours, then shut off. The furnace is then considered blown out.

PLANT 14.

Water connections are made on top to give about six ½-inch lines running about three-fourths full. We have never estimated the amount of water exactly, but use sufficient to keep the gas and top cooled down. If the furnace has been working irregularly and given signs of a scaffold, the coke blank on the last period of filling may be 300,000 pounds, but if we are not uneasy about the furnace, this may be reduced to 200,000 pounds. All water valves, etc., on the lines are examined to see that they are in good condition.

After the coke blank is put in, the large bell is propped open about three-fourths of an inch. The small bell is kept closed and the bleeder stack is opened. The six water sprayers are now passed into the gas seal and rodding hole. The blast, in the meantime, has been taken off the furnace.

The blast is then put back on the furnace and water permitted to run through the six ½-inch pipes into the furnace. Men are on the stoves during this time watching the top closely. The volume of air is now reduced to approximately 60 per cent of the original amount and is gradually reduced every two hours.

After approximately 20 hours' time the blast will be down to about 10,000 cubic feet per minute, and we can as a rule see across from tuyêre to tuyêre. In the meantime, when the furnace is beginning to get this low, the tapping hole is opened and the last cinder and iron allowed to run out. The water on the top is then shut off. After as much of the cinder and iron is removed as possible the snort valve on the blast line is opened and the stove valve closed.

The engine is allowed to turn over slowly for some time after this before the tuyêres are taken down. After 30 or 40 minutes three of the tuyêres at a time are opened at different points around the furnace and plugged, water pipes are placed in on the coke and water is allowed to flow through them. This has the effect of forcing a little more cinder and iron out through the tapping hole.

This may be kept up for two or three hours until no more material can be drained from the hearth, after which time all blowpipes are taken down and the tuyêres pulled and the furnace allowed to stand until thoroughly cool inside.

PLANT 15.

Our practice in blowing a furnace out is to place ¾-inch pipe in at least two of the try-rod holes. The bottoms of these pipes are perforated so as to throw the water in the form of a spray underneath the bell, and this has a tendency to keep the top of the furnace cooler than any of the other methods we have tried. There is also a small spray pipe on the top of the bell. A little coarse ore is spread around the seat of the bell and hopper. During the last hour or two that the furnace is being blown out the water seal is closed and the blowing out finished through the bleeders. At least one-half hour before taking the blast off and during the time that the furnace is putting out her last cast we always close the valve on the water line and break the union so as to disconnect the pipe entirely from the furnace; this to make sure that no water is going into the furnace, which would be liable to generate hydrogen gas. After the blast is taken off, one blowpipe is dropped at a time and each tuyêre plugged immediately with clay, so that the furnace can not draft any air through the bottom and continue making gas. As soon as all the blowpipes are down and the tuyêres plugged the large bell is lowered, and the furnace is then drowned with water. It has always been our practice before taking the blast off to fill the dust catcher and gas main from the water seal to the furnace with steam and we have not had any trouble as regards having any "kicks" from gas explosions.

We always start to blow a furnace out about 9 p. m., so that the night shift can get along without any supervision, and the furnace can be finished in the daytime under the direct supervision of the superintendent. This, we think, is a better plan, as it is a good deal easier to do the work in the daytime than at night.

PLANT 16.

When possible, filling is always stopped at such times as will permit the furnace being blown out during daylight. No change in burden or addition of coke is made in the last filling. All gas is directed into mains in the usual manner until the gas becomes wild, owing to the addition of water for cooling the top. Excess gas is taken care of through bleeder valves. The blast is reduced as the stock line falls. When low pressure, coke, cinder, time elapsed, etc., indicate that little stock remains in the furnace, the gas valves leading from the dust catchers into the gas mains are closed and the gas from the furnace being blown out is allowed to escape from the bleeders until the process is completed.

The furnace top is kept cool by water sprays, and the main sealing bell is kept closed or only slightly open in case it is considered essential for saving the edge of the bell projecting below the sealing point on the hopper. A hole is usually drilled in the apex of the bell and a pressure spray pipe inserted for additional cooling of the bell from inside. No water other than from this pipe, or from the external cooling of the bell and top, is permitted to go into the furnace. Special precautions should be taken to see that there is no accumulation of water on the furnace top, as the precipitation of any considerable quantity into the incandescent crucible or bosh will cause an explosion which may be disastrous.

The iron notch is usually left open after the last cast so that the remaining cinder may run out as it is melted down during the last stages of blowing out. Our usual practice is to blow the furnace down to within a close distance to the tuyères.

PLANT 17.

As soon as the regular filling is discontinued, we charge into the furnace about 15,000 pounds of wet flue dust and dump onto the charging bell about 2,000 pounds of sand or other semifine material that will not bake but will partly close any large openings between the bell and the hopper. Then we take the blast off the furnace long enough to block the bell shut, put a spray pipe around the apex of the bell, and spray pipes about 16 feet long down each of the four gage holes. The amount of water sprayed on the bell is adjusted to keep the bell nearly covered with water. The quantity of water on the gage-hole spray pipes is regulated to keep the gas temperature less than 1,000° F. The amount of air blown is usually reduced about 15 per cent as the furnace is blown down. The furnace is cast every three hours and checked whenever the appearance of gas and other indications show that the top of the stock is blown down to the neighborhood of the tuyères, and the furnace is cast as dry as possible. During this cast the water level in the dust catchers on the furnace being blown out is raised from the regular operating level, which is carried 30 inches below the downtake, to 72 inches above the downtake, which seals off the gas and confines it to the furnace and downcomers with no opportunity for the ingress of air. All peep sights around the furnace are wired shut. After the gas has been cut off in the above manner, the snort valve is fastened open, the cold-blast and hot-blast valves closed, and a blowing engine kept turning over for 12 hours, when the blowpipes are taken down and the dismantling begun. During this 12-hour period the bleeder and explosion doors remain open, no opportunity is given for the admission of air around the lower part of the furnace, and water is constantly sprayed through the gage holes.

Our experience and the attitude observed in others, leads us to believe that many of the obscure precautions in handling blast-furnace gas are apt to be neglected as not essential. It strikes us as pertinent to mention an incident which occurred during our last blow-out. About three hours after casting, after blowing out, a mammoth scab dropped a distance of 30 feet, dislodged several water blocks, and punched a hole in the bosh.

PLANT 18.

The water seal valve separating the furnace from the general gas main or from the other furnaces is closed. Four spray pipes are put down through the rodding holes on the top of the furnace. A rodding device also is reserved in one of the holes in order to determine the movement of the furnace. The little bell is propped open and a spray pipe placed across the top of the gas seal. Coarse ore, gravel, or limestone is placed on the bell. After this preparation the bleeder is opened, the blast put on the furnace, and a little water allowed to flow through the pipes. After the stock goes down the gas will become pretty wild, but this is overcome by allowing more water to enter and by reducing the volume of the blast. The furnace is rodded and checked every half hour. Care is exercised at all times to keep a strong outward pressure on the gas. Three or four hours after the water is allowed to enter the top the stoves are taken off entirely and the gas is taken to the boilers, one boiler after another being taken off until only the last battery remains at the end of the blowing-out period. The furnace is generally blown down until such time as pressure can not be maintained on the furnace, and also, very often, water is noticed dripping down in front of the tuyères. The tapping hole is then opened and the furnace drained, after which the blast is taken off, the main bell lowered, explosion doors opened, blowpipes dropped, the water turned fully on at the top; also water is introduced through four or five tuyères by means of hose and ¾-inch pipe, which is pushed into the hearth of the furnace. Water is then allowed to flow until the furnace is cooled down sufficiently to scrape the material out.

OTHER METHODS OF BLOWING OUT.

Two methods of blowing out not brought out in the foregoing are:

1. The furnace is charged with 20,000 to 30,000 pounds of limestone before blowing down is started, or limestone is charged in 300 to 5,000 pound lots at intervals during the blowing down, as the top temperature becomes high. Not only does this keep the temperature at the top considerably lower, but the calcining of the limestone furnishes a certain amount of carbon dioxide, thus diluting the gases and making them less explosive. This is an old method infrequently used at present.

2. The furnace is not blown down at all, but when the furnace is to be blown out the furnace is cast as usual, the blowpipes dropped, and the gas mains drafted out. Then by means of a number of spray pipes or hose water is introduced at the top and the furnace is drowned. The contents of the furnace are then raked out through the tuyère arches, thrown into cars, and dumped in the stockyard, to be recharged in small amounts when the furnace is again in blast.

The method is of course safe, and is claimed to be not unduly expensive. It is laborious, however, and finds a negligible following at present, only two establishments following this method as far as is known.

PRECAUTIONS IN BLOWING OUT.

The essential features of the foregoing descriptions, showing the steps taken and the reasons therefor, are summarized below. No attempt is made to specify procedure or rules, as innumerable points must of necessity be taken care of as they arise and according to the plant layout and furnace design.

1. Before starting to blow down put a water spray on the large bell and three spray pipes through the try holes. The holes in these pipes should be below the lip of the large bell, and be so drilled that the water is sprayed toward the center of the furnace. The spray cools the gas and prevents it from heating the top excessively, warping the bells and hopper, or damaging the offtakes and downcomers; the steam generated also tends to prevent gas explosions.

2. Examine the receiving hopper and the large bell hopper to make sure that not enough material has collected to wash down and seal the opening between the large bell and its hopper. It is inadvisable to seal the bell and hopper with flue dust, ore, or sand when water is used on the bell, as the water may accumulate in quantity on the bell and be dropped into the furnace. It is better to provide an opening between the bell and hopper by hanging rods, cables, or chains from the gas-seal doors between the large bell and hopper extension, and then to close the bell against them. This prevents the accumulation of water, provided the bells and hoppers are cleaned before starting to blow down.

3. The bell should be locked, blocked, or clamped in position after these distance pieces are placed, in order to prevent its being opened by mistake. Also block or fasten shut the dust-catcher bells, bleeders, etc., to prevent any possibility of gas drafting up through the downcomer in case the blast is taken off unexpectedly.

4. Provide a water-pressure gage on the supply line to the top sprays, at the cast-house floor level, so that an idea may be had of the adequacy of the pressure and supply of water. It is also a good idea to provide a water-escape valve on a tee at the same place, so that the line may be drained at casting, or when it is essential to stop the water going into the furnace. Such a valve removes any uncertainty as to the positive cut-off of the valve controlling the water supply. A water meter is used on the spray-supply line at a few plants, and is an excellent idea.

5. Keep the top temperature at about 800° F. This temperature has been shown to require approximately the correct amount of

water to prevent the gas from becoming wild, provided the blast is reduced rationally, and at the same time prevents water accumulating on top of the stock where it may cause an explosion in case of a heavy slip or fall.

6. When the blast is taken off for any purpose, or when it is necessary to check the furnace, the water should be shut off 5 to 15 minutes before this is done, and the relief valve at the bottom of the water-supply line opened to insure that no water is going in.

7. It is safest to keep both engines on the furnace in reducing the blast as long as they can be kept on without danger of stalling. When it becomes impossible to run two engines slowly enough and one engine alone can be kept on the furnace, it is advisable to keep the idle engine in readiness in case of any accident to the one in operation.

8. When the gas becomes too poor or too wet to burn, or the gas engines start to backfire, close the valves between the dust-catcher system and the gas mains. If sand or mechanical valves are used, it may be advisable to take the blast off at the next to the last cast and close them at this time rather than wait until the last moment, inasmuch as many types of these valves require considerable work, which must be done in proximity to gas, to get them closed. If no valves are provided, close the stove and boiler burners, unless the bleeder capacity is inadequate. Many furnace men make a practice of using the gas through the stoves until the furnace is down, but there seems to be no especial advantage in this. There is little heat value in the gas and the time of closing the valves is postponed until the last moment, when as a rule there are many other important details to be attended to.

9. See that all water connections at sprays, valves, and other equipment are in working condition, not plugged with dust, and that all dust bells, bleeders, and doors are secured in position before starting to blow down. About half an hour before the gas is shut off, the dust catcher should be emptied, as red-hot material may have blown or been thrown over into it from the furnace slipping, and if permitted to remain there may cause an explosion.

10. The furnace should be rodded every half hour by a trustworthy and experienced man and should not be allowed to hang longer than half an hour, and an excessive amount of water should not be put in the top while the furnace is hanging. If the furnace has shown evidences of being scaffolded, it is a good plan to insert shorter tuyères a few hours before blowing down, or to lighten the burden, reduce the proportion of limestone, or charge a coke blank. Little is gained by rapid blowing out. The stock descends more regularly and less difficulty is encountered with wild and excessively

hot gas if the engine speed is slackened 20 per cent at the start and the number of revolutions lowered progressively while blowing down.

11. Charging a carload of coarse coke dust on top of the burden aids in keeping the temperature of the gas down, as this interposes a blanket of permeable material which becomes thoroughly saturated with water from the top sprays.

12. Blowing out should be started so as to bring the last cast in on the morning of the day following.

13. When the stock line is at the top of the mantle or about 2 feet below it the furnace should be cast. Blowing down to the tuyères is hazardous, because unburned air may be blown into the space above the stock and form an explosive mixture, and is unwarranted because the hearth will not, as a rule, drain well, and the top of the salamander will be higher when there is little pressure in the furnace on account of there being no stock above the tuyères.

14. Be sure that no water is going into the top sprays at the last cast; that no bells, bleeders, burners, explosion doors, or manhole doors are open on the gas-main system below the furnace top when the last cast is made. Examine the bell to insure that there is no water on the big bell to be thrown into the furnace when the bell is lowered.

15. After the last cast is made open the snort valve, close the cold-blast and hot-blast valves and open the chimney valve. The mixer valve should have been shut at the beginning of the cast. Fasten the mixer valve shut and the snort valve open. One man, under the direction of the foreman, should then knock the caps off the tuyère stocks. When this is done and the men are out of the cast house turn the sprays on full to drown the furnace, and open the large and small bells.

16. If the furnace is blown out for reasons other than relining, and preservation of the lining is essential, it is sometimes advisable to keep the caps on, thus eliminating any chance of a draft up through the furnace, causing a hot gas flame and heating of the lining.

17. The blowing engines should be kept turning over until the blowpipes are dropped. These should not be dropped until 18 to 24 hours after the furnace has been taken off, and every one should be kept out of the cast house during this period, as a scab may fall and break the bosh or throw hot material or flame through the tuyères. The gas should be drafted out of the dust catcher before work is undertaken about the bosh openings or on top.

18. Do not attempt to draft out the dust catcher and downcomer until the furnace top is cooled off. This may be four to six hours after casting, provided that the sprays have been turned on at the top in the meantime to drown the burning coke and cool the furnace walls. Sometimes in blowing out the pyrometer may indicate a

temperature of 600° or 700° F. in the downcomer or dust catcher; when the offtakes and interior of the furnace may be red hot and time must be allowed for the furnace to cool before the gas is drafted up through.

19. In drafting out, open only the door or bell farthest from the furnace top in the usual line of travel of the gas. Sprays should be kept on full at the top while this is being done.

20. If the gas-main system is equipped with a steam connection, steam should be turned into the system from the moment one stops using the gas until the gas-main system is full of air after the blowing out is complete.

EXPLOSIONS IN COLD-BLAST MAINS.

There have been few blast-main explosions during the past few years. Such explosions are very rare, but, as the possibility of their happening is always present, mention is given them. When these explosions do occur they are of a most violent character, usually extending back into the manifolds and blowing tubs at the engines. As descriptive of what may occur the following incidents may be taken as typical:

TYPICAL EXAMPLES.

At one plant the practice was followed of taking the blast off the furnace entirely at casting time, when the tapping hole was closed, the hot-blast valve also being closed to prevent gas from working back into the stove from the furnace. The furnace cast at the regular time, and as the tapping hole was closed, the blower signaled the engine room to start, and the stove tender opened the hot-blast valve. No air was turned into the furnace, however, and the blower ran to the blowing room, which was close to the furnace, to see what was the trouble. Before arriving he found that the work of adjusting a part on the blowing tub was unexpectedly prolonged, and he at once ordered the hot-blast valve shut. Upon entering the blowing room he smelled gas and as soon as possible gave orders to the stove tender to open the chimney valve on the stove to draw the gas undoubtedly present in the cold-blast main out into the stove chimney. He then returned to the blowing room, but had hardly entered it when an explosion occurred. The windows were shattered and doors blown off their hinges. The three-eighths inch steel plate of the cold-blast main was split and the air valves and top of the blowing engine blown off. Three men were killed. This explosion was caused by opening the hot-blast valves before the engine started, thus making it possible for gas to draft back from the tuyère through the stove and into the cold-blast main to the air tub. The gaseous mixture probably ignited in the hot stove and burned back through the main to the engine room where it exploded.

A similar explosion occurred at a plant still using pipe stoves. At a furnace stop to change tuyères the usual practice was to stop the engine and open a relief valve on the hot-blast main. For some cause the relief valve did not open, nor was the hot-blast valve closed at the stove. Gas worked back into the cold-blast main, and after the tuyère was replaced and at the instant the engine was started there was an explosion in the cold-blast main, which split or bulged it at several places and blew the manifold off the air tub.

Two other explosions have been noted at plants having modern equipment. In each case there was lack of definite knowledge as to the circumstances surrounding the explosion. In one of these the men in the blowing room were killed. It is thought that a heavy slip may have stalled the blowing engines through gas surging back in the hot-blast main and stoves or may have even started them turning backward, as the pressure chart showed that the pressure suddenly increased and then fell rapidly.

In the second case it is stated that the blowing engines were running slowly—at about 15 revolutions per minute—when the explosion occurred. On account of the apparent impossibility of gas working back in the main with a somewhat vigorous volume of air going countercurrent to it, this statement of the condition of affairs has often been viewed with incredulity. It is useless to speculate about it, but an incident which occurred at another plant may throw some light on it.

The blast was on full and the furnace had been running regularly for two hours after casting. The stoves were of small capacity, were being forced very hard, and the temperatures at the chimney stack were excessively high. The cold blast entered the stove at the chimney stack. Soon after a fresh stove had been taken off gas and put on blast the cold-blast main was discovered to be red-hot. The night foreman shut the blast off, slowed the engines down till they were only turning over with the snort valve open, and ran to the office and called up the superintendent, who ordered him to put the engines up to full speed immediately. By the time this was done the cold-blast main was at a bright red heat nearly to the engine room. By running the engines at full speed the danger of an explosion was averted. There was no oil drain on the cold-blast line, and it was found that oil had been blown over into the base of the stoves, where the mixture evidently had ignited and the flame had traveled back in the cold-blast main. With a current of air, after the blast was taken off, the oil lying in the main naturally burned vigorously, and it was possible that an explosion in the oil separator near the engines might have resulted. The high velocity of the air current, when the engines were run at full speed, blew the fire out.

Fires in the cold-blast main caused by the furnace slipping and gas surging back through the mixing valve are not uncommon, but the writer does not know of any having resulted in an explosion.

Another explosion occurred at a plant where the by-pass led from the end of the cold-blast main at the back of the stoves to the hot-blast main between the furnace and adjacent stove. The stove tender forgot to close the by-pass mixer valve at casting time, and as the butterfly valve in the cold-blast main closed tightly gas from the furnace evidently drifted back into the cold-blast main, where it exploded with a sharp detonation, not doing much damage, however.

PREVENTIVE MEASURES.

To prevent explosions or fires in the cold-blast main there are three elementary precautions:

(1) Always close the mixer valve at the first check on the furnace; (2) provide oil drains at the blowing rooms, and in close proximity to the stove, on the cold-blast line, and then (3) at a stop of any description always keep the engine turning over with the snort valve open until the blowpipes are dropped.

Other precautions that may be taken, in addition to those given above, are as follows:

Provide a steam connection with the cold-blast line near the engine manifold, which may be turned on from the floor in case a fire develops in the cold-blast main, and if the engines are accidentally suddenly stopped close the air valves at the engine at once.

In case of accidentally "loosing the blast" on the furnace close the hot-blast valve and immediately open the chimney valve of the stove on the furnace. Drop the blowpipes, drafting back through another stove.

Install an automatic check valve in the mixer or by-pass line between the hot and cold blast mains.

Provide a check valve at the junction of the cold-blast main with the air-tub manifold, or, if the blowing engine is of the type which will turn over backwards from excess blast pressure, install an automatic stop or check device to prevent this.

CHECK VALVES.

Check valves should be of the type that gives external indications as to whether it is working properly or sticking. All check valves, with two exceptions, in which the valve is operated by an actuating piston and cylinder, are capable of being freely opened by the pressure of the entering blast, so that when the cold blast is by-passed to the hot-blast main by opening the mixer value the check valve remains open. When the blast is cut off from the by-pass line the valve automatically closes of its own weight. In addition, if air and gas surge back in the by-pass or mixer pipe, the valve is thrown against its seat.

Check valves are of two general types, a completely inclosed swivel clack valve with a horizontal turning joint and a valve which with the blast on, closes a vent to the atmosphere, but with the blast off or at any predetermined pressure, such as 4 pounds, closes against back travel of gas and opens the by-pass main to the atmosphere. The difficulty with some valves of this latter type is that they may not close automatically against a back surge of gas when a heavy slip occurs at 10 to 12 pounds blast pressure; that is, when the furnace is being checked.

OTHER AUTOMATIC VALVES.

There are a few additional appliances in use for preventing a back surge of gas reaching the cold-blast main; chief among them are the Schutte-McHugh valve for the hot-blast main and the Dyblie-Larimer appliance for hot-blast valves.

The Schutte-McHugh valve is used to prevent back-flow of gases from the furnace to the hot-blast stoves and cold-blast mains. It consists of a valve casing, located in the hot-blast main, with a water-cooled valve seat placed at an oblique angle from the vertical, in the direction from which the blast travels. The valve is also water cooled, the pipe extending out through the valve stem. One end of the stem is provided with a counterweight lever; on the other end is a lever connected to a piston, the piston-cylinder being fastened to the valve casing. This cylinder is connected by a pipe to the cold-blast main on the engine side of the snort valve. With the blast on the furnace, the pressure transmitted to the cylinder keeps the valve from being actuated by fluctuations in the pressure of the blast. When for any reason the blast is reduced as at checking or casting, the valve will gradually approach the seat, and when the blast is entirely off the furnace, the valve will rest on the seat; when it is in this position a back flow of gas from the furnace through the hot-blast main can not pass it and enter the stoves and cold-blast main.

When the gas must be drawn back into the stoves for repairs to the furnace, the valve may be held open by a cable attached to the counterweight arm. If when the furnace is being checked it is desired to have the valve free to act independent of the actuating cylinder and close instantly, a two-way valve may be used which cuts off the cylinder from the cold-blast connection and opens it to the air.

This valve has received some adverse criticism by furnace men, but it is working satisfactorily at some furnaces.

The Dyblie-Larimer valve automatically opens and closes the hot-blast valve as the blast is shut off or turned on, thus preventing gas from passing from the furnace through the stove to the cold-blast pipe at casting time or checking. This valve consists of a cylinder and piston, with a cable from the piston rod to the hot-blast valve stem, and a special piston valve connecting the cold-blast pipe on the stove side of the cold-blast valve to the top of this cylinder. When air is admitted to the stove it raises the valve; then the air pressure on top of the piston lifts the hot-blast valve. The hot-blast valve is heavier than its counterweight, so that when the blast is taken off it closes, the pressure in the actuating cylinder being automatically released by the special valve. When the stove is taken off the furnace a pull on the release trigger of the special valve allows the air in the cylinder to escape, causing the hot-blast valve to descend to closed position, where it can not be raised until the blast is on again. One merit of this safety device is that it should keep in working order because of its being used on routine operations at least twice every four hours.

VALVES IN TUYÈRE STOCKS.

Another provision, sometimes found at old plants, is the placing of valves in each tuyère stock or gooseneck.

As mixer valves are sometimes neglected and not closed, and because a shutdown may be a matter of seconds, a check valve in the mixer pipe is necessary. The utilization of other automatic valves must be at the discretion of the furnace superintendent. When any automatic or semiautomatic valves are used, it is necessary to see that they are always in working condition, and also that workmen do not fasten such valves open or make them inoperative. Unless this is done confidence in them may prove misplaced.

EXPLOSIONS OF AIR COMPRESSORS AT BLAST-FURNACE PLANTS.

Air compressor or receiver explosions occur occasionally at blast-furnace plants and sometimes cause considerable damage. As they are somewhat analogous to blast-main explosions they are briefly discussed here, although such accidents are not, strictly speaking, metallurgical hazards.

Fires in the receiver tanks of air compressors are not uncommon, and point to the cause of the explosions, as the fire is started by the temperature of the compressed air becoming higher than the flash point of the oil used to lubricate the air cylinder. Although the formula for the generation of heat by adiabatic compression of dry air to a pressure of 100 pounds does not account for sufficient increase in temperature to flash ordinary lubricating oil, it may be that oil oxidizes more readily under pressure than under ordinary atmospheric conditions. This may account for a lower flash point and more vigorous combustion than is anticipated from the grade of oil used. Other factors introducing the danger of explosion are defective discharge valves or piston packing rings. A leaky discharge valve or badly fitting piston rings may let the heated air in the compression end of the cylinder leak past the piston to the suction or admission side of the cylinder to such an extent that the initial temperature of the air to be compressed is so high that the temperature on compression reaches the flash point of the oil.

The precautions are proper upkeep of the valves and rings and the use of a noncoking oil of high flash point. Too much oil should not be used, and an oil drain should be led from the air receiver to remove deposits or accumulation of surplus oil carried over. In some cases a steam line is led into the receiver, this being available for extinguishing a fire, should one start, before it develops into an explosion. On no account should kerosene be thrown into the air inlets to clean the walls of the compressor cylinder. The intake should always be from outside the engine room, as the lower the initial temperature of the air the lower is the temperature reached during compression. The most recently installed air compressors are, as a rule, of the two-stage type, and this is in itself a safety provision, as compression in two stages results in a lower temperature than one-stage compression for a given pressure.

EXPLOSIONS OF MOLTEN IRON.

Explosions of molten iron are due to the sudden and confined generation of steam when the molten iron comes in contact with moisture. A secondary cause may be the formation of hydrogen by the action of incandescent iron upon water, the hydrogen in turn exploding in contact with air. There are some peculiar features about the action of water on molten metal. For instance, molten iron may be run into water and be granulated or made into shot without any explosion, provided the water is deep and in large quantity. However, a blue hydrogen flame always appears upon the surface of the water. If iron in great excess enters water, however, a violent explosion takes place. This sometimes occurs in dumping ladle cleanings into quenching pits or in dumping cinder ladles into water at the bank of a river, if there is a pocket of molten iron in the bottom of the ladle. Other illustrations are the overturning of a ladle of iron into a pig-machine cooling trough, ladles filled with iron breaking away from an engine and overturning at the dead end of a hot-metal spur track into an accumulation of water, ladles being derailed into a river, or the collapse of a bridge and plunging of ladles filled with hot metal into a stream. The resulting explosions are terrific and destructive.

If molten iron runs over a damp spot in an iron runner, frequently great quantities of hot metal are blown out, the amount being entirely disproportional to the amount of water present. On the other hand, provided sand runners or beds are evenly tamped, hot metal may be run in them with impunity, even though they are much damper than can be permitted in a clayed, loamed, or sanded iron runner. A wet or even a cold bar touched to the surface or plunged beneath hot metal causes a snappy explosion; often dangerously large amounts of metal are thrown out. If a freshly loamed hand ladle is plunged into or filled with hot metal, the entire contents may be explosively ejected. Hot metal spilled on a damp or wet floor, whether of iron, brick, or packed soil, will explode very violently. The turning of water into the skimmer trough onto the skull of iron and pockets of molten iron left after casting in the bottom depressions rarely causes an explosion. Occasionally, however, if a fragment of solid cinder is lying on top of a small pool of hot metal, the force of the stream of water may carry the wet piece of cinder down into the molten iron. The inevitable result is a violent detonation, and serious injury may follow. In one instance a man lost both eyes from flying iron from such an explosion. Usually water can be sprayed on the surface of hot metal without an explosion, although such procedure is, of course, hazardous, as is illustrated by accidents resulting from attempting to chill iron leaking from ladle cars, the water penetrating beneath the surface and causing an explosion. Other causes of explosions are when hot metal is poured into a ladle with a wet bottom, or into one containing large lumps of cold wet scrap, or when cold or wet heavy scrap is placed in the runners to be melted at cast, or when at a hearth breakout hot metal comes out in contact with water, or when at the end of the cast a large amount of iron escapes from the skimmer and plunges into the cinder granulating pit, or when water-cooled plates at the tapping hole are cut by iron at casting time.

The cause of these explosions is the sudden generation of steam under confinement. When the steam is free to escape, as downward in sand beds or upward from the surface of the hot metal, there is no explosion. If the steam is generated within the hot metal, then it breaks through the overlying iron, as it does through any insufficiently strong barrier, and throws the hot metal with great force and with a loud detonation. A similar action results when a quantity of molten iron is plunged into water, the water preventing the escape of steam. Analogous to hot-metal explosions are explosions of the fluid contents of cinder-ladle cars when the cinder is run in on top of wet rubbish, particularly if iron is carried over with the cinder and has accumulated on the bottom. Infrequently, as at a breakout, hydrogen gas is generated and bursts into flames, adding to the danger and destructiveness of the explosion.

The precautions against such explosions of metal and cinder are well known and as a rule are carefully followed. The furnace crew occasionally trangresses the rules and some one uses a cold or wet bar or hand ladle, puts scrap in the runners or iron ladles, throws rubbish into cinder ladles, stands too close to the skimmer trough in turning the hose on at ridup, allows too many ladle cleanings to rush into the quenching pit, or is careless in skimming. Where plant or equipment design can provide against hot-metal explosions, they are adequately guarded against as a rule by design of ladle quenching pits, skimmers, catch basins, iron and cylinder ladle cars, hearth construction, etc. These safeguards have been fully described under "Blast-furnace breakouts" on pages 41–78.

TUYÈRE EXPLOSIONS.

Explosions at the tuyères are among the most unpreventable and unforeseen accidents encountered at blast furnaces. The cause is obscure, but lies essentially in the sudden generation of steam from the failure of a tuyère in consequence of faulty water cooling. The forming of a crack or hole in a tuyère does not necessarily result in an explosion, as leaking tuyères are common. Even with nearly all the tuyères leaking there is usually no tuyère explosion, the water leaking into the furnace being entirely harmless as far as explosion of steam is concerned, except under peculiar circumstances. Usually the only result is to "iron up" the tuyères with low-carbon iron and slag, as the formation of steam and hydrogen merely abstracts heat and chills the furnace, the gases escaping up the stack. Evidently steam must form suddenly and not escape immediately in order to cause a tuyère explosion. This may occur in two ways: First, if the tuyère fails and a large amount of water impinges upon incandescent material inside the furnace; or second, if molten iron penetrates suddenly into the tuyère. The first may take place if the tuyère is suddenly broken open, but even then, with water suddenly discharged into the furnace, explosions do not always take place. The second cause is lack of water, permitting bubbles of steam to form in the tuyère nose, allowing the walls to melt. Other factors are uneven expansion, sudden bosh slips, deposits of mud or lime, and slagging of the wall about the tuyère.

For an explosion to take place it seems to be requisite that molten metal meet the water when the nose of the tuyère collapses, or rush back into the tuyère, as tuyère explosions usually develop shortly before casting time, or when iron is lying in front of or over the tuyère.

The violence of some of these explosions is almost incredible. Instances have been related of a tuyère being blown out and breaking a cast-iron water main, and of a cinder cooler being blown a distance of 300 yards. Several men have been killed from tuyère explosions, one plant having two such accidents within five weeks of each other, and innumerable injuries, such as burns, ignited clothing, and bruises, have been caused.

The best and virtually the only safeguards are careful supervision of the water supply, strict watch for leaks, and, especially, regular furnace practice, as tuyère explosions are especially characteristic of rough and irregular furnace work. The essential precaution lies in not standing about any more than is necessary in line with a tuyère which is "sloppy" or leaking, especially at casting time.

BLASTING OUT HEARTH BOTTOMS AT RELINING.

HAZARDS FROM THE USE OF EXPLOSIVES.

The only noteworthy use of dynamite about blast furnaces is in blasting out "salamanders" in the furnace hearth bottom at relining. In former years the use of explosives was sometimes resorted to in dislodging scaffolds in blast furnaces. This practice is discussed in detail in Part III of this report (see pp. 249, 250). Several accidents have occurred in blasting salamanders in the past 15 years, but in any one year the accidents from this cause are almost negligible, particularly in recent years. This is because, at a blast furnace, the opportunity or need of having a salamander dug out occurs only once in every three or four years at the most, and it may be dug out only at alternate relinings, or not at all. Another reason for the infrequency of such explosions lies in the fact that expert contractors are increasingly employed to remove the salamander.

The salamander, as previously stated, consists of a solid lump of pig iron, usually from 16 to 18 feet in diameter and from 3 to 30 feet deep, embedded in the foundation, the original fire brick being gradually replaced with iron during the years the furnace has been in blast. Most furnace men think it advisable on blowing out the furnace to remove the salamander, as a large salamander in the hearth foundation is believed to give rise to breakouts, split hearth jackets, displaced columns, cracked base plates, and off-grade iron at blowing in and especially to low bottoms in operating.

The salamander can not be removed until the brick lining is completely torn out of the stack and bosh, and the relining can not be started until the salamander has been removed, as every day the furnace is not in blast means a loss in production of about 500 tons of iron. The work of blasting the salamander is likely to be hurried.

This adds to the hazard in two ways, (1) the salamander was originally at red or white heat in the interior and cools off slowly, and consequently the temperature of the blast holes may be as much as 500° F. when ready to charge, and (2) under the drive and rush of relining work, men will not always take time to cool an originally hot hole, to cool a hole heated in "springing," or wait long enough or take the proper precautions in event of a misfire.

The work of removing a salamander is usually tedious and slow. Not only is the fire brick surrounding it excessively tough and hard in consequence of being exposed to high temperatures and pressure, being much harder than when laid, but the salamander itself may contain segregations of low-carbon iron which the drills can hardly penetrate or may require the starting of a new hole, so that by the time the holes are ready to charge, the men are impatient to finish the task. Hasty charging and blasting is not only dangerous but is foolish, because in removing a salamander drilling the hole is the time-consuming and expensive factor. Too much hurry in shooting may destroy the hole, which is relatively of much greater importance than a possible 24 hours saved in shooting and breaking up the salamander. The hole can easily be destroyed by using too heavy a charge of dynamite, which fills the hole too full, or by insufficient tamping on top of the charge. Such a heavy charge may widen the hole from top to bottom and destroy its effectiveness by blasting out a cone-shaped opening in the upper part of the hole. Therefore the importance of saving the holes, as well as safety considerations, should dictate care in placing and firing the charges.

CUSTOMARY PRACTICE IN BLASTING SALAMANDERS.

PREPARATION OF HOLES.

The holes are drilled either by air or steam percussion drills or by electric twist drills. Electric drills are faster, make a truer hole from top to bottom, and the drill bit freezes and sticks less than a percussion drill. Burning holes with an oxygen flame has been tried, but with little success. The size of the drill holes ranges from 1 to 2 inches in diameter, the usual size with twist drills being 1¼ inches. The depth of the hole varies. For a salamander of moderate size, resulting from one or two blasts with the furnace, the holes are 18 inches to 6 feet deep, the aim being to go only slightly over half the depth so as to avoid blowing the bottom of the hole out when the charges are fired. The arrangement of holes varies. Sometimes when only the edge of the salamander is to be split off, a concentric circle of holes is drilled about the periphery, 15 to 24 inches from the edge. If only the top is to be split off, horizontal holes are sometimes drilled into the face. The most common method is to drill a row straight across the top, dividing the salamander in halves. Occasionally sufficient rows are put in to quarter the mass. These holes are drilled 15 to 36 inches apart, but are most effective at close intervals.

CHARGING THE HOLES.

The explosives used vary from ordinary "40 per cent" to "gelatin" dynamite; a few plants use potassium-chlorate explosives. The amount used varies from 1 to 10 or more sticks (as much as can be put in) per hole. Exceedingly heavy charges are put in at some plants, sometimes sufficient to shatter windows in adjoining stores and residences. The explosive is charged both in stick form or loose, the sticks sometimes being wrapped with asbestos paper. The hole is tamped with sand or clay, a couple of plants using plaster of Paris.

FIRING THE CHARGES.

The charges are connected in series and fired with a blasting machine at practically all plants, although a few use the electric-light circuit. It is important in order to get the maximum breaking power of the explosive charged that all holes be fired simultaneously, and on that account fuses are not used.

PRECAUTIONS TO BE TAKEN IN BLASTING SALAMANDERS.

PREPARING THE HOLES.

One method, which is typical, consists in "chambering" or "springing" the hole and is believed to be the most efficient method of shooting blast-furnace salamanders available for furnace men, who encounter the necessity only infrequently. Blasting contractors, of course, have their individual methods which they adapt to the needs of each particular task.

Before the holes are drilled the salamander should be undermined or bared along the face as much as possible, or at least to the bottom of the hearth jacket, in order to determine the depth of drill hole necessary. In case only the sides of the salamander are to be removed the hearth jacket, if left in, should be protected by heavy beams, and enough of the sides of the salamander should be removed to permit building a brick wall as thick as the original wall. At every opportunity while the furnace is being torn out, the top of the salamander should be flooded with water, and also where no drilling is being done, so that the salamander will be cooled, and there will be less danger of premature firing of shots.

QUARTER DRILLING.

Small holes, not over 1¼ inches in diameter, should be drilled with electric or air drills. These are preferable to the larger holes made with rock drills, because there is less flying of pieces when the shot is fired. The holes should be drilled at intervals of 12 to 15 inches, quartering the top face to depths not more than three-fifths of the depth of salamander. Six-foot holes should be sufficient for any salamander formed from not more than two blasts with the furnace.

When the holes are drilled and ready for charging, the temperature of each one should be tested with a thermometer. For safety, the holes should not be more than 100° F. at the hottest part; if any hotter, they should be thoroughly cooled with water before shooting is begun. The holes should be loaded by a special foreman with two special helpers. All other men should keep away and only enough dynamite should be carried to the furnace to charge the holes.

The holes along one axis only should be fired at one time, and should be fired by electric detonators connected to a blasting machine, or to an electric-light circuit. Only a small charge should be employed at the start, one stick of dynamite in each hole. With this small charge and good tamping, the bottom of each hole is expanded. Each succeeding charge may be increased as the hole becomes larger, and after six to eight charges have been fired, cracks or fissures will start to form at the holes, in the direction of the line of holes. By this time as much as three or four sticks may be charged per hole, and the fissures rapidly develop into a clean split of the salamander with little flying of material. The two halves can then be similarly split.

DISTRIBUTING HOLES OVER THE FACE.

Another method of drilling is to put down a large number of holes over the surface, 15 to 24 inches apart. Light shots can then be placed in three or four holes at one time, the holes "sprung," reloaded, and shot, and so on, until the piece is cracked off. This breaks the salamander up smaller but requires more drilling, which can as well be done on larger pieces after they are removed from the furnace.

HOLES SHOULD BE THOROUGHLY COOLED.

In reloading holes when springing and chambering them, plenty of water should be used and enough time permitted for them to cool. Swabbing the hole with a wet rag is not sufficient, as the swab only extinguishes burning sparks and does not cool the hole. The water should be blown out of the hole with compressed air, and the temperature of the hole tested with a thermometer before it is recharged.

Cooling of the hole is essential; a fatal accident recently occurred from dropping sticks of dynamite in a hot hole. When more than one stick of dynamite is used in a hole, care is needed to see that there is a good contact between the sticks. In connecting up with the lead wires be sure that the splice between the wires from each hole does not touch the salamander, so as to cause leakage of current and a misfire. Misfires are especially dangerous in a salamander, and particularly so if the holes have not been thoroughly cooled with water. In event of a misfire in a hot hole, from displacement of the detonator, leakage of current, or a weak detonator, the heat will explode dynamite sooner or later. For this reason, thorough cooling of the hole rather than inclosing the sticks in an asbestos tube, and care in connecting the detonator, firing, and lead wires, is essential to avoid misfires.

FIRING THE BLAST.

The firing lines must be kept entirely separate from the lighting circuit or firing machine until the moment of firing, preferably by stationing one helper at the end of the lead wires, with instructions to hold them in his hand. All people should be kept at a safe distance, guards being placed at all passages that might lead to the danger zone. When the holes are loaded a whistle may be blown continuously until after the explosion to give warning. No explosives except the amount required for each shot should be kept near the furnace. The top of the furnace should be covered, or better still, a barricade of railroad ties and brushwood placed around and on top of the salamander before shooting. At least 30 seconds' warning should be given either by blowing a whistle or by the lookout shouting "Fire," before the shot is fired.

After the blast has been fired, the ends of the lead wires should be immediately disconnected from the firing machine, or electric circuit, and the lead wires examined to see that the insulation has not been injured or stripped by flying material. When such defects are found they should be repaired with insulating tape. Any uninsulated spots in the wire may cause leakage of current and misfires.

CONNECTING SHOTS IN SERIES OR IN MULTIPLE.

The following discussion of methods of connecting shots and the relative safety of the two methods, prepared by H. H. Clark, electrical engineer of the Bureau of Mines, is from Technical Paper 111:[a]

There are two general methods of connection that may be used when several shots are to be fired at one time. These methods are known as series connection and parallel or multiple connection. As a general rule, shots should be connected in series when they are to be discharged by hand, or by spring-operated magneto generators, because these generators have not sufficient current capacity to fire shots in multiple. Where the shots are discharged by current taken from a power circuit, either series or multiple connection may be used. If shots are connected in series, a minimum potential of about $1\frac{1}{2}$ volts per shot will be required if the source of potential is constant, and if it is variable, as is the case when hand or spring operated magneto generators are used, a somewhat larger voltage will be desirable. The source of power used to fire shots connected in series should be capable of supplying at least $1\frac{1}{4}$ amperes.

When the shots are connected in parallel, the source of power should have sufficient capacity to supply about an ampere for every shot to be fired, and should be capable of supplying sufficient potential to force the total current through the conductors that connect the shots to the source of power.

When the shots are connected in series, it is easy to make a preliminary test to determine whether or not the circuit is open; and, barring the presence of defective detonators, all shots will be discharged if the proper voltage is supplied to the firing circuit. If the charges are connected in multiple, there will be no easy means of testing for poor connections and for faulty detonators, and consequently the presence of either is more likely to pass unnoticed. On the other hand, if the connections are in wet ground (or on a metallic surface such as a salamander) and the wires are not properly protected from moisture and leakage to the ground, it is quite possible for some shots to fail when connected in series that would surely be discharged in multiple. It is practically impossible to state which of the two methods of connection is inherently safer if a sufficient supply of voltage and current is available.

Faulty connections are probably the most prolific cause of failures of shots, and the best advice is to emphasize that connections should be made very carefully; that wires should be prevented from leaking to ground and short circuiting with each other; that firing machines should not be overloaded with shots or used for firing in mutiple when they are designed for series only; and that all conductors used in connection with shot firing should be of ample size to carry their required current without appreciable decrease in voltage.

The danger of misfires may be minimized by the use of a testing galvanometer. This simple instrument employs a very weak current, which is insufficient to fire the charge but is enough to deflect a needle and thus indicate a perfect wiring connection. When the test is made the lead wires should be long enough to prevent any mishap. If such tests are made before tamping, wiring defects can be corrected.

PRECAUTIONS IN CONNECTING SHOTS.

The following rules given in Bureau of Mines Bulletin 80[b] should be followed:

[a] Bowles, Oliver, Safety in stone quarrying: Tech. Paper 111, Bureau of Mines, 1915, pp. 21–23.

[b] Munroe, C. E., and Hall, Clarence, A primer on explosives for metal miners and quarrymen: Bull. 80, Bureau of Mines, 1915, pp. 47–48, quoted by Bowles, Oliver, Safety in stone quarrying: Tech. Paper 111, 1915, p. 24.

CONNECTING LEGS TO LEADING WIRES.

An electric igniter or an electric detonator should be so loaded into a bore hole that while it is in perfect contact with the charge the legs of the igniter or detonator reach at least 6 inches out of the completely stemmed and tamped hole. Both legs should be bared of their insulation for about 2 inches from their ends, and the wires so cleanly scraped that a good electrical contact can be made with them. Each leg is then firmly connected with one of the leading wires by about five turns.

SPLICES SHOULD NOT BE OPPOSITE—WRAPPING SPLICES.

It is bad practice to have the two splices directly opposite each other, because when the leading wires are pulled the splices may touch one another and thus make a short circuit, which will prevent the electric igniter or electric detonator from being exploded. A better plan is to wrap the bare-wire splice with tape made for the purpose, which completely insulates them.

CONNECTING LEADING WIRES TO FIRING MACHINES.

After the legs are spliced to the leading wires (and not till then), the wires are connected to the firing machine from which the electric current is to be obtained. This last connection should never be made until all the men are at a safe distance from the place where the blast is to be fired.

ALL CONNECTIONS TO BE MADE FROM BORE HOLE TO FIRING MACHINE.

The rule should be made and never broken that when bore holes are charged the " connecting up " shall move from the bore hole back to the firing machine. The work in all blasting operations should be so organized that it can never be possible for the leading wires to be coupled to the firing machine while anyone is about the place where the holes are being charged and where the blast is to be fired.

PRECAUTIONS IN STORING AND HANDLING EXPLOSIVES.

The following rules regarding the use and care of explosives are taken from Miners' Circular 6,[a] of the Bureau of Mines.

STORAGE OF EXPLOSIVES.

Don't store detonators with explosives. Detonators should be kept by themselves.

Don't open packages of explosives in a magazine.

Don't open packages of explosives with a nail puller, pick, or chisel.

Packages should be opened with a hardwood wedge and mallet, outside of the magazine, and at a distance from it.

Don't store explosives in a hot or damp place. All explosives spoil rapidly if so stored.

Don't store explosives containing nitroglycerin so that the cartridges stand on end. The nitroglycerin is more likely to leak from the cartridges when they stand on end than it is when they lie on their sides.

Don't repair a magazine until all explosives are removed from it.

[a] Hall, Clarence, Permissible explosives tested prior to January 1, 1912, and precautions to be taken in their use: Miners' Circular 6, Bureau of Mines, 1912, pp. 3–6.

THAWING EXPLOSIVES.

Don't use explosives that are frozen or partly frozen. The charge may not explode completely, and serious accidents may result. If the explosion is not complete, the full strength of the charge is not exerted and larger quantities of harmful gases are given off.

Don't thaw frozen explosives before an open fire, nor in a stove, nor over a lamp, nor near a boiler, nor near steam pipes, nor by placing cartridges in hot water. Use thawers such as are furnished by the manufacturers of explosives.

Don't put hot-water or steam pipes in a magazine for thawing purposes. Where large quantities of explosives are used, a special thaw house should be built large enough to hold the quantity of explosives needed for a day's work.

HANDLING DETONATORS AND EXPLOSIVES.

Don't carry detonators and explosives in the same package. Detonators are extremely sensitive to heat, friction, or blows of any kind.

Don't handle detonators or explosives near an open flame.

Don't expose detonators or explosives to direct sunlight for any length of time. Such exposure may increase the danger in their use.

Don't open a package of explosive until ready to use the explosive; then use it promptly. All explosives are injured by exposure to the action of the air.

Don't handle explosives carelessly. They are all sensitive to blows, friction, and fire.

USING DETONATORS AND EXPLOSIVES.

Don't crimp a detonator (blast cap) around a fuse with the teeth. Use a cap crimper which is supplied by any manufacturer of explosives.

Don't use a metal tamping rod. Even a copper-tipped rod is not to be recommended. Use only wooden rods.

Don't return to the face until at least five minutes after a shot has been fired. All explosives tested to date, including black blasting powder, yield inflammable and poisonous gases.

Don't return to the face for at least one-half hour after a misfire. Hangfires and misfires are most likely to happen when squibs or fuse are used.

Don't attempt to draw nor to dig out the charge in case of a misfire. Drill and charge another hole at least 2 feet away from the hole that misfired.

Don't use an ordinary dry-cell battery for firing electric detonators unless it is carried in a box having a safety key or button contact. The battery should be so constructed that if the leading wires or the legs of an electric detonator should come in contact with its poles the current will not be discharged until the safety key or button is used.

PART III. BLAST-FURNACE SLIPS.

PURPOSE OF INVESTIGATION.

The mechanism of blast-furnace slips, the chemical and physical conditions causing them, and the various theories to account for irregular movement of stock in the furnace have been an attractive field for discussion and speculation among blast-furnace and technical men for many years, because the subject related to the attainment of regular practice, and consequently to tonnage, quality of iron, and costs, and also to the safety of the men and of the equipment. The dangers incident to blast-furnace slips are comprised in the ejection of coke, limestone, ore, and scrap from the furnace top over the yards, tracks, roofs, and pathways, and in the added danger about the base of the furnace from bursting tuyères, burned blowpipes, chilled iron notch, and filled tuyère stocks. Occasional bosh failures, blown-off tops, or ruptured furnace shells have added to the apparent hazard, and, in addition, a marked tendency toward slipping tends, at many plants, to increase the accident risk of other operations about the furnace.

The safeguards against slipping are extremely few. Essentially the best safeguards and precautions against slips, with their attendant damage or hazard, lie in suitable furnace construction, design, and practice, and in the wise selection of the materials used for the burden. The number and severity of slips at blast furnaces in this country have been considerably lessened by progress along these lines. This reduction has been accomplished chiefly through many costly experiments and trials in the contour of linings, methods of distribution of charges, and changes in design and practice to suit the various ores and cokes American plants have had to use, covering a considerable range of years, rather than to any improvement which may be attributed to contribution of fact or theory by technical authorities.

In undertaking to review the theory and prevention of blast-furnace slips no attempt has been made to suggest a panacea for supposedly poor practice or unduly hazardous conditions at American furnace plants, for such a condition does not prevail. A summary of the more important contributions to the technical literature, with a tabulation of information obtained from various sources by word of mouth, has been prepared for the benefit of those in charge of and working about blast-furnace plants. Every slip of any consequence is indicative of deranged conditions in the furnace which need correcting. It is believed that the review of causes and remedies here presented may be found suggestive in overcoming the abnormal conditions which lead to slipping.

OCCURRENCE OF SLIPS.

A blast-furnace slip is always preceded by "hanging" of the charge in the furnace, where, because of irregularity in practice, or the augmenting of some abnormal or detrimental factor, a part of the charge becomes wedged. Sooner or later, from a few minutes up to several hours, this material gives way and falls inside the furnace; this sudden descent of material has been given the name of a "slip."

At many plants small slips are of daily occurrence, usually frequent, and many large furnaces apparently work only by slipping. As a rule, such slips cause little disturbance to furnace processes and offer little hazard to life or property. If this were not so, practice and work about blast furnaces would have become intolerable many years ago. However, chronic and excessively heavy slips may develop and may disarrange the working of a furnace for weeks at a time, in addition to introducing a considerable hazard to the force. After a furnace has hung for some time the charge may descend quietly, or gas and dust may be blown from the bleeders or explosion doors for several seconds, or the stock may fall so heavily that the impact shakes the furnace foundations or bursts the bosh. Sometimes the slip becomes so violent that it resembles an explosion. There is a deep, heavy roar, and dust and gas are ejected from the bleeder 150 feet or more in the air and from the explosion doors; a sheet of flame plays about the furnace stack, hiding the top; and large quantities of ore, coke, and limestone are ejected over the yards and tracks. Sometimes the top is blown off and the side is split, and in some instances blast furnaces have been completely destroyed. This explosive type of slip is prolonged rather than instantaneous, as it lasts 5 to 15 seconds.

INDICATIONS OF HANGING.

APPEARANCE OF THE GAS.

A furnace will nearly always give some indication that it is hanging. The most ancient and time-honored indication of good or bad furnace working has been the "top flame." This practice dates back scores, perhaps hundreds, of years, to the time when furnaces had open tops, and later on, to the time when the usual excess of gas was led off through a bleeder, where it might or might not burn. A furnace working regularly will usually emit a gas characterized by a gray fume, more or less heavy. At night there is usually a continued emission of pyrophoric sparks about the bleeder. If the gas burns, it usually gives a blue-red smoky flame.

As a furnace begins to hang, the gas becomes clearer and more translucent and the flame bluer. When the furnace becomes very tight and cold, the gas burns with a dust-free and translucent flame, or the gas may completely disappear, when the furnace is said to be "dead on top." With tight tops and bleeders the appearance of gas on top has ceased to be a conclusive indication of furnace working. However, as considerable amounts of gas leak from about the bleeder seats, it is still watched closely by experienced and practical furnace men. The use of washed gas at stoves removes any possibility of judging the working of the furnace by the appearance of the gas at this point; moreover, the characteristics of stove gas have never been a reliable indication of furnace conditions. The connection between hanging and the top flame is not necessarily constant, as different rates of driving, the use of coke blanks, the character of slag, or the wetting of the ores, affect the appearance of the flame and it may mislead those who are not familiar with the variations introduced in blowing and charging the furnace. When a furnace hangs for some time, becomes tight, and the gas apparently disappears or is "dead on top," the starting of the slip is often indicated by small jets of yellow flame about the seats of the explosion doors, several seconds to a few minutes before the furnace slips.

RATE OF CHARGING.

A second indication of hanging is the slackening in the rate at which the furnace takes the rounds of burden. A furnace taking 96 charges in 24 hours should, when working regularly, take on an averages 12 charges in each three-hour period; the number of charges is, however, above this average during the night and below it during the day. Wider variations in rate of taking burden are not uncommon, as on some days the furnace may take many more charges than corresponds to the average daily rate of driving and tonnage, or, on the contrary, charging may be so retarded that the tonnage for the day represents a gain of 5 to 15 per cent over the equivalent amount of iron charged. This may take place with regular driving and absence of marked slips. As a rule, however, a deficiency of more than two rounds from this established average over a three-hour period is an indication of hanging. Of course, the rate of charging is checked at much less than three-hour intervals, because hanging may develop in as short a time as 30 minutes.

A furnace may be working "stiff" and after taking two or three rounds stick for possibly 10 or 15 minutes, move, take another round, stick, move; then take three rounds, stick, and move, and so on. Many furnaces work this way day in and day out with no serious effect. At other furnaces the charge descends regularly at short intervals by a series of slight drops, and the beginning of a "stiff" movement is likely to develop into serious hanging. A furnace, whether working "stiff" or regularly, may "stick" very suddenly, or may work into this condition only by becoming gradually stiffer. As a general rule, subject to some leeway, when a furnace which is working stiff stands still for periods of more than 20 minutes, in which no charges are taken, it may be said to be sticking or hanging.

TEMPERATURE AND PRESSURE OF THE GAS IN THE TOP.

Closely connected with sticking, or a reduction in the rate of charging, is the temperature of the top gas, as in this case the temperature invariably rises, sometimes as much as 200° F. in 20 minutes. This rise in temperature is primarily due to cessation of charging, and may indicate nothing more than a "spell" (fillers stop charging to rest or eat) in the stock house. It may, however, if charging is stopped on account of the furnace sticking, indicate abnormal conditions inside the furnace. If the furnace is an isolated one, a marked drop in the pressure of the top gas, as its temperature increases, indicates hanging of the charge.

At a few plants where instruments for recording the composition of the gas are installed, a relation can be traced between "hanging" and the carbon dioxide content of the gases. Such information is, however, more of historical interest, after hanging has developed, than of immediate value in anticipating the condition.

BLAST PRESSURE.

Another indication of hanging is variation in the blast pressure. For example, the pressure almost invariably increases after casting, when the furnace hangs for a while, especially if the blast has been off the furnace for over two or three minutes and if the furnace has been running on blast temperatures of more than 1000° F. In normal practice and with an average blast pressure of 15 pounds, the pressure may rise to 17 or 19 pounds immediately after casting, and then gradually fall in the course of 40 minutes to the normal average pressure. The blast pressure may similarly rise when sticking and hanging develops between casting periods. A furnace running at a blast pressure of 15 pounds between casts may start to hang on top without any increase in blast pressure, or, on the contrary, the blast pressure may suddenly increase without any immediate sticking or decrease in rate of charging.

RELATION OF VARIATIONS IN BLAST PRESSURE AND RATE OF CHARGING.

An increase in blast pressure is almost invariably accompanied, however, by a decreased rate or the cessation of charging. Whenever hanging assumes serious proportions, increase in blast pressure and irregularity of charging are closely related, although a period of chronic hanging and heavy slipping may be brought about by a "hanging" in which the blast pressure remains normal until the slip has occurred. The most unmistakable, and the earliest, indication of hanging is to be found not in the blast pressure or character of the top gas but in the rate of charging. If the furnace is watched closely and at the first indication of hanging, steps are taken to anticipate its developing into protracted sticking and heavy slipping, the more serious and chronic hanging can usually be avoided, this depending somewhat on whether the hanging is at the top or bottom of the furnace.

CONDITIONS CAUSING TRANSITION FROM "HANGING" TO "SLIPPING."

Whenever the charge sticks or hangs a cavity is formed at some point in the furnace. For every 40,000 cubic feet of air blown per minute there is burned approximately 730 pounds of coke, which will occupy a space of about 25 cubic feet.

Accompanying the coke is 1,460 pounds of ore, occupying about 9 cubic feet, and 400 pounds of limestone, occupying 4 cubic feet, making a total of 36 cubic feet of material which is smelted per minute and disappears into the hearth as slag and iron or out the gas offtakes as gas and steam. In 40 minutes, therefore, a cavity about 1,200 cubic feet in size would be formed beneath the hanging part, representing in the shaft an average depth of about 5 feet or at the top of the bosh about 3 feet. Above this cavity, which is filled with gas, is a column of stock weighing, roughly, 25,000 pounds per foot of height, so that the total weight of the column of stock above the cavity ranges from 1,500,000 pounds when hanging takes place at the bosh to 250,000 pounds at 10 feet below the top.

The downward movement of the stock column having been arrested, it remains at rest until the cause of its sticking or hanging is removed. Uhling[a] has brought out the fact that as the friction of rest is greater than the friction of motion, then, if the latter is sufficient to bring the descending stock column to a standstill, the fric-

[a] Uhling, E. A., Fundamental principles involved in blast furnace practice; Jour. Franklin Inst., vol. 159, 1905, p. 117.

tion of rest must be more than enough to hold the material stationary. Also, the column is supported by the gas pressure against its base, and this pressure becomes greater as the top of the descending part of the column is lowered, because the shorter the descending part becomes the less resistance it offers to the ascending gas, and, therefore, the greater the temperature and pressure of the gas passing into and from the cavity. Finally, if the sticking has occurred in the upper part of the furnace, the arrested part of the column probably grows in bulk from the moment of retardation, and thus wedges itself still more tightly against the lining. Eventually, when the pressure of the gas in the cavity is high enough to dislodge the overlying column, or is so reduced by slackening the blast that it will not support the hanging material, or when the gas-filled cavity gets hot enough, or is abnormally cooled, the arrested column drops into the cavity, or "slips."

THEORIES OF THE CAUSES OF BLAST-FURNACE SLIPS.

The effect and appearance of a slip depends upon where the hanging started, the depth and shape of the cavity, the pressure of the gas beneath, the weight of the suspended column, the physical character of the ore, and the manner of falling. There being no means of direct observation, one can only surmise the mechanism of a slip from the correlation of a great deal of experience, data, and observation of various men. Some slips have been so violent that they have been termed "explosions," and many furnace men believe that a true explosion may take place under certain conditions, this theory being based on the fact that the so-called explosion has been observed to follow the slip by an appreciable interval. A knowledge of the various theories of hanging, slips, and explosions is important in order that the most effective steps to prevent their occurring too persistently and excessively may be taken. Hanging of the charge probably takes place throughout the depth of the stock column, but to distinguish the different causes it may be considered to be divided into two varieties, "top hanging" and "bottom hanging." The causes are quite distinct in each case, but as the location of the hanging or sticking approaches midway between the mantle and the top the causes probably become due to a combination of irregular working, both at the bottom and the top.

CAUSES OF BOTTOM HANGING AND SLIPPING.

"Bottom hanging" or "deep hanging" may be considered to take place from the lower bosh to the top of the zone of slag formation and to be due to excessively refractory slag caused by variations in the materials charged or in the blast, fluctuations in silicon content of the iron, or by running regularly on too limy a slag. Although the theories of fusibility of slags are not exact, it is well known that an excess of lime or alumina renders a slag refractory. The point of fusion rises with increasing percentages of lime or alumina, and the excess of these constituents over the percentage represented by a slag of normal fusibility is apparently dissolved, the slag being a solution of a spinel, basic silicate, or aluminate in a silicate or aluminate which makes up the body of the slag. For example, a slag analyzing 33 per cent silica, 15 per cent alumina, and 48 per cent bases would roughly correspond to a solution of one part $2CaO.SiO_2$ in two parts $2SiO_2.Al_2O_3.3CaO$. The most fusible slag-forming constituents are considered to combine first in the upper bosh or lower inwall, the excess of basic constituents entering in as the materials sink farther down in the furnace and become hotter. Under these conditions it is evident that throughout the descent of slag-forming material some of the cinder-forming constituents are at the limit of their fusibility, and any violent irregularity which causes chilling of that part of the furnace where slag formation is under way, or any sudden increase in basicity, must cause these parts of the slag to congeal or freeze.

The effect of the lowering of the temperatures on slag formation is described in the following:

In normal work the first portions of the slag may be assumed to melt in contact with gas at 2,400° F. at 3 feet above the bosh line, the remainder of the basic gangue remaining in a pasty state until a temperature of 2,800° F., say, at a point 1 foot below the bosh line, is reached, when it goes into solution with the slag first formed. If the furnace suddenly works cold, the temperature may be 2,400° F. at, say, 1 foot above the bosh line, whereas the last stage of melting will be at 3 feet below the bosh line and the portion of slag held in the upper zone will now tend to freeze out the more basic part. That portion of the cooling slag away from the walls of course continues to descend, but the part next the walls may stick to them. As the working of the furnace again becomes normal, the slag stuck to the walls should melt, and probably does more often than not. Under certain conditions, however, the slag frozen to the walls may contain a large amount of fine coke dust and carbon dust, which makes it sufficiently refractory to withstand the normal temperature at the place where it has formed. When such scaffolds are analyzed or examined, they are usually found to consist of a conglomerate of very limy slag, iron oxides, lime dust, coke, and coke and carbon dust, cemented together into a solid refractory mass by slag and cyanide of potassium. These scabs may be augmented by fresh deposits of congealed material, or by somewhat plastic material plastered against the scab by compression and weight of the stock column above. In a way such action of a furnace in producing accretions at or below the working temperature, which the same or a higher temperature can not smelt is an anomaly, but it is a condition that has been repeatedly and thoroughly demonstrated.

Scabbing may also be caused by the furnace working erratically and excessively hot. A furnace running on 1.25 per cent silicon in the iron, with 1,000 pounds slag volume containing 34 per cent silica, 14 per cent alumina, and 48 per cent bases, will on making iron with 2.25 per cent silicon withdraw 48 pounds of silica from the slag, making the analysis 30.6 per cent silica, 14.7 per cent alumina, and 50.4 per cent bases, which represents a much more refractory slag and one which may conceivably lower the zone of fusion and cause scabbing of the furnace walls. Other factors, such as an excessively limy burden, flat boshes, high or overcooled bosh, too hot a blast, varying coke structure, irregular weighing of charges, variations in moisture content of the blast air, and, in fact, any defect in design, construction, or practice, may similarily change the location of the fusion zone, or cause the more infusible parts of the slag to freeze, and thus start scaffolds. Any one of these conditions, although possibly insufficient in itself to cause serious scaffolding, is aggravated by large variations in the temperature, volume, or moisture content of the blast. When scabbing or accumulation of material on the lower inwall or bosh becomes chronic, and the deposits refuse to come off, scaffolding is introduced. The accumulations of material project out into the furnace, diminish the cross section, increase the velocity of gas and hence its supporting effect on the descending burden, and afford a foothold on which the charge may rest and arch across. In one instance a plate had been cut by a slip, and the blast was taken off at casting, and upon the plate being pulled part of an arch could be seen on the opposite side of the furnace, on the upper part of the bosh.

Most cases of bottom hanging doubtless start in the fusion zone from one or more of the above causes, approximately as indicated. When such hanging develops into chronic slipping, other factors may be introduced, such as tight jamming of material in the lower inwall and bosh when the stock column slips down, bringing down of cold or unreduced, uncarbonized, or unsmelted material to the fusion zone, or the formation of a shelf or shoulder by erosion of lining. The primary difficulty and the one to be corrected is, however, the formation of an incrustation of slag, coke dust, and lime conglomerate on the lower walls of the furnace.

CAUSES OF TOP HANGING.

CARBON DEPOSITION.

"Top hanging" is entirely different both in occurrence and seriousness from bottom hanging and is more difficult to account for. The most attractive theory has been that hanging is due to the deposition of finely divided carbon on and in the interstices of finely divided and easily reducible ore. Van Flotten[a] was the first to advance this theory strongly, although Bell had demonstrated its plausibility and furnace men were familiar with the presence of carbonaceous dust in the charge, as in repairing a furnace it can be noticed that a fine voluminous mass of carbon fills every interstice of the charge, and when a furnace is blown out the walls are covered and the cracks filled with carbon, and also when a furnace slips or "rolls" a cloud of black dust is frequently ejected. The theories of carbon disposition may be summarized as follows:

1. The reaction (*1*) $2CO=CO_2+C$ occurs between 750° and 1,800° F., being strongly from left to right at 750° F., with consequent separation of carbon but diminishing rapidly from 1,300° F. up. The velocity of the reaction is increased in contact with catalytic or accelerating agencies, such as finely divided iron, manganese, or nickel.

2. When the carbon dioxide formed by the decomposition of carbon monoxide comes in contact with the finely divided iron, the iron may be oxidized to ferrous oxide, according to equation (*2*) $CO_2+Fe=FeO+CO$.

3. Above 1,200° F., inside temperature, a blast furnace works ideally, and reaction *1* can not take place to any marked degree because the partial pressure of carbon monoxide in the gaseous mixture of monoxide and dioxide is smaller than the equilibrium pressure of the reaction.

4. If from any cause the temperature falls below 1,200° F. in the zone in which the formation of metallic iron sponge from the reduction of ores has begun, then the equilibrium pressure of the reaction *1* becomes proportional to the temperature; and the partial pressure of carbon monoxide in the gaseous mixture being greater than the pressure corresponding to equilibrium, decomposition of the monoxide follows, with separation of carbon.

5. This is because the effect of increasing the pressure is to accelerate reaction, which may take place with decrease in volume. The decomposition of carbon monoxide takes place with lessening volume from two to one.

With these physical laws in mind, one can build up a theory to account for hanging at the top of the furnace. If temperatures in the furnace above 1,200° F., which will comprise zones where the reduction of iron oxide is virtually complete, are ignored, it is evident that at temperatures of 1,200° to 500° F. uninterrupted reduc-

[a] Van Flotten, W., Das Hangen der Gichten in dem Hochofen: Stahl und Eisen, Jahrg. 22, February, 1892, p. 114.

tion of ore is taking place, and with theoretically ideal conditions there should be little or no deposition of carbon. This is in spite of the fact that metallic iron may appear at a temperature of 750° F. and is usually present in marked amounts at 1000° F., and is therefore in contact with the carbon monoxide and carbon dioxide gases. However, a sufficient change in the temperature of the gas will, according to physical laws, promote splitting up of carbon monoxide and reoxidation of iron, with resulting carbon separation. Suppose that a charge of extremely fine and reducible ore is introduced. On account of the accelerated rate of reduction and heat absorption the temperature drops. The pressure of the gas consequently drops below the equilibrium pressure for carbon monoxide and carbon dioxide in contact with finely divided iron and iron oxide, the partial pressure of carbon monoxide causing its decomposition according to equation *1* ($2CO = CO_2 + C$).

By the increase in concentration of CO_2 and its higher partial pressure iron is reoxidized according to the following equation (*3*) $Fe + CO_2 = FeO + CO$, and the CO thus produced again forms CO_2 and C, according to equation *1*. The catalytic effect of iron sponge increases the velocity of the reaction and results in carbon accumulating in such amounts that it fills all the spaces of the charge and an extraordinary increase in volume takes place which causes the stock column to wedge between the walls, especially when they are only slightly sloping, and the column remains hanging. The increased density and imperviousness of the charge retards the flow of gas and pressure builds up between the bottom of the hanging part and the top of the descending column beneath, which also tends to prevent the wedged part from moving.

The net effect of the two reactions is to give off heat according to the following equations:

(*1*) $2CO = CO_2 + C.$

(*3*) $Fe + CO_2 = FeO + CO.$

Adding (*1*) and (*3*)

(*4*) $Fe + CO = FeO + C.$

$-29{,}160 = +65{,}700$ British thermal units.

Therefore the net addition of heat is 36,540 British thermal units. That is, the ultimate effect of the process of carbon separation will be to increase the temperature of the charge at the point where carbon separation is taking place until eventually the reaction ceases and may even be reversed, and the carbon dissolved again. The above process is assumed to be taking place under ideal working conditions in the furnace, which presumably never occur in actual practice, and if every reduction factor were correct carbon deposition would never occur in amounts sufficient to cause difficulty. At every temperature throughout the height of the furnace there should be, theoretically, that amount of carbon deposited which corresponds to equilibrium between CO_2, CO, Fe, FeO, and C, but owing to the high velocity of the gas current, equilibrium is probably seldom reached, and the content of CO in the blast furnace gas is always higher and that of the deposited carbon lower than would correspond to equilibrium at the various temperatures of the different zones.

INVESTIGATION BY METZ.

Carbon deposition is, for this reason, held lightly by many furnace and technical men and is not regarded as the cause but rather as an effect of hanging. In an investigation by Metz made on a blast furnace in Luxemburg,[a] the following observations were made which bear on this theory:

> The charges did not slide gradually, but intermittently. The masses alternately lessened and compressed, and just as intermittently do the gases stream upward, not so much through the mass as through accidentally formed chimneys. Since the time of Bell the separation of carbon has been regarded as the cause of scaffolds. If we regard as correct the results of the investigation, then a separation of carbon is possible only at temperatures below 1265° F., that is, only in the upper part of the blast-furnace stack and at a height of 9 to 13 feet under the throat; then the ores stay about 3 to 4 hours in the zone. As has been mentioned, the charges slide intermittently in the uppermost zones of the furnace; the carbon, which settled on the surface of the ores, is therefore partly blown off by the violent gas streams which arise during the descent, partly pressed against the surface of the ore fragments, and perhaps partly used in the direct reductions so that the increase in volume brought about by the separation of carbon becomes very small after the charges continue their descent for a short while. I am of the opinion that the separation of carbon is not the cause of scaffolds. It is, on the contrary, the effect of scaffolds and it only influences unfavorably the condition thereof.
>
> If for any reason an obstruction has been formed, then the gases flow only through channels of the mass. In the remaining parts thereof the velocity of the gas is but slight, and the temperature falls off gradually and carbon separates. The mass grows thereby considerably in its volume and is still more maintained in its hanging position. Here the conditions are favorable for a rapid, almost gas-tight obstruction.

EJECTION OF CARBON DUST.

Another argument against carbon deposition being a cause of hanging is found in the behavior of furnaces when they are hanging periodically on top. When the charge slips, often a cloud of black smoke is ejected, which consists mainly of carbon. By the falling of the stock owing to the collapse of the arch the entire contents of the furnace in the upper zones undergo considerable shaking up, and any carbon deposited should be blown out and cease to cause further trouble. Yet in spite of the burden material being

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[a] Metz, N., Studien über die im Hochofen zwischen den eisenerzen und Gasen obwaltenden Verhältnisse: Stahl und Eisen, Jahrg. 33, 1913, pp. 93–104.

free from carbon deposit after a slip, hanging may persist and grow worse after each check and slip. This is taken as indicating that the carbon, often ejected in astounding amounts, must have formed after hanging developed, and that its appearance should not be confused or distorted into being the cause.

AMOUNT OF CARBON DEPOSITED.

The experiments of Laudig[a] showed that the volume of carbon deposited on Lake Superior ores may twice exceed the volume of the ores, and that the weight of carbon deposited may be 50 per cent more than that of the oxygen extracted from the ore. Such an increase in volume is out of all proportion to the usual batter of furnace walls, and it goes without saying that such an action can not regularly take place in any furnace even with the usual defects in operation, as it would make operation impossible or reduce practice to the expedient of checking the furnace every hour or every 40 minutes. As all furnace operators, when not confronted with scaffolds at or about the mantle, or with eroded inwalls, manage to get along with only infrequent or minor slips or checks, except for spells of irregular work, it must be that the amount of carbon normally deposited is small. Although carbon separation takes place to a considerable extent in the interior of an ore fragment when carbon monoxide diffuses in, and may persist until reduction is completed, the amount separated on the surface can not be equal to the amount theoretically or experimentally determined, because the gas at a given temperature is in contact with the ore during only a small fraction of a second. From the way furnaces work when running regularly the amount deposited can not be much in excess of the amount required for carburizing the iron, say 90 pounds; for absorption by CO_2 of limestone, say 150 pounds; for direct reduction, say 200 pounds; and some indeterminate portion which may travel down with the burden to the lower zones of the furnace, where at a higher temperature a larger amount of carbon monoxide remains in equilibrium with carbon dioxide, and the carbon dioxide again dissolves the carbon. Altogether the quantity deposited according to this hypothesis should be not more than about 450 pounds per ton of iron, whereas, according to experimental tests in combustion tubes, nearly 1,000 pounds of carbon would be deposited per ton of iron.

OTHER THEORIES OF THE CAUSE OF TOP HANGING.

This theory that excessive carbon deposition is the effect of hanging and not the cause requires its followers to furnish another cause

[a] Laudig, O. O., Action of blast-furnace gases upon various iron ores: Trans. Am. Inst. Min. Eng., vol. 26, p. 269.

for hanging, which is not easy. Top hanging can not be attributed to sticking in the bottom of the furnace, because charging may be stopped for an hour or more while the furnace is working normally at the tuyères and making cinder, nor can it always be attributed to erosion or overcooling of the middle inwall from 15 to 30 feet above the mantle, because hanging and top slipping occur in uncooled furnaces not eroded above the mantle. Hanging has been attributed, leaving carbon deposition aside, to the formation of scaffolds or accumulations on the sides of the furnace. One instance of such a scaffold was seen where the charge, after continued slipping, hung two hours and then slipped to 50 feet below the top, blowing the top off. In examining the furnace from the top a distinct scaffold was seen on the 45-foot line, sloping at an angle of 45° over the cinder notch and leaving an opening of about 10 feet. The material was analyzed after the furnace was torn out, with the following results:

Results of analysis of material from scaffold.

Constituent.	Per cent.
SiO	4.11
Fe	9.30
Al_2O	1.38
Lime	2.26
KCN	2.80
C	49.29

A similar scaffold analyzed as follows: Ignition loss, 52.87 per cent; SiO_2, 8.60 per cent; Fe_2O_3, 16.35 per cent; Al_2O_3, 6.56 per cent; and bases, 8.97 per cent.

Another cause of hanging may be found in the tendency of the stock to travel faster in the center of the column, and for fine coke, stone, and ore dust to accumulate on the sides. If the tendency becomes too pronounced there may be lodging or wedging of the interior part of the column on the slowly descending ring next the walls, as such accumulations of tightly packed ore, coke, dust, and lime have been found next the walls.

A theory infrequently advanced is that potassium cyanide sublimes in the bosh and is deposited in the cooler part of the furnace, where it may, if accumulated in excessive amounts, cement portions of the burden together and cause them to congeal on the wall. Deposits of this salt have been found as high as 40 feet above the mantle. Another possibility is that if the gas channels up through, under a gas offtake for instance, there are formed lumps of partly carburized iron, partly reduced ore, and slag, coke, and lime dust, which may adhere to the side of the furnace. If alkaline salts, heat, and abrasion cause deep erosion of the inwall, this may afford a foothold for an arch to form on, and thus easily induce hanging.

PROBABLE CAUSE OF TOP HANGING.

The most apparent cause of top hanging is a combination of carbon deposition in excessive amounts and of mechanical wedging independent of carbon deposition. It is possible that if, on account of irregular charging, or variations in the amounts charged, or in materials, the reactions do not proceed properly and equilibrium is destroyed, then carbon may be deposited in excessive amounts. This deposition may conceivably occur in but one limited segment of the charge, but be sufficient in itself to wedge the adjoining material firmly in the throat of the furnace. Mechanical causes, such as markedly uneven descent of charges, improperly designed gas off-takes, channeling, and obstructions or depressions in walls can also introduce conditions productive of hanging, with consequent carbon deposition. Obviously, remedies for this condition are to be found only in improvements in design, construction, and practice.

COLD WORKING.

Top or bottom hanging should not be confused with hanging and slipping due to cold working. This condition is simply the result of the furnace getting too cold from lack of heat in the blast, over-burdening, too refractory a charge and insufficient reduction, or "cold-bottom" iron. In such a case the cause as well as the remedy is well known and consists primarily in reducing the blast volume, which usually goes hand in hand with increase of temperature or lightening the burden. Neither should top or bottom hanging be confused with the condition that arises when on account of insufficient blast penetration, badly arranged charges, or improper dumping of the bell, or improper size of bell, a column of material forms in the center of the furnace which does not smelt as fast as the material nearer the furnace wall. This column at first may consist of coke, but if it persists it may clog with cinder and dust and become quite refractory. When such a condition occurs, unusual hanging may take place. In these cases the use of a cold or light blast, light burden, coke blanks, or checking the furnace, does not have the desired effect, but the furnace conditions steadily grow worse. Luckily, such occurrences are rare. The time-honored expedient used to determine whether this condition exists is to rapidly drive a 1½-inch bar across the furnace, through a tuyère, let the bar remain about 20 seconds, rapidly pull it, and then place a chalk mark at the limits of the cold center. The practice is in some disrepute, as it only rarely indicates the anticipated condition. The writer has seen this test result satisfactorily only once in seven years' work.

HANGING NEAR THE CENTRAL PART OF THE STACK.

Hanging at the central part of the stack is usually due either to excessive water cooling of the inwall or to excessive erosion of brickwork at this place. The erosion is due, probably, to abrasion by the poorly distributed stock as it slides along the walls, softening of the walls from heat, and the attack of incandescent lime dust and alkaline salts on the brickwork. The most that can be done is to lessen by good bricklaying, better distribution, and shaft cooling the destructive action of these agencies on the ring of fire brick midway up the furnace.

CHARACTER OF BLAST-FURNACE SLIPS.

After hanging has developed, sooner or later the stationary part breaks away and descends or falls into the cavity formed beneath it. There is little or no relation between the violence of a slip and the duration or location of the hanging that preceded it. A furnace may be hanging in the bosh for two hours and then settle quietly, or may slip so violently that the escaping gas from the bleeder makes a terrifying roar. Hanging at the top may develop into a slip which manifests itself only by "rolling" of the stock and large quantities of dust carrying over into the gas, or by the sudden ejection of stock accompanied with a loud report resembling an explosion, or by a momentary cessation of gas escape at the bleeder, followed by an ejection of stock and gas, moderate or excessive in character, or may partake somewhat of the characteristics of two or more of the above types. Sometimes a slip may occur with no further hanging, or, on the contrary, it may be followed by increasingly protracted hanging and more heavy slips, until finally the charge sticks so firmly that ordinary measures will no longer suffice to make the furnace move.

MECHANISM OF TOP SLIPS.

If a furnace has been hanging on top for 60 minutes, at a point, say, 11 feet below the stock line, it is evident that a cavity 4 to 6 feet deep will be formed beneath the stationary port. Beneath this cavity is a deep column of somewhat dense stock, permeated with gas under pressure, the pressure increasing toward the tuyères. As the stock column below the cavity becomes lower and shorter the temperature and pressure of the gas in the cavity will increase as long as blast pressure is maintained; but if the blast pressure is reduced by checking the furnace, the pressure in the cavity will slowly drop until it is insufficient to hold up the overlaying wedged column, and the latter falls. If on account of the conical slope of the furnace lining the material falls in a mass like a plunger, the gas below is highly compressed by the weight and velocity of the falling charge. As the compressed gas can not escape to any extent or quickly enough through the lower column, the pressure will continue to build up until the gas bursts up through the weakest part of the falling column, carrying with it any overlying material. This may happen within two or three seconds, the escape of gas resembling an explosion. The uprush takes place almost instantaneously, and, finding easy relief at bleeders or explosion doors, the pent-up gas bursts out at the top, lights with a roar, and coke and ore are vomited up vigorously.

It is only rarely that the wedged column can fall as a solid mass. To slip in this manner, the bottom of the mass would have to hang tightly together and the brickwork would have to be smooth and of equal periphery. As a rule the hanging part starts to fall on one side, or piecemeal, from the bottom to the top. The former condition is often indicated by the stock line being lower on one side than the other after a slip, indicating that the gas has probably broken through along the walls and in its escape has taken most of the ejected material from the depressed side. When the hanging part gradually breaks away from the bottom up the resulting ejection of stock is less, owing to the more gradual release in gas pressure.

As a general rule, the higher the scaffold or hanging, or the higher the temperature of gas in the cavity, or the more suddenly and completely the stock falls, the greater the expulsion of stock. Also, the finer the ores and the greater the amount of coke, limestone dust, and fines the greater is the expulsion of stock. This latter statement explains why in former days with use of lumpy ores these ores allowed gas to escape throughout the cross section and hanging, and explosive slipping on top was not so prevalent as with the use of finer ores. Because of these various factors it is evident that the time and duration of a slip is somewhat variable. For example, it is well known that a furnace may slip 10 feet without "spitting," whereas at another time a slip of 10 feet will eject huge quantities of ore and coke.

MECHANISM OF BOTTOM SLIPS.

Bottom slipping is indicated by burning of gas from leaky blowpipe and tuyère-stock joints, by incandescent gas and coke surging back into the hot-blast main and filling the blowpipes with coke, a distinct shock or shaking of the furnace base or foundations, and usually by a more or less sudden expulsion of gas and dust from the bleeder. The pressure in the cavity beneath a scaffold near the bottom of a furnace is partly relieved when the hanging material falls, as the gas escapes to some extent up through the charge, and the blast mains and stove afford a considerable reservoir to lessen the back pressure. As the escape of gas must be up through a considerable height of burden, the friction muffles or delays any tendency toward an excessively violent outrush in the upper part.

When an arch formed at the bottom falls, it drops into a cup-shaped cavity, in contrast to the falling of an arch higher up where the lining increases in inside diameter with each foot of fall. Therefore, although an arch near the top may possibly hang together in part when it falls, an arch in the bottom must crack and collapse before the overlying column can fall. However, when the yield point is reached in a bottom arch, the great weight of burden above makes the material fall so suddenly and heavily into the empty bosh space that the increase in pressure of the gas, and the impact on the sloping hearth walls may burst the bosh or crack it, especially if it is badly eroded and weakly banded or jacketed. Top slips never come heavily on the bosh, whereas bottom slips do.

PRESSURE GENERATED BY SLIPS.

When the high pressure from top or bottom slipping ejects tremendous quantities of material, if explosion doors are provided, or as has occurred, throws out or displaces bells and hoppers, and resembles an explosion within the furnace, it is sometimes difficult not to believe that an explosion has occurred. Since 1901, when furnaces were first built without explosion doors and of sufficient strength to withstand the maximum blast pressure at any point, many furnace men have come to believe that explosive slips are merely the result of physical forces, that is, the release of pressure pent up by the falling column of stock.

METHODS OF CALCULATING PRESSURE.

The force which may theoretically come into play from a heavy slip is as follows: Assume that a 90-foot furnace with the stockline at 14 feet is hanging, and that after $1\frac{1}{2}$ hours or more a cavity 9 feet in depth has formed at the 34-foot line. The overlying column is therefore 20 feet deep, with an average diameter of 17 feet, thus containing 4,540 cubic feet, or 490,320 pounds of burden material.

The problem resolves itself into finding the maximum pressure produced by the column falling into the cavity like a solid plunger or cylinder. Any pressure drop from the escape of gas due to the slope of the walls and leakage up the sides and through the burden as the cylinder falls is disregarded in order that the maximum pressure from the velocity of fall and weight of material compressing the gas may be calculated.

The weight per cubic foot of burden material may be calculated as follows: Three hundred pounds of ore equals 2 cubic feet, 150 pounds of coke equals 5.9 cubic feet, 75 pounds of stone equals 0.7 cubic foot, whence 64 pounds of burden equals 1 cubic foot. The initial gas pressure in the cavity may be taken as 3.5 pounds per square inch. As the cylinder falls the point of maximum pressure will be where the work done by the cylinder produces a force equal to the resultant upward force exerted by the compression of the gas in the contracted cavity. Consider an area 1 square foot in section. The work done by the falling weight equals the work done by the gas.

$$\text{Work done by the gas} = \frac{P_2V_2 - P_1V_1}{n-1}.$$

P_1=initial pressure.
P_2=pressure resulting from fall of cylinder.
V_1=initial volume.
V_2=volume resulting from fall of cylinder.
n=adiabatic constant=1.407
W=weight of column A per square foot at bottom.
X=distance of fall,

$$V_1 = 1 \times 9 = 9$$
$$P_1 = 3.5 \times 144 = 504.$$
$$P_1V_1 = 4536$$
$$n - 1 = 0.4$$
$$V_2 = 9 - X$$
$$P_2V_2 = P_2(9-X)$$
$$P_2(V_2)^n = P_1(V_1)^n$$
$$P_2 = \frac{504 \times 9^{1.4}}{(9-X)^{1.4}}$$
$$WX = \frac{P_2(9-X) - 4536}{0.4} = \frac{\frac{504 \times 9^{1.4} X (9-X)}{(9-X)^{1.4}} - 4536}{0.4}$$
$$0.4WX = \frac{504 \times 21.674}{(9-X)^{0.4}} - 4536$$
$$0.4WX = \frac{10923.70}{(9-X)^{0.4}} - 4536$$

The total weight in the column is $4,540 \times 64 = 290,560$ pounds, or 1,142 pounds per square foot at the base of the column. Hence

$$456.8X = \frac{10923.7}{(9-X)^{0.4}} - 4536.$$

By trying various numbers, 4, 5, 6, etc., the value for X, the distance fallen, can be closely approximated, the true value being such that when it is substituted in the above equation both sides are equivalent or equal. Six feet is a close approximation of the distance at which the resultant forces acting upwards and downwards should bring the plunger at rest. To find the pressure in the cavity at this point the following calculation is necessary:

Let X = distance of plunger from bottom of cavity.
Y = pressure in pounds per square inch.

Then $X^{1.4}Y$ = constant, at any point in the fall.

If $X = 9$ and $Y = 3.5$ at the instant the plunger starts to fall, then $X^{1.4}Y = 75.859$ = a constant, during the fall. Values for X and Y are given in the following table:

Values for X and Y.

X.	Y.	X.	Y.	X.	Y.
9	3.5	6.0	6.17	3	16.29
8.5	3.79	5.5	6.97	2.5	21.03
8	4.23	5	7.97	2	28.75
7.5	4.52	4.5	9.24	1.5	43.00
7.0	4.98	4	10.89	1	75.86
6.5	5.52	3.5	13.13	.5	200.2

From the above table it is apparent that the maximum pressure will be at a point 3 feet from the bottom, which corresponds to a pressure of 16.3 pounds.

The same method can be applied to a bottom or bosh slip as follows: Assume that the charge is hanging at the top of the bosh. The volume of the column is 14,000 cubic feet, corresponding to a weight of material of 840,000 pounds. The weight per square foot at the bottom will be 2,211 pounds. With the blast checked, the pressure in the cavity may be considered as reduced from 20 to 12 pounds per square inch, or 1,728 pounds per square foot.

Then:

$$V_1=14$$
$$P_1=1728$$
$$P_1V_1=2192$$
$$n-1=0.4$$
$$V_2=14-X$$
$$P_2V_2=P_2(14-X)$$
$$P_2(V_2)^n=P_1(V_1)^n$$
$$P_2=\frac{1728\times14^{1.4}}{(14-X)^{1.4}}$$
$$WX=\frac{P_2(14-X)-24192}{0.4}=\frac{\dfrac{1728\times14^{1.4}\times(9-X)}{(14-X)^{1.4}}-24192}{0.4}$$
$$0.4WX=\frac{1728\times40.23}{(14-X)^{0.4}}-24192$$
$$884.4X=\frac{69,477.4}{(14-X)^{0.4}}-24192.$$

By a series of approximations it is found that when X, the distance of fall, equals 5 feet, that both sides of the equation are nearly equal. Calculating the pressure at this point by means of the equation $X^{1.4}Y=$constant, it is found that with X taken at 9 feet from the bottom, Y is equal to 22.3 pounds.

The same method may be used to calculate the ideal or theoretical pressure under any combination of circumstances. It is to be noted that the pressures thus indicated are of necessity higher than the actual conditions can possibly cause. The calculated value may be taken as that beyond which the pressure may not be expected to mount under any combination of circumstances for a given point of hanging in the stack, height of arrested column, and depth of cavity. It is to be noted that the maximum pressure in the two cases illustrated is more than the pressure per square foot at the bottom of the wedged column. This explains adequately why sometimes the entire furnace contents from the point where the hanging develops is shot out of the top. This, as far as is known, has occurred only where the bell and hopper have been insufficiently tied in, or where an excessive area of explosion doors is provided at the gas offtakes. If an easy vent is provided, then the entire furnace contents may be lifted bodily by the excess pressure. If the gas can escape only through one to three bleeders of limited capacity and through the downcomer, then the throttling effect gives time for the gas to escape and for the pressure in the cavity to drop without an excessive amount of the burden being blown out by the gas.

FURNACE DESIGN FOR RELIEVING PRESSURE FROM SLIPS.

From the records of burst boshes, split furnace shells, and blown-off tops at slips, it is evident that if the physical theory of explosive slips is correct, a burst bosh or a split shell results from the fact that at the point of maximum pressure the bosh reinforcement, or the shell and its lining, offers less resistance to the escape of the built-up gas pressure than do the columns of overlying and underlying stock, and consequently the pressure bursts this barrier rather than the one offered in the columns of burden material. As regards the blown-off tops, if the bell and hopper weigh 15 tons, and have an area of 200 square feet sealing the top, then a pressure of $1\frac{1}{4}$ pounds per square inch will be sufficient to counterbalance the weight of the bell and hopper, and a slightly higher pressure should suffice to blow it out if it is not bolted or tied in. If the pressure of the gas under the bell, as the result of a slip, should be as much as 10 pounds per square inch, a total lifting pressure of approximately 130 tons would be exerted on the bell and hopper. Originally the bell and hopper were simply set in the brickwork at the top of the furnace. From the fact that they were frequently displaced by even small slips, and sometimes fell into the furnace on account of failure and collapse of the brickwork from erosion at the stock line, various expedients were resorted to, the four chiefly used being as follows: (1) Tying the bell and hopper in by rods and washer plates embedded about 16 feet in the brickwork; (2) placing I-beams across the furnace top and resting the bell and hopper on them, these being bolted to the beams or held down with washer plates; (3) riveting brackets to the shell, bolting a top or bull ring to the bracket, and bolting the hopper and bell to the bracket ring, washer anchor plates being sometimes used in addition; and (4) contracting the top two rings of the furnace shell or jacket, riveting or bolting a cast-steel ring to the top of the shell, and securing the hopper and bell to this ring. The fourth method is now standard construction. With this construction, many still think it necessary to provide one or two bleeders at the top gas offtakes to relieve excessive gas pressure, and this is a reasonable precaution. A few plants, however, have bleeders of the butterfly-valve type which will not open automatically in event of a slip, but must be opened by hand if relief is desired. A few have bleeder valves which are forced against their seats by any rush of gas, no relief being afforded whatever.

Mitigation of the dangerous results of blast-furnace slips can be provided for only by adhering to the physical theory of the origin of explosive slips and constructing the furnace to conform with this belief.

THEORIES OF THE EXPLOSIVE CHARACTER OF SLIPS.

Those unable to find an explanation in the physical theory for the violence of some slips have attributed the apparent explosion to intensive oxidation reactions. These theories will be discussed briefly.

COMBUSTION OF FINELY DIVIDED COKE AND ORE.

Van Flotten[a] attributes the explosion to the intense carbon monoxide evolution caused by the intimate mixture of finely divided glowing ore and carbon according to the equation, $Fe_3O_4+3C=3FeO+3CO$. He reproduced the conditions inside the furnace by putting fine ore and coke dust separately into two tubes. These were inserted in a larger tube, which was sealed and brought to a bright red heat. The materials were then mixed by placing the large tube in a vertical position. When this was done a gage attached to the tube showed a pressure of 60 pounds within a few seconds, and on a stopcock being opened there was ejected a thick dark dust cloud as at furnace slips.

A pressure of 60 pounds is, of course, sufficiently high to explain the destructive results which have attended some slips. Van Flotten refers to the theory of carbon deposition and the wedging of burden in the furnace, which he considers sufficiently well proved by circumstantial evidence, to account for the conditions that may give rise to accumulations of red-hot fine ore and carbon dust in the furnace. As these materials stick in the furnace, they absorb heat and may become bright red, and when a slip occurs and they are precipitated into the lower and hotter part of the furnace reaction sets in. Van Flotten considers that the use of fine or friable ores, or friable coke,

[a] Van Flotten, W., Die Explosionen beim Stürzen der Gichten im Hochofen: Stahl und Eisen, Jahrg. 28, 1908, p. 1015.

is disadvantageous because these promote the formation of scaffolds as well as the violence of the reaction.

COMBUSTION OF DEPOSITED CARBON BY CARBON DIOXIDE.

Reaction between carbon and carbon dioxide, with formation of carbon monoxide, according to the equation, $C+CO_2=2CO$, obviously takes place with double increase of gas volume and is supposed to be accelerated by some catalytic agent. Simmersbach[a] possibly first advanced this theory. If it be assumed that a furnace is hanging and that the stock in the upper part of the furnace is impregnated with carbon, then when the furnace slips the finely divided carbon falls with the burden into a deeper and hotter zone, where it will jar loose in great part and, as a separate body, quickly attain the surrounding high temperature, become intimately mixed with carbon dioxide, and react to form carbon monoxide, thus generating two volumes of gas from one. This, Simmersbach holds, is the cause of explosions at slips, reasoning back from the phenomena he had observed at several slips. The objection to each of the oxidation theories is that they comprise reactions which take place in any normally working furnace, are incident to the process, and take place every minute without explosive violence. In fact, if this were not so it would be impossible to blow in and run a furnace without its exploding. Both reactions take place with an absorption of heat as follows:

(1) $Fe_3O_4+C=3\,FeO+CO$

$-270{,}800=+3\times 65{,}700+29{,}160$ calories.

Net heat requirement=44,540 calories.

(2) $C+CO_2=2CO$

$-97{,}200=+2\times 29{,}160$ calories.

Net heat requirement=38,880 calories.

As a general rule, an explosion can not take place by chemical means while heat is being absorbed, and the above reactions can take place only when heat is led in from the outside. The conditions attending an explosion of coal dust in a mine or of grain dust or wood dust in a mill are different from those in a blast furnace, because in the former the dust combines with oxygen, with an evolution of heat, which fulfills the conditions necessary for an explosion, because a chemical reaction takes place in which the formation of gas is simultaneous with liberation of energy, the gas phase transforming heat energy into volume or work energy. In addition, there is a tremendous acceleration in propagation velocity, a progressive rise in flame temperature, and thereby an excessively rapid increase in gas volume, which accounts for the destructive results of such ex-

[a] Simmersbach, Oscar, Ueber die durch das Hängen der Gichten veranlassten Hochofenexplosionen: Stahl und Eisen, Jahrg. 23, 1903, pp. 922–925.

plosions. One can not find any characteristic reaction in the blast furnace approaching these requirements. An accelerated explosion temperature, or, in fact, any generation of heat to give an explosion temperature, is absent, because the heat of explosion is the heat set free divided by the specific heat of the products, and in both of the above reactions no heat is liberated. This should suffice to contradict the theory of accelerated oxidation.

ADMISSION OF AIR TO SPACES ABOVE THE HANGING STOCK.

The fact that just before a slip occurs there may be a decided diminution or stoppage of flow of gas from the bleeder, or even an apparent sucking of air, followed by an explosion, has led many to attribute such explosions to mingling of air with gas or fine carbon. In one instance an explosion door 42 inches in diameter was kept open at the top of a gas offtake of the "castle type" pending a slip and this allowed air to be sucked in when the slip occurred. The mixture of air and gas exploded on top of the stock line and displaced the bell and hopper. This explosion was almost simultaneous with the furnace slip and could very easily have been confused with it. A gas explosion on top of the stock line can not expel ore, is very different from so-called explosions at slips, and is likely to be so much more serious in results that it is safe to say that when such an explosion occurs the operators will recognize it. The theory has been much elaborated, the assumption being made that when a furnace hangs at the bottom, and slips, the entire stock column does not fall, but that the upper part remains hanging. Beneath this stationary part the falling part tends to produce a cavity with a vacuum into which air is drawn or sucked down through the overlying column. As soon as the hot combustible gases force their way from beneath the falling column into this air-filled cavity an explosion takes place with its usual effects. For obvious reasons this theory has never received any credence.

A less incredible theory assumes that with pronounced sticking the required amount of gas does not come back into the furnace to fill the empty space created when the charge slips, and that air rushes in through crevices in the top and about loose valves to form an explosive mixture under the bell. The assumption is also made that this gaseous mixture will diffuse with the scanty gas and may penetrate down deep into the stock, because it should not ignite until an ignition temperature of 1,100° F. is reached, and in this assumption explanation is found of the throwing out of ore and the sometimes almost incredible force of the explosion. Explosions of gas and air in the top of the furnace may and do occur, but that such an explosion can eject tons of ore and coke into the dust catcher, or out of explosion doors, is difficult to believe, because the force ejecting the stock must originate beneath the surface of materials in the furnace. It does not seem reasonable that an explosion of gas on top of the stock can explode gas beneath the top, nor that air can diffuse down into material through which gas is rising, or which is wedged so tightly that gas under pressure can penetrate it only with difficulty.

ADMISSION OF AIR TO SPACES BENEATH ARCHED STOCK AT BOTTOM OF FURNACE.

Occasionally one sees, hears of, or reads of a scaffolded furnace in which an arch has formed in the upper part of the bosh. The space beneath a scaffold at the top of a 16 by 22 by 13 foot bosh is 3,720 cubic feet, and the burden in this space would contain about 100,000 pounds of coke, which at the rate of 750 pounds per minute would completely burn out in 2¼ hours, assuming that the material remained bridged at the top of the scaffold and that the furnace was blown at an undiminished rate. If such conditions should occur and the bosh be entirely empty, or contain only a small amount of coke at the bottom through which the blast channels, this combination of circumstances might give rise to an explosion. It has been assumed that wedging at the top of the bosh is partly due to an excessive accumulation of fine carbon which traveled, undissolved, from the top of the furnace to the bosh, and that when by a slip this pulverent carbon was carried into the bosh, being full of air and incandescent, it burned explosively, thus producing all the results which give rise to so-called explosions at slips. A few instances in which the explosion blew the bell and hopper off and emptied the furnace down to the top of the bosh or lower seem to give credence to this theory. Against its plausibility is advanced the trouble experienced in anthracite practice, when the coal decrepitated and filled the furnace from top to bottom with fine carbon, ran out of tuyère openings when the tuyères were changed, and caused much trouble from scaffolding and hanging. So-called explosions, however, did not occur even with this excessive carbon dust. An experience may be cited where the existence of an arch across an empty bosh was conclusively known, and on blowing cold air for nearly an hour the furnace slipped very easily, with little lifting of explosion doors. If it is considered that in such a bosh cavity there can be not over 300 pounds of air, or 69 pounds of oxygen, which would at best burn explosively only 50 pounds of carbon, that all experience unites in recording only a pronounced thud or jar when the scaffold falls, and that eliminating excessive area of explosion doors and consequently throttling the gas has stopped ejection of stock to the 40 and 50 foot line, to say nothing of emptying to the bosh, then the plausibility of this theory of explosion becomes remote. That there is oftentimes free oxygen beneath bosh scaffolds and arches is true, but that it does more than to burn out carbon or coke in the bridged stock, induce smelting to begin in the arch, and open up cracks by which it eventually drops, is not likely. Some of the most severe and explosive slips seen have apparently had their origin at points 20 to 30 feet above the mantle, or 40 feet below the top, and it is difficult to imagine how any free oxygen could find its way up to this point in the furnace.

SKAPPEL'S THEORY.

Another theory concerned with explosion phenomena is as follows:[a]

For some cause hanging develops, the under charges melt down, and then a gas-filled cavity develops, which may be considered to contain 26 per cent carbon monoxide. If now the charges fall, the gases will be strongly compressed and mixed with catalytic substances, thereby the reaction velocity of $2CO=CO_2+C$ will increase greatly, in virtue of the reaction heat the temperature increases from the pressure, and consequently the reaction velocity again. Further, the separated carbon works as a catalytic agent acceleratingly on the reaction, so that it augments itself into an explosive character. These effects add themselves to those of mechanical compression of gas under the falling charges, thus generating a tremendous gas pressure which under certain conditions may blow the furnace shell open; that a black cloud is noted at blast-furnace explosions (slips) agrees most favorably with the above explanation.

The above theory is diametrically opposite to that of the formation of carbon monoxide from carbon and carbon dioxide. It finds its basis in the fact that the oxidation of CO to CO_2 and C takes place with evolution of heat and largely ignores the fact that it takes place with volume decrease and that it must stop at a certain temperature and increase in concentration of CO_2. It is included as illustrative of the divergent conclusions arrived at when theory is too enthusiastically relied upon to account for facts.

CONCLUSIONS AS TO CAUSES OF SLIPS.

The explanations for explosive slips discussed in the preceding pages are largely of historical interest, and are a product of the period through which furnace men struggled, when with increasingly finer ores and demand for greater tonnage slips assumed an increasingly destructive character. That furnace men were not satisfied with an explanation based upon simple physical facts but continued to search for obscure reasons for violent slips is possibly difficult for those unfamiliar with furnace phenomena to understand.

[a] Skappel, H., Discussion of Van Flotten's papers on "Die Explosionen beim Stürzen der Gichten im Hochofen": Stahl und Eisen, Jahrg. 29, 1909, p. 214.

Those who have had experience with stubbornly hanging furnaces and the accompanying slips will find no difficulty in realizing the state of mind of their predecessors in the profession and their earnest efforts to establish an acceptable theory on the basis of which they could proceed to make improvements and changes in design, construction, and practice.

The physical theory was first formulated by Van Flotten, in 1892, who said, "If the upper hanging column falls, the gas in the cavity will be strongly compressed; it can not escape from beneath quickly enough, and in breaking through the weakest part of the arch and in creating a passage the overlying parts come out with it." Not until 1901 were furnaces built upon this theory. A furnace in Illinois was designed and built by Julian Kennedy with a tight top, and since that time his design has been increasingly widely followed. Some furnace men still are inclined to believe that explosive slips may be due to the sudden generation of gas. They point to the fact that an explosion occurs at a breakout of iron into water, which introduces reactions requiring heat, and that although reactions which are supposed to produce explosions take place normally in a furnace, they proceed too slowly, on account of their heat requirements, to produce a pressure increment. This failure to react explosively under ordinary conditions is because the heat necessary for the reaction is led in so slowly that it never becomes available quickly enough to cause explosive combustion; but if this necessary heat becomes available almost instantly, as it is claimed to occur at a slip, then the explosion will and does occur. Dynamite, burning quietly by ignition but exploding by shock, is also cited as an analogous illustration of how an explosive tendency may be accelerated when a slip occurs. As it has not been demonstrated that certain types of explosions can not occur, the subject will be concluded with the statement that development of design and construction based upon the physical theory has afforded almost complete freedom from blown-off furnace tops, and has also given increasingly more regular work, less terrific and less frequent slips, and a marked decrease in the hazard from injuries from these causes.

PREVENTION OF HANGING AND SLIPPING.

Where the subject of hanging and slipping is treated from purely physical and mechanical aspects, leaving aside theories of chemical reactions causing explosions at slips, one immediately begins to find reasons for improvements effected and the paths along which future improvements may be expected. Keeping in mind the facts of hanging due to wedging, arching, and bridging on account of mechanical obstructions or excessive carbon deposition induced by local irregularities, the principal items which cause hanging, and consequently slipping, are as follows:

1. Construction and design.
   (*a*) Relation of size of bell to stock line.
   (*b*) Distribution of materials in the furnace.
   (*c*) Contour or lines of furnace.
   (*d*) Preservation of lines and linings.
   (*e*) Inferior brick and bricklaying.
   (*f*) Location of gas offtakes.
   (*g*) Distribution of blast.
2. Materials.
   (*a*) Physical condition of ores.
   (*b*) Structure of coke.
   (*c*) Size and cleanliness of coke and flux.
   (*d*) Irregularity in materials.
   (*e*) Insufficient slag volume from materials.
3. Practice.
   (*a*) Insufficient, excessive, or varying blast volume.
   (*b*) Tuyères of unsuitable length or diameter.
   (*c*) Improper charging.
   (*d*) Excessive water cooling of lining.
   (*e*) Unsuitable slag composition.
   (*f*) High heat.
   (*g*) Water leaks or excessively varying moisture content.

It is not possible to prepare a description of design, construction, selection of materials, or practice covering such a variety of factors as the above, which can be of universal application over the wide range of ore mixture, cokes, fluxes, and grades of iron that characterizes the blast-furnace industry of this country. The following discussion primarily applies to practice on Lake Superior ores.

DESIGN OF BELL AND RELATION TO STOCK LINE.

The relation between the diameter of the bell and that of the stock line is held within close limits at present. Not many years ago there was a wide variation, as is shown below.

Variation in relation between diameter of bell and of stock line.

Furnace.	Diameter of stock line.	Diameter of bell.	Furnace.	Diameter of stock line.	Diameter of bell.
	Ft. in.	*Ft. in.*		*Ft. in.*	*Ft. in.*
A	16 0	9 0	G	15 6	11 1
B	16 0	9 11	H	16 6	11 0
C	16 0	9 11	J	16 0	12
D	15 6	8 0	K	14 0	10 6
E	15 6	12 0	L	17 0	12 0
F	15 6	9 0			

Some plants used a narrow bell with the idea of preventing the accumulation of fine material next to the lining, while those using a wide bell claimed that such a bell did place the greater proportion of fines next to the walls and thereby prevented channeling next to the lining, and cutting of the brickwork by excessive localized reduction and melting. The main objection to placing fines next to the walls was that the fine ores, stone, and coke dust would become semifused in the course of their descent and stick to the lining, giving rise to scabs and scaffolds. To support this belief was the fact that many furnaces using a relatively large bell experienced severe slips, accumulation of scabs, and cutting of lining.

Smaller bells, however, gave no marked improvement, and so-called distributor devices were introduced. These consisted of deflector rings, cylindrical or conical, placed outside of and extending below the hopper extension to a point below the lowest position of the bell when open. Some variations of the distributor were an annular casting which could be raised or lowered at predetermined charges in order to distribute the ore alternately against the walls or in a ring away from the walls, or cutting out of alternate segments of the deflector ring to allow certain parts of the discharge from the periphery of the bell to go to the walls while the adjacent parts were deflected. In most instances, such modifications of the bell afforded relief from excessive and heavy slipping, erosion, and scaffolding, but at the expense of some other desirable feature of practice, usually in higher fuel consumption and decreased tonnage, even if the walls were kept clean. Two instances are known where a distributor of the above type was replaced, during the blast, with a large bell, and the furnace upon being started got hot faster than burdens could be put on to keep the silicon content in the iron down.

The best work on Superior ores is now being done with a relatively large bell, 12 feet to 12 feet 4 inches on a 16-foot stock line, which places an annular heap of ore about the walls with a central conical cavity or depression. The fines accumulate in larger proportion at the outside, with the coarse ore running down the face of the pile to the center. The difficulties which seemed connected with the large bell have largely disappeared with changes in the design of furnace lines, modification of means employed for the preservation of linings, and improved distribution of the charge on the bell before it is dumped. Attributing difficulties to the accumulation of fines next to the walls is not logical, for experiments with small-scale model furnaces have demonstrated that fines tend to move toward the center, and with the central part more permeable to ascending gases, this tendency would be accelerated by the faster dropping or movement at the center. This keeps the more intense action to the center of the furnace, in contrast to the action where coarse material accumulates in excess at the sides.

The method of dropping the bell has considerable effect on the relation of fines going to the outside to coarse material going to the center, and the condition of the ore also causes variations in the relation. With a bell opening slowly, or with a charge of wet or clayey ore, the tendency of the ore will be to drop nearer the center than when a bell opens quickly or when the charge consists of lumpy ore.

A final factor is the height at which the stock line is carried. With a 16-foot throat and 12-foot 3-inch bell the stock line is usually carried at 14 feet below the top, or about 5 feet below the bottom of the bell when it is dropped, and 7½ feet below the bottom of the bell when closed. It can be carried at 12 feet to advantage when the gas offtakes are not led off at too great a distance below the top. As a matter of fact the height of the stock line in relation to distribution of ore from the bell is at most plants seemingly more of theoretical than of actual importance, for a stock line supposedly at 14 feet varies from 12 to 19 feet. One of the advantages claimed for the Kileen distributor was that irrespective of the variations in the height of the stock line the distribution of material as discharged from the distributor was approximately constant. With no distributor the height of stock line has a considerable influence upon distribution.

DISTRIBUTION OF BURDEN.

The correct distribution of the charge on the bell is perhaps a chief factor in promoting regularity in furnace operations and one in which it is most difficult to obtain theoretically correct results. In getting the ore from the bins to the large bell there are from two to four drops, at each of which the coarse material may roll more or less to one side. The direction of fall being usually always the same, there is likely to be a pronounced concentration of coarse material toward the side of the furnace opposite the skip incline. This induces channeling by the blast and cutting back of the lining, which causes hanging and slipping. Upon the extent to which design of the charging apparatus obviates this detrimental sizing of the charge depends largely on the uniformity of movement of the furnace.

The majority of furnaces use a stationary double-bell top. At these a great deal of experimenting is necessary in determining the angle and speed of dumping of the skip car. Overthrow of material from the skip is also a point to be watched. If the angle and speed are correctly fixed to give the best possible distribution of material about the periphery of the large bell and the distribution still falls short of the desired result, defects in the design of the receiving hopper or in the capacity of the throat are usually responsible. In some cases lengthening the throat to equal the capacity of the skip has almost eliminated sticking and slipping. The stationary top has given regular and good practice on exceptionally low coke consumption, but the possibilities of defects in the distribution are nevertheless very great with this type. Even if the top adjustment and the dumping of the skip are correct for one mix of burden, with a progressive or sudden change in materials, the furnace may develop a hot spot through irregular heating within six weeks to six months after it is blown in, or sooner or later hanging and slipping may become a menace to safety and good practice.

REVOLVING DISTRIBUTORS.

The present tendency is to install a mechanical distributor. There are two classes of distributors—those revolving on top and those revolving at the base of the skip incline. Those revolving at the top of the furnace are all alike in principle; that is, the charge is deflected from an angle of about 60° to one of about 90° before it is dumped onto the hopper of the large bell. They differ in the way the charge is dumped onto the large bell and, to some extent, on the small bell. Some are open to the objection that if the operating mechanism of the distributor is deranged, the furnace must be stopped until repairs are made. Distributors revolving at the bottom of the skip incline are represented by modifications of the Neelend bucket. With this device the revolving mechanism is removed from the top of the furnace, the distribution can be inspected easily, and in event of a breakdown the furnace can still be filled satisfactorily.

DESIGN AND POSITION OF BELL.

No distributor or design of receiving hopper and throat can exert its maximum benefit unless the large bell is centered in the furnace. In addition the bell should be balanced before placing in order to avoid side thrust and swinging of the bell when it is lowered. The bell, for the large percentage of Mesabi or fine ores now used, should have a slope of 53°, and machining the surface is advocated at many plants. The resulting regularity of practice repays many times the time expended and the cost of constructional charges and design. The life of the lining is invariably reduced by localization of coarse ore in one segment of the furnace. Hot working will always occur at this point, the abnormal heat softens and fluxes the lining, and erosion and hot spots are the result. Spraying with water may prevent damage to the furnace shell, but there is no remedy for the hole gouged out, as material tends to build up and peel off, and the hole to constantly grow larger.

LINES OF FURNACE LINING.

Alteration of the lines of the furnace has often been essential, in addition to correct distribution, to freedom from slips. It is a matter of record that furnaces of relatively small height are freer from slips than high furnaces. Although this fact has been attributed to less crushing of coke, the principal factor contributing to this condition is that such short furnaces have a more tapered stack, which offers less opportunity of a foothold for material to freeze onto.

CONTOUR OF UPPER PART OF FURNACE.

Improvement in lessening slips has been obtained in high stacks by extending the straight brickwork down from the top of the furnace for as much as 22 feet and by running the inwall straight up from the top of the bosh as much as 9 feet. Shortening the cone segment of the inwall in this manner has greatly lessened the tendency toward slips, because the greater slope of the inwall affords less foothold for arches to spring from and for wedging of the stock. Wedging may be considered to take place in the upper part of the furnace, whereas arching usually is confined to the lower part. The wedging is due to expansion of the stock from heat in its descent, carbon deposition, channeling, and formation of scabs. Arching is more usually due to the cementing of slag-forming materials at the top of the bosh.

The extent to which straight brickwork may be carried at the top of the bosh and from the top of the furnace down is problematical. If a height of 5 feet at the top of the bosh and a depth of 20 feet at the stock line is taken as typical of the extent of straight lining in the stack, the fact that freedom from slipping is being attained in furnace practice with wide variations from these contours indicates that the requirements for satisfactory lines are not rigid. There is some point down to which the straight brickwork at the top may be carried that will present the maximum advantages of a steep batter of the lower inwall, without overreaching the point where the increase in bulk from carbon deposition and disintegration of the ore would cause wedging of the charge. The depth of straight brickwork at the top is a problem to be settled only by experience at individual plants or groups of plants using closely identical materials for burdens. Knowledge of the depth at which reduction, carbon deposition, disintegration, and swelling of the charge begin is not available. In view of the improvement that might be effected by definite data along these lines, it is to be regretted that more is not known, as such information would possibly enable the lines to be designed with more precision and with greater expectation of more regular working, decreased flue-dust losses, less off-grade iron, and fewer slips. Knowledge of the gas-ore reactions for various mixes is totally lacking for American blast-furnace practice.

CONTOUR OF LINING AT THE BOSH.

Slipping caused from scaffolds is confined largely to the bosh and slightly above it. Here furnace men are also confronted with uncertainty as to the exact conditions. One may, by a study of the lines of furnaces when blown out, form a theory of the location of the zone of slag formation and of the nature of the physical changes taking place there. It is known from various researches abroad that there is a point where swelling of the ore from its reduction ceases and its further descent through the furnace is accompanied with only such small expansion as would be caused by the increased heat. At a certain point well localized under conditions of uniform practice the various solid materials begin to soften, become pasty, and then to liquefy by reason of the combination of the various entities, such as sand, clay, lime, and oxides. Simultaneously with the formation of slag the liquefaction of such iron sponge as has arrived at this point and the reduction of residual iron oxide begins. The range of this action is evidently not confined to a narrow belt, and for a distance of a few feet there must be a zone of more or less pasty material in the transition stage between the solid and molten phase. The transition from the solid uncombined state, in which the material bulks large by virtue of the spaces between the particles, to a molten condition is accompanied by the following changes: A marked contraction in volume and a change of state from a solid slowly descending body, through a condition of agglomerated pasty material, to the relatively great fluidity at which the slag and iron quickly drop to the hearth.

If this zone of slag formation can be held where the area of the cross section is at a maximum—that is, at or just above the bosh—it is clear that the transition from solid to liquid phase should not interpose any resistance to the passage of the gas upward. If this zone, however, should be embraced in the contracting walls of the bosh, the effect of its diminished cross section would be to compress the pasty or agglomerated mass into a plug of relatively impervious material through which the blast could penetrate only with difficulty. Exposure to the cooled bosh would congeal adjacent portions of the slag, unreduced iron oxide, and carbon dust into a scab of refractory material, thus further decreasing the area of the cross section in which slag formation is taking place. The combined effect of resistance to blast pressure and freezing of material to the sides can easily be sufficient to arch the charge and prevent further descent, when the furnace will commence to hang.

Building the inwall straight for a few feet above the bosh provides some leeway for the inevitable rise and fall of the semifused plug of material in the fusion zone, but such a cylindrical section above the bosh is without benefit unless the height of the bosh is kept down. If the burden material should pass the cylindrical section and enter the water-cooled bosh before fusion and shrinkage takes place, the furnace will either work irregularly—that is, the iron will be alternately too hot or too cold, and frequently hanging and slipping will result—or the furnace manager will have to accommodate his practice to the furnace lines at the expense of lower blast heat, higher fuel consumption, and probably more rapid deterioration of the furnace lining.

The location of the top of the bosh must be dictated by the study of previous "blow-out lines" and furnace practice, in the absence of authoritative information as to intervening furnace temperatures and pressures, and points of slag formation. Keeping the bosh at a moderate height necessitates enlarging the hearth, or making a relatively flat bosh. The most satisfactory construction when working on Bessemer and basic iron has been found to be a low bosh, a steep bosh angle, and a wide hearth. A flat bosh accumulates material, wedges the descending coke, and causes high blast pressure, whereas the steeper bosh gives the least likelihood of material hanging to the side, keeps the column of coke open and thus promotes smoother working. The location of the top of the bosh, and consequently the hearth diameter and bosh angle, is somewhat dependent upon the limits of blast temperature which it is possible to carry, upon the sulphur content of the coke or ore, and consequently the basicity of the slag, and the character of ore smelted and pig iron made. Smelting of hard Clinton ores, or magnetites, is a very different proposition from the smelting of easily reduceable Lake Superior ores. High-silicon iron introduces a variation, the definite limits of which are fixed with difficulty.

PRESERVATION OF LINING.

After the operator has fixed upon the distribution that guarantees the best arrangement of charges in layers of uniform permeability for a given cross section, with the least possible channelling, and upon furnace lines which assure uniform and unobstructed descent of material with the least distortion of distribution, the preservation of these conditions is necessary to insure uniform and safe working. Failure of the lining to stand up under the work is detrimental because much of the benefit from good distribution is lost when the lining becomes worn in one or more spots.

PRESERVATION OF THE LINING AT THE STOCK LINE.

At the stock line the lining has to resist the continued impact of material discharged from the conical bell as well as the disintegrating effect of carbonaceous gases and varying temperatures. The abrading action of coke, scrap, and limestone as they are deflected outward from the bell hopper against the lining cuts an irregular channel or recess in the brickwork. This cutting action may extend some distance above and below the normal position of the stock line, according to the varying heights of burden in the furnace when the bell is dropped. The disintegration of the brickwork may reach such a stage that whatever advantage is obtained by relative distribution of coarse and fine material or contour of the top of the stock line is lost. If it be assumed that the lower inwall retains its shape, the inferior distribution and arrangement of material at the stock line may result in slips, because the increased diameter allows a thin stratification of less impervious material at some point or points. As this defective spot lowers in the furnace it induces channeling; the relatively thicker section receives insufficient gas to preheat it; and some portions of the charge arrive at the bosh insufficiently reduced or relatively cold, where they may introduce hanging and slipping by chilling the furnace, lowering the fusion zone, or plastering the sides of the furnace.

The effect of good distribution is also lost when the lining becomes eroded below the stock line. With proper distribution the movement of stock should be faster in the center of the furnace, on account of the greater coarseness of the core. Its more rapid descent creates a tendency in the surrounding material to work toward the central part. So long as this movement is regular about the surrounding ring of fines, no detrimental distortion of material is introduced, and the penetration by the gas tends to become more uniform by reason of the column of stock becoming of more uniform permeability throughout its cross section. If the lining should erode at some spot, the stock tends to spread out and fill the increased space. This promotes thinning of the layers in the charge at this place and permits an increased local upflow of gas. Any such effect is slowly cumulative, because the increased velocity and heat of the gas causes the adjacent materials and wall to become pasty and agglomerated. The recess formed in the wall affords a skewback, upon which an accumulation of the conglomerate material builds and pushes its way out into the descending stock. This material may continue to build out and form a permanent scaffold, may alternately build and slip off, on account of the heavy weight of the column of stock lodged on it, or may be melted off by cleaning blanks or by "blowing down" at low heat.

Various means are employed to preserve the shape of the stock line. In one type of construction the brickwork is replaced by a cast steel or iron shell which is riveted to the furnace jacket on top of the inwall brickwork and is either spray cooled or air cooled. The construction is somewhat complicated because expansion and contraction of the metal shell must be provided for, and the shell can be relied upon to carry only its own weight, so that much of the top work must be carried by other construction. Large wearing plates or rings of steel, embedded in the brickwork and tied in with rods, have caused trouble where used on account of their warping and displacing the brickwork. Tile of hard-burned brick have given fair satisfaction, but are not an absolute guaranty of preservation. The use of cast-iron brick invites trouble from variation in size when exposed to varying temperatures. Such action has resulted in shearing of the rivets on horizontal seams of furnace shells on top. The use of cast-steel plates, which are sometimes water-cooled and are hung and tied in front of the lining, or of high-carbon (or cast-steel) plates of small area anchored in the brickwork or set in concrete, at the stock line has proved to be the most efficient means of protecting the stock line from abrasion. When small plates are used any warping that takes place is in small local segments, which does not greatly affect correct distribution.

Most furnace men regard stock-line protection as an important means of attaining regularity in furnace working. A few anticipate the need of renewal and the necessity for shutting down at some time during the blast to repair the stock line and do not provide mechanical protection. As a rule, however, most furnace men consider the difficulties of access, the hazards from gas, the trouble in starting up, and the slipping and irregular working from the failure of the stock line prior to repairs as sufficient incentive to provide maximum mechanical protection at this point. Only a minority consider the preservation of the stock line as a minor point.

PRESERVATION OF THE LINING ABOVE THE BOSH.

Preservation of the brick lining in the inwall, from the bosh up to about 40 feet above the mantle, is a most difficult problem. Although intensive water cooling in the bosh, to the inside face of the lining, has proved sufficient to preserve an ample thickness of lining over a blast of several hundred thousand tons, in the inwall the lining must be largely left to its own resources and to the attack of heat, gas, and fluxes. These destructive agencies act in different ways, but all, under certain conditions, will effectually disintegrate refractory linings. Alkaline salts have been known to enter the body of the brickwork and to flux out the fire clay; lime dust at high temperatures readily combines with clay; furnace gas on penetrating fire-brick construction and coming in contact with iron oxide undergoes a decomposition by which carbon is deposited in the interstices of the brick lining, and this may disrupt and completely disintegrate the brick. The wear upon the lining by abrasive material in the stock may be a fairly insignificant factor except at points where there is local heating sufficient to soften the brick.

However, as the concentration of coarse abrasive material in any vertical segment of the stock column induces channeling by the blast, with consequent higher temperature and increased velocity of gas travel, there is likely to be intermittent, and at times constant, periods when the wear of the lining by abrasion is markedly accelerated by partial softening or incipient fusion of the lining from the increased temperature and velocity of the gases.

THICKNESS OF LINING, AND WATER COOLING.

The means taken to preserve the lining in the inwall are comprised in the use of thick, moderate, or thin linings, and in the extension of water cooling to the inwall construction.

USE OF THICK LININGS.

An excessively thick lining is characteristic of older practice, and some furnaces built within the past three years have thick linings. Good work has been done with these linings, but because of the high cost of construction, and the expense and time required for removal and replacement at relining, the natural tendency is to use them to destruction. Long before the lining has worn back to the shell, however, the furnace lines may become so irregular from local failure or erosion of the lining that it is difficult to prevent protracted hanging and heavy slipping. There is usually a period, preceding the blowing out, in which the furnace crew have to contend with severe scaffolding and hearth trouble. Water sprays are used on these thick linings when the shell becomes hot, but as a rule sprays can not counteract failure at any point until the lining has become eroded to a detrimental depth. Repeated observation shows that although brick in the upper inwall can withstand the heat and friction, the brickwork 6 to 30 feet, or more usually 15 to 30 feet, above the mantle wears out relatively quickly on thick linings. This is the zone of maximum erosion and is roughly the point at which the material is still coarse and firm, although at a heat sufficient to somewhat soften the brick. When the face of the brickwork has worn away so that the shell gets red hot, a spray is put on. By this time, however, there may not be more than 6 inches of brickwork left of an original 60 inches. The water spray may succeed in holding this thin wall, or if the wall crumbles the spray may preserve the shell for long periods, although incandescent coke is against the lining. If the spray is put on as soon as the paint on the shell starts to darken and before the shell becomes red hot, a thicker inwall will be preserved. Steam is sometimes introduced between the lining and the shell, a ½-inch steam line tapped into the shell protecting about 100 square feet of surface. These steam jets are more useful for patching cracks than for checking erosion, as in the latter case they are of doubtful benefit. Tonnages on linings 48 to 72 inches thick amounting to 1,800,000 tons of iron have been obtained, although the last 150,000 or more tons has usually been made under very trying conditions of slipping and with high consumption of coke.

USE OF THIN LININGS.

The other extreme is to use a thin lining, 9 to 13 inches thick. The difficulty with thin linings is that the life of the entire lining is dependent upon that of the weakest part. When local failure occurs the entire lining may fail on account of lack of stability, owing to the thin wall and falling in of adjacent brickwork. Failure of the lining is followed by heavy slipping, caused by the adhering and building of material on the cold shell, a condition which necessitates blowing out after too short a run to make this construction feasible. Also, the temperature of the cooling water must be carefully watched in order to prevent scaffolding, even when the lining is intact. One instance is known where a thin-lined furnace being blown in was very nearly put out of blast by the formation of a scaffold at the mantle, a shutdown being averted only by cutting off the water on the first two cooling rings of the jacket above the mantle, with much trouble from hearth difficulties and cold iron. Thin linings have been replaced at some furnaces with 22½-inch linings.

USE OF LININGS OF MEDIUM THICKNESS.

Moderately thick linings have given good results and tonnages of 600,000 to 900,000 tons to a lining. A lining 27½ to 36 inches thick has a seeming advantage for the reason that the brickwork on a thick lining will cut back to a thickness where exterior cooling checks further erosion of the brick. On a moderately thick lining this cooling action will be almost immediately effective, also a water spray can be used to immediate advantage when local failure of the lining develops, thus obviating deep erosion before the spray is effective. Consequently the contour of the walls can be expected to remain more uniform, without the excessive chilling caused by a thin lining.

PLACING OF COOLING PLATES.

The practice of water-cooling linings has been very successful, although it has been brought into disrepute repeatedly by the practice of placing the nose of the cooling plate flush with to 9 inches back from the face of the lining or too close together.

The plates have been placed so near the face in order to preserve the lining at approximately its original lines. That this is unnecessary is indicated by the usual experience that a furnace starts to work most smoothly three to five months after it has been blown in, when it may be assumed the contour has reformed by the cutting back of the original lines. Although the deviation may be small, it is a sign that rigid holding of contours is far from necessary. Placing the plates near the face of the lining has been a failure, either because they could not survive long, owing to cracking and erosion of the nose, or because the water had to be turned off on account of the scaffolding and slipping induced by excessive chilling of the face of the lining. The best practice is to place stock-cooling plates 14 to 18 inches from the face of the lining, spaced 3 feet to 3 feet 6 inches on vertical centers and about 5 feet on horizontal centers, each row being staggered. Such cooling is not intense enough to cause scaffolding or disposition of cyanides, but chills the face sufficiently to check abrasion by the grinding of descending stock against softened brick and to retard fluxing action. Thick linings which had previously shown hot spots and commenced to work irregularly at the end of 12 to 18 months have worked smoothly on successive linings with stack-cooling plates inserted for upward of three years. The height of the top plate is about 30 feet, to prevent the formation of a recess or shelf on top of the top row from erosion, as may occur when the height is but 20 to 25 feet. Several plates may be lost without apparently affecting the work of the furnace, and the effect of possible shelf formation between the rows, although theoretically detrimental, has not been marked.

INFERIOR BRICK OR BRICKLAYING AS A CAUSE OF FAILURE.

Failure of the lining, when not due to faulty distribution or the contour of the lining, is frequently ascribed to the brick itself. In the inwall defective brick have a wide opportunity to cause failure. Among the chief factors contributing to inferior brick for the inwall are irregular size, spalling propensity, and insufficient hardness. Excessive porosity, excess iron oxide, sand, or other impurities, deficient resistance to fluxing, insufficient refractoriness, and shrinkage are possible faults, although not as a rule outstanding or of frequent occurrence. The open joints left by irregular brick require an excessive quantity of fire-clay grouting, which is comparatively easy to flux and is permeable to gases; any spot in the inwall of insufficient hardness begins to abrade at an early stage of the blast, and spalling may accelerate any failure due to other tendencies; but, as a general rule, it is the opinion of furnace men that fire-brick construction for the inwall is fully abreast of the perfection to which other factors affecting regular working have been brought.

Given satisfactory brick, good bricklaying is essential. The expense of grinding, washing, weathering, mixing, molding or pressing, and burning demands equally painstaking work in placing brick in the furnace. If the shell is heavy—$\frac{3}{4}$-inch plate, double and triple riveted—the brick can be placed against the jacket. Such construction prevents the packing space yielding and permitting cracking of the brickwork by expansion strains. The formation of cracks, and a hot jacket are not uncommon where a large packing space is used. For jackets lighter than $\frac{5}{8}$-inch, a packing space filled with some yielding material is usually essential. There are several examples of split shells or sheared rivets on furnace jackets when insufficient or no packing space has been provided. It is, of course, common opinion that thin joints should be made in laying the brick, and that accuracy in making the joints should be exacted. After the lining has been placed, it is essential to dry it thoroughly. Blowing it with a green damp lining handicaps the durability of the lining by the generation of steam in the interstices of the structure, thus introducing the possibility of the formation of crevices and rupturing of the fire-clay bond. Two weeks is none too long, in the opinion of most furnace men, for drying out the lining.

GAS OFFTAKES AND DISTRIBUTION OF BLAST.

Other structural defects which induce slips are improper blast distribution and improper location of the gas offtakes. The gas offtakes should be high enough above the stock line so that opportunity will be afforded for any stock carried upward by a rush of gas will fall back before it is swept over into the downcomer, and so that stock dropped from the bell will not be carried over into the gas offtake. The offtakes should be large enough in diameter and of sufficient number so that the velocity of gas at each opening will not be excessive. With fast driving, there is a tendency for the gas to channel up through the stock column, cut the walls, and cause hanging if an excessive amount of material is lifted and carried over directly from beneath the location of the gas offtake. A similar tendency may be noted when a gas offtake is directly over the juncture of the bustle pipe and hot-blast main, or over the tapping hole or cinder notch. Accordingly the best location of offtakes is off center from the location of the blast main and notches.

Improper blast distribution is seldom the cause of slips, but occasionally a defect in blast allows more air to enter on one side of the furnace than at the other. This causes one side of the stock column to travel faster than the other, the top of the stock becomes lopsided, and the distribution is distorted, with channeling of the gas up one side; then cutting of the walls, and scaffolding, and heavy slips may result. This is avoided in construction only by having the hot-blast main join the bustle pipe at right angles to the tangent of the bustle pipe at the point of juncture. The hot-blast main should preferably extend from this point in a straight line back past the stoves.

MATERIALS USED FOR THE BURDEN.

FLUX.

Limestone or dolomite occasions the least difficulty and produces the least irregularity in furnace work of any of the materials of burden. Dolomite, when used exclusively for a flux, may cause considerable trouble with some practices and grades of ore, but the trouble is very easily remedied by introducing calcite into the mix. The difficulty is due to indeterminate causes, involving the fusion point, fluidity, and sulphur-saturation point of the slag. When a more suitable proportion of lime and magnesia in the slag has been determined, other factors which may cause slipping are too large a proportion of dust or dirt, too refractory limestone, crushing the stone to excessively large or small sizes, and irregularity in analysis. Elimination of fines by screening and washing the crushed limestone has been specified at several plants, and the additional cost has been offset, it is stated, by improvement in practice. Further elimination of gangue is obtained by specifying a lower silica content in the limestone. With increasing amounts of gangue in the burden to be fluxed, the use of a limestone with lower silica content decreases the amount of stone used, and thus reduces appreciably the variation from changing the amount of available lime in the burden. This is a source of irregularity which is aggravated by a large proportion of silica in the stone and by the use of a large amount of flux. The size of the stone should be dependent on its refractoriness, as the temperature at which carbon dioxide is completely expelled from various kinds of limestone varies. So long as excessive amounts of limestone persist in coming down to the tuyères, there is need of finer crushing. On the other hand, it should not be crushed so fine that all the carbon dioxide is expelled before the limestone has passed through the zone of reduction. Charging finely crushed stone, similar to road-building material, has been found to cause slips. The usual specifications are for limestone to be crushed to pass a $4\frac{1}{2}$-inch ring, and not through a $\frac{1}{2}$-inch ring.

COKE.

The character of the coke may be the keystone of uniform practice and freedom from excessive slips, as even with satisfactory ore and flux, and with every attention to details of construction, inferior coke is productive of irregular practice. The chemical analysis of blast-furnace coke is becoming less an object of scrutiny, because the working limits of ash and sulphur content are approximately fixed, and excessive percentages of these constituents are kept down either by the use of coals which contain the proper percentages within limits, or by washing the coal before coking. If the percentages come within the desired limit, the usual variation in practice appears to be negligible in coke from the same operation. However, from the fact that many furnaces do not draw coke from one operation or set of ovens, there is usually a sufficiently wide variation in analysis to demand attention. It is common experience that variations in coke, as shown by analysis, do not bring about the irregular furnace practice that a similar variation in the ores or fluxes do. The fact that probably the greater proportion of the ash is incorporated in the slag at the tuyères accounts for this. Variations in slag-forming constituents which combine at the bosh should introduce a more direct effect upon the regularity of descent, because a wide variation in fusibility of the slag in the smelting zone is immediately reflected in increased pressure, hanging, and slipping, whereas a considerable range in acidity or basicity may exist in the hearth without any marked effect on the working of the furnace.

High-ash content is in itself frequently detrimental, in that it introduces cleavage planes into the coke structure and may thus characterize physically weak coke. The physical requirements for coke are a certain uniform degree of hardness, toughness, porosity, density, and possibly absence of dense graphitic coating on the surface. Excessive softness and brittleness invite crumbling during drawing, transportation, and charging, with the formation of an excessive amount of dust. This introduces a handicap to uniform practice and freedom from slips by reason of the less open character of the column of stock. To eliminate this drawback, the coke is largely screened at the bin, and this, in addition to causing a more open stock column, also lowers the ash content and involves little or no loss in heat value, inasmuch as fine coke is evidently dissolved to a large extent in the top of the furnace by carbon dioxide. A more serious consequence of very soft or brittle coke is its liability to be ground to pieces by the abrasive action of the furnace walls and of the burden in its descent through the furnace, thus choking the furnace, with detrimental results to uniform working.

The effects of variations in the size and density of the coke are especially serious when the coke is charged by volume. By reason of the variation in weight charged, for the same volume, there is a tendency from day to day, or period to period, for the fusion zone to rise or fall. Excessively large pieces of coke permit the fragments of ore, especially if it is fine ore, to roll or heap together, so that the ore may be insufficiently reduced or even fused prematurely, and on arriving at the fusion zone in this condition cause chilling of the furnace. Coarse coke also presents a difficult handicap to the accommodation of charging practice to the lines of the furnace, if the coke is too dense or not porous enough to permit prompt combustion of the large pieces in a restricted zone at the tuyères. The burning must necessarily extend high up, thus making most difficult the concentration of combustion and localization of intensity of heat necessary to keep the slag-formation zone at the desired point. This introduces a possibility of irregular working, because the contraction in volume of material from combustion may not take place in a manner suited to the batter of the bosh. Excessively small coke, even if of the desired porosity and toughness, introduces irregularity by reason of its lessened ability to keep the stock column open enough to allow an approximately uniform and easy upward flow of gas throughout the section of the stock column. The blast is forced to tear a local channel through the impervious heap of material, which is not conducive to proper preheating and reduction of the other parts, thus giving rise to slips.

Variations in the porosity, density, cell structure, and surface of the coke may also cause irregularity and slipping. The increase in speed with which a furnace works when more combustible coke comes down to the tuyères is often beyond control by any increase in blast temperature. In this case the heat of the blast is insufficient to meet the demands from the quicker movement of the burden down to the hearth and chilling takes place, or slag may form lower down and chill on the walls, and the charge may arch and hang. Corrective measures, such as using smaller tuyères, plugging the tuyères, lightening the burden, or reducing the blast, are often no sooner applied than it is found that the character of the coke is changing to a normal or even excessively dense character.

Irregularity in the size, density, structure, and surface of coke is common where furnaces are furnished coke from several operations or sets of ovens, even from the same coal. Variations in temperature and time of coking and in methods of drawing and quenching cause variations in the characteristics of the coke that are difficult to cope with, even with coke from the same ovens. The development of tests that will indicate the probable behavior of coke in a furnace from a preliminary study of its physical characteristics and a rational set of specifications based upon physical qualities for coke would afford furnace men much relief from irregularity in practice and the attendant difficulties and dangers incident to the hanging and sticking of the charge.

ORES.

The tendency in blast-furnace practice throughout the country is of necessity toward the use of ores of increasing fineness and of decreasing metallic content. This movement has been retarded from time to time by the utilization of new deposits previously unknown or unavailable by reason of geographical location or prejudicial composition and by the fact that, as the richness decreases and the difficulty of smelting the ore at a profit increases by reason of the growing fineness, leanness, and cost of the charge, hitherto excessively expensive processes for concentration and agglomeration of the metallic material become an accepted and profitable feature of practice.

EFFECT OF CHARGING COARSE ORE.

The handicaps to safe practice introduced by the character of the ores charged is dependent upon their size and uniformity. Large lumps of ore may pass through the furnace without becoming completely reduced. The effects of charging occasional lumps of ore the size of a man's head are almost impossible to detect, but occasionally some of the hard ores are insufficiently crushed for furnace use or are charged in excessive amounts. Experience is common where a proportion of 15 or more per cent of a hard "old-range" ore has immediately caused difficulty. The presence of lumps of partly reduced ores beyond the point where indirect reduction takes place and where the direct action of carbon must take up the unfinished work may result in frequent chilling of the hearth and in scouring cinder. The loss of equilibrium at the fusion zone in cases where direct reduction is in high proportion results in insufficiently carburized and smelted iron and also partly reduced and relatively cold ore being precipitated into the hearth. Such material demands a higher heat to be restored to normal condition than does partly plastic iron sponge and may easily result in ironed-up tuyères, loss of bronze cooling equipment, and chilled holes with their attendant danger and difficulty. Considerations of correct practice no less than of safety require further crushing of any ore so dense or difficult to reduce that it comes down through the furnace without adequate indirect reduction.

EFFECT OF CHARGING FINE ORE.

Similar conditions obtain when the burden is made up of excessively fine ore. Even the most ideal distribution of burden, proper lines of furnace, proper grades of coke and limestone, and skillful practice do not suffice to overcome completely the erratic behavior of such burdens. Several factors contribute to this. Too high a proportion of fine oxides induces deposits of finely divided carbon as a result of any marked variation in the distribution or the rate of descent, thus causing the column to swell and stick in the upper inwall. The black fume given off during such practice is an indication of this carbon deposition, and is sometimes observed when a large proportion of flue dust or exceptionally fine Mesabi ore is used. This results in frequent slipping at the top, which causes irregularity in charging, a condition which aggravates and magnifies any tendency toward irregular working to which the furnace is prone. Hanging is also induced, farther down in the furnace, by the fact that the fine materials cause an excessively dense stock column by reason of their easy reducibility and their consequent increase in fineness. As the gas can ascend through such a charge only with difficulty it forces irregular paths through the column. The tendency of the fine material to pack and fill the interstices of the charge precludes much possibility of the gas currents being diverted from their segregated paths until the column is shaken up by a slip. The channeling permits the gas currents to reach the top of the charge without giving off their sensible heat and those parts of the charge adjacent to the streams of rapidly ascending hot gas become plastic. Where this fine plastic material comes in contact with the walls, it congeals and adheres to the relatively cool surface, and results in hanging, scaffolding, and slipping. Such agglomerated material, if dislodged, and portions of the ore charge which have packed and become impervious to gas currents, may arrive at the melting zone insufficiently reduced. Lack of reduction of fine ores gives rise to all the hearth difficulties and slipping which characterize difficultly reducible ores, or ores crushed to too large a size.

From the extreme of irregular and often dangerous practice characterized by an extreme proportion of fine ores, the practice improves as their proportion is reduced, the furnace finally exhibiting only occasional and infrequent symptoms of hanging. It is often difficult to mark the point at which poor practice begins, or the percentage of fines which definitely causes poor working, as the effect of the use of such material is usually cumulative, possibly not immediately producing a slowing up in production, offgrade iron, or heavy slipping. Although indeterminate, there is a point where further inclusion of fines in the burden is detrimental to both practice and safety, and among investments calculated to promote efficiency and improvement in practice and working conditions, equipment for the proper treatment of the ore, often only a small proportion of the total charge, holds out great promise not only of effecting the desired object, but also of returning interest on the investment.

SINTERING AND BRIQUETTING ORES AND FLUE DUST.

Many processes of sintering, nodulizing, and briquetting ores and flue dust are in use, both in the United States and abroad, which give products of varying strength, reducibility, density, purity, and cost. Their introduction among American works has been slow, largely on account of the possibility of using ores of rich iron content and good physical characteristics, and also on account of conflicting claims of promoters. Definite information would be of value to furnace men in enabling them to apply the most suitable of the several available processes to the treatment of flue dust and fine or concentrated ores. Irregularity in the chemical and physical composition of ores presents hindrances to uniform practice which have to be obviated to prevent slipping in furnaces. Physical variations introduce the most discouraging handicaps, as the abrupt irregularities such changes of burden introduce are extremely difficult of control, and the variable practice induced by variation in physical constitution must often be faced without opportunity for an adjustment of burden which will be of immediate avail. Irregular working due to changes in burden can usually be controlled between surprisingly narrow limits provided the furnace crew are watchful and prompt to take action. If variations in the appearance of the slag and iron, the brightness and liveliness of the tuyères, fluctuations in the pressure, movements of the stock line, and appearance of the gas are disregarded, the furnace will inevitably become beyond control, and can be saved only by rapid changes in burden, blast pressure, and volume, or the use of heavy coke blanks. In fact, given the best in design, construction, and material, the fundamental factor of success and safety lies in the interest and attention that the furnace crew manifest in their work.

FURNACE OPERATION.

VOLUME AND PRESSURE OF THE BLAST.

INSUFFICIENT VOLUME OF BLAST.

Insufficient volume of blast is seldom the cause of slips nowadays, it being more a feature of former practice where the blowing capacity of the engines did not keep pace with the increase in size of the furnace. A few years ago, when "slow driving" was for a time emphasized as a means of saving coke and promoting regularity in furnace practice, numerous plants experienced a period of heavier slipping than had been experienced for several years previous, when fast driving had been the slogan. Instances are sometimes encountered, however, of deficient volume of blast, for example, in blowing in a furnace where the burden ratio is increased faster than the rate at which the volume of wind is stepped up, or where a furnace sticks tightly and the blowing equipment does not deliver the desired amount of wind against the higher pressure. Serious difficulties are always introduced by this condition, as the low volume of air and gas in its ascent through the charge always selects the easiest path and it does not penetrate the more difficultly permeable parts. As a rule, this causes hot working near the walls, resulting in scouring cinder from an inner core of raw unreduced ore, which requires direct reduction and an excessive amount of coke, erosion of the inwall, and eventually a cold hearth, off-grade iron, and slipping are the results. If the ore descends faster at the center, with annular rings of unreduced and insufficiently prepared material coming to the smelting zone next the walls, this material may, in addition to the above results, attach itself to the walls and thus promote scaffolds.

EXCESSIVE VOLUME OF BLAST.

An excessively large volume of air in proportion to the hearth diameter or to the combustibility of the coke is probably responsible for a certain proportion of furnace troubles from hanging and slipping. Theoretically, with an increase in the blast the zone within which the combustion of coke is confined is higher, the melting zone is raised, and whatever erosion of lining normally occurs takes place higher up and forms profiles, which may prove detrimental to the resumption of normal practice. Scaffolding is made more pronounced at such times because with a higher blast volume and lower heat than on normal practice a limy slag is sometimes used in an attempt to keep the fusion zone down. The consequence may be that under the normal irregularities constantly encountered, the excessive basicity of the slag magnifies any tendency it may have to build on the wall or to erode the lining, erosion being especially promoted by the abnormal increase in temperature of the lower inwall section. A large volume of blast may also definitely retard the descent of the charge, and, added to any incipient tendency insufficient in itself to cause sticking, may introduce slipping, which would not develop with a normal blast volume.

IRREGULAR VOLUME AND PRESSURE.

Variations in the rate and pressure at which the blast enters the furnace have from time to time been seized upon as explaining the constant irregularities to which furnaces are prone. As regards constant volume, this is closely attained by the use of modern types of engine governors and of recording tacnometers and revolution counters to check the quantity of air blown and regularity of delivery. As a rule the only variations are chiefly introduced by varying moisture content and temperature of the air and by air leaks at the engine and mains. The effects of leaks are perhaps not serious when kept at a minimum, but if they are excessive, as indicated, say, by a consumption hour of 62 cubic feet of air per pound of coke, then if the pressure goes up because of hanging, the leaks increase the proportional amount of air lost. Consequently the furnace receives less air and generates less heat, although more heat is required in the hearth and there is a constant loss by radiation and tuyère water, and therefore the furnace gets cold very quickly. Before a furnace is blown in, the tuyère stocks should be stopped with blank flanges, an engine turned over slowly with the snort valve partly open, and then each stove be put on the line. Inspection of hot and cold blast valves, doors, bolted flanges, and keyed junctions will usually disclose a surprisingly large number of leaks. Hot-blast and chimney valves should be inspected once a week for air leaks. The delivery efficiency of the air tubs can be checked by cards and temperature observations.

After air leaks and piston slippage have been eliminated and the engines are running at uniform speed there remain moisture and temperature variations of the air at the blowing tubs. The use of air that has been dried eliminates these variations, but as furnace men are slow to adopt this method, the problem becomes one of obtaining the advantages of dry blast by other means. The expedients resorted to are to draw the air from outside the blowing room, obviating the high temperatures and moisture contents found in the blowing room, and increasing and decreasing the revolutions 2 per cent for every change of 10° F. in the temperature of the air. Both practices prevail to a limited extent and solve approximately the problem of delivering a constant weight of oxygen to the furnace. The effects of varying moisture, usually unimportant in cold weather, at times become detrimental to uniform operation in the summer. Theoretically an increase of one grain per cubic foot in the moisture content of the blast should cause a change of 25° F. in the combustion temperature and a change of 100° F. in blast temperatures should introduce a change of about 45° F. in the combustion temperature. The obvious remedy for variations in moisture content is to adjust the blast temperature to meet them. However, as other variations in furnace conditions may have an effect opposite to that of the moisture variations, introducing a mathematically calculated correction for moisture may cause more serious variations than the one which is supposedly being eliminated. Such an adjustment has been tried, but its use has not lasted long, as an experienced blower or hot-blast man can judge the necessity of changing the heat more quickly and accurately than can be accomplished by adhering to a calculated schedule.

DISTRIBUTION OF BLAST.

Severe slips, loss of ore dust, and similar troubles are often caused by the irregular distribution of blast at the tuyères. Apart from incorrect design of the hot-blast main and bustle pipe, irregular distribution of air may be caused by the accumulating of dirt in the bustle pipe, by channeling of descending stock by the blast, or by a tuyère opening being directly at the juncture of the hot-blast main and bustle pipe. Cases in which one side of a furnace is receiving more than its share of blast are characterized by vertical shearing of the column of stock, owing to faster driving on that side; the top of the stock column becomes sloping, being lower over the tuyères which are driving fast, thus increasingly disarranging the distribution on top; this distortion of distribution, the folding and shearing of the column, and channeling by gas cause the furnace to work stiffly and irregularly. The combined effect of fast and slow driving and of poor distribution must be combatted, the resultant sloppy or ironed-up tuyères, scaffolding, scouring cinder, slipping, and off-grade iron being alternately indicative of almost every possible cause of irregularity. A portable pyrometer should be used at regular intervals to detect this condition, as a higher temperature at any tuyère indicates that more air is entering that particular tuyère. If two or more tuyères are taking regularly and persistently an undue proportion of the blast, the size of their openings should be promptly reduced in order to equalize the blast distribution. The bustle pipe should be cleaned regularly, as large accumulations of dust result in a few months' operation when dirty gas is used at the stoves.

CHANNELING FROM THE BLAST.

Channeling over one tuyère is not infrequent and is easily detected from the appearance of the material in front of the tuyère; often unmelted scrap and lumps of unreduced ore and uncalcined limestone come down to the tuyère persistently. Channeling over one tuyère is not as serious as over two or more tuyères, nor are these conditions to be confused with the normal variations in the brightness and liveliness of different tuyères from hour to hour. Persistent channeling at some definite side has to be corrected to avoid erosion of the lining. When such channeling takes place directly beneath a gas offtake, it is sometimes due to excessive lifting of stock at the top, and to check it plugging the tuyères on that side for a couple of casts must be resorted to.

BLAST PRESSURE.

Variations in pressure are usual in normally working furnaces, even between furnaces of the same design working on the same burden and practice, and the pressure can vary over a somewhat wide range without apparently materially affecting the working or tending to cause slipping. The pressure of the blast is often held to have a direct bearing on the penetration of air into the center of the hearth. This is because, if the air is assumed to be delivered in constant quantity, the delivery of a given volume through a smaller area should result in a higher back pressure within the blast main and also in a higher velocity of discharge. That a change in tuyère diameter resulting in greater velocity has such a marked or beneficial effect as is indicated by the frequency with which this means is resorted to is doubtful. Penetration of the blast to the center of the hearth is of course essential, but rather than its being due to the pressure of a jet of air, it is more probably due in part to the temperature of the blast and of the hearth, as the higher the temperature is the more eagerly will the oxygen combine with the carbon and the further it will travel, and in part to the blast being supplied in sufficient volume and against sufficient pressure to fill all void spaces, tending to flow laterally before it disperses upward through the less permeable overlying material. A glance into a tuyère suffices to show that the incoming air does not drive direct to any one part of the hearth, nor in a straight line, but that it expands and flows into the cavities or voids in the coke filling the hearth.

No matter at how high a pressure a furnace is blown, if the burden is not properly charged and distributed the gases will find the channel of least resistance, and if this is up through the column of burden rather than through to the core of the hearth there will be little chance of uniform work. Forcing the blast pressure up to 16.5 pounds by inserting smaller tuyères can give only a semblance of the conditions at another furnace doing regular work on a larger tuyère area, where the blast pressure also averages 16.5 pounds. The essential condition for penetration by the blast is to have sufficient back presssure inside the furnace, and this is attained by correct charging. There is naturally a limit to the size of tuyères, a certain initial pressure of the blast is necessary, and an increase in this initial energy or velocity will increase the area of horizontal section reached by the blast. This is brought out by experience with wide hearths. However, in instances where insufficient penetration is regarded as the cause of irregular working of a furnace receiving the normal amount of air it is often found that the difficulty is in the arrangement of materials on top.

SELECTION OF TUYÈRES.

In order to effect penetration by the blast long tuyères have been used, 18 inches being the length usually substituted for the standard length of 12 inches. When a furnace tends to work toward the walls such expedients are useful in temporarily overcoming this condition. The cause is essentially some defect in charging, however, and the continued use of a long tuyère may easily introduce serious obstacles to smooth working, in that it produces a flatter bosh. Such distortion of the bosh contour affords a base on which the column of descending stock more easily comes to rest. The important bearing the length of tuyères has on the smoothness with which a furnace works may be illustrated by the fact that in one instance substituting 6½ by 9 inch for 6½ by 12 inch tuyères transformed a 16-foot 6-inch hearth furnace from a very stiff working to a regular working furnace.

This indicates also the marked effect the bosh shape has on smoothness. A steeper bosh affords less foothold for arching and scaffolding and probably does not jam the coke coming down to the tuyères as tightly as would a flatter bosh, thus permitting easier penetration of the blast to the center.

CHANGING THE TUYÈRES.

A few furnace men believe in a cycle of tuyère changing—for instance, changing from sets of 6 by 12 inch to 6½ by 9 inch tuyères, thence to 6½ by 12 inch to 6 by 9 inch and back to 6 by 12 inch. In this way, so it is claimed, the furnace does not settle down to a uniform method of working, in which hanging and slipping occur at approximately definite intervals. Seemingly such a procedure has considerable merit, because distribution is never perfect, and, consequently, there should always be a proneness to faster work in some perpendicular circle or ring. If the charge tends to work away from the walls excessively, changing the tuyères as indicated above would tend to make the furnace work hotter near the walls at times and prevent scaffolding. Conversely, if the tendency is to work on the walls, changing the tuyères may decrease the temperature near the lining often enough to check detrimental erosion. Obviously such tuyère changes have to be made with some appreciation of the needs of the furnace, as shown by its driving or smoothness of operation.

A method of combating stiffness which is decreasing in popularity is to blank half of the tuyères on the side opposite from where the presence of a scaffold is indicated. This practice is still followed at a few plants, and the time over which the tuyères remain blanked varies from four hours up to three days. Good results are claimed, but many furnace men believe that the practice introduces as many irregularities as it is supposed to eliminate.

There is naturally a tendency to resort to tuyère changes to correct irregular working and slipping, because there is still much to be accomplished before technical control of furnace practice is perfect, and those variables most under the control of furnace men are most often changed to cure indefinite and obscure troubles. On this account the crew often resorts to tuyère changes so frequently that the superintendent is inclined to avoid them, except under a definitely indicated necessity. For this reason a majority of furnaces are blown with the same size tuyère from about the second to the last month of the blast, the method of blanking opposite tuyères being resorted to, as a rule, only in event of irregularities amenable to treatment by variation in tuyère area.

PREVENTION OF LEAKS IN THE WATER-COOLING SYSTEM.

Leaks in the bosh-cooling system or at the stove valves are a somewhat frequent cause of irregular working and slips, and are often most difficult to detect. Leakage of water into the furnace may be indicated only by scouring cinder, cold gas in the bosh, sloppy tuyères, or slipping; at the same time it is difficult to detect gas by the discharge water. It is easier to detect gas if the pressure of water at the circle pipe supplying the bosh is carried at about 4 pounds less than the blast pressure. Under such conditions gas from inside the furnace will force itself into the plate and tuyère in event of a leak, and gas will show at the water discharge almost immediately. A small gage should be attached to the circle pipe so that the pressure carried can be checked.

That some defects in old linings are due to minute leaks on the cooling bronze is indicated by the fact that when plates from an old lining are tested, preparatory to use on a new lining, often as many as 50 per cent may be rejected owing to small cracks and pinholes, the existence of which could not be determined while on blast. Testing of all bronze, new as well as old, at 75 to 100 pounds pressure is essential to eliminate leaks. Possibly the best way to detect minute leaks is to immerse the plate or tuyère in water and apply an air pressure of about 75 pounds. The frequent analysis of the scrap used, as failure and especially cracking develops, is a valuable check on the probable behavior of the metal. The use of pure copper has proved of advantage in causing freedom from cracking and in increase of life, and analyses will sometimes develop the fact that deleterious alloying has crept in through mistakes in the use of material or scrap. Accurate alloy analyses are more difficult than the usual analyses in blast-furnace laboratories; and if more than traces of bismuth, lead, antimony, arsenic, or iron are found the analysis should be verified before the metal is condemned.

Certain sections of the cooling system, such as the tuyères and the first two rows of plates above the tuyères, are subject to the maximum effect of the combined action of the blast, slag, and iron, impinging on the surface, in addition to the temperature, and are more subject to cracking, burning, and leaking than other parts of the system. Some plants test the discharge water from these tuyères and plates for gas every afternoon in order to detect any small leaks.

The use of screens in the bosh-water supply line is of marked value in preventing bronze being burned from slackening or stoppage of the water supply by débris. Regular flushing of each plate, cooler, and tuyère with high-pressure water also helps to eliminate leaks, especially in the bosh plates, because the deposits of mud are stirred up and ejected. The discharge pipe over the trough should be in such position that the men do not have to go on the bustle pipe to see the water, but can see it easily from the cast-house floor. The employment of every means which facilitates watching, testing, and keeping the water supply and discharge going is urgent on the basis of efficient furnace practice as well as freedom from slips.

EFFECT OF WORKING AT HIGH TEMPERATURES.

The use of high heat—that is, blast temperatures upward of 1,050° F.—is frequently productive of continued hanging and sticking. This was originally attributed to the use of Mesabi ores. As much of the future supply of ores must come from the Mesabi district, and good practice and tonnage could be obtained with lower heats, 800° to 1,000° F., there has not been, until recently, any widespread efforts or facilities for applying higher heats. By changes in the lines of the furnace, in materials, and in slag, several plants have succeeded in operating at temperatures of 1,100° to 1,350° F. without continual slipping and hanging.

Recognition of the fact that the sulphur content of the coke and the basicity of the slags, or the lines of the furnace, either by design or by the use of low heats, or both, are unsuitable to readjustments in heat practice, will do much to eliminate excessive slipping due to high heat. Although examples are not lacking of furnaces hitherto on low heat being worked into the use of high heat, it has invariably been the result of gradual increase in heat for weeks and months, accompanied by a progressional increase in burden and decrease in slag basicity, with repeated setbacks and stiff furnace conditions. Attempts to rush the furnace to higher temperatures may be set down as ineffectual, as the use of high heat involves such changes in practice, considerations of profile of lining, and improvements in distribution that, unless these are obtained, pronounced slipping will result.

COMPOSITION OF SLAG.

Unsuitable slag composition is a prolific cause of hanging. There may be, and probably are, several complex reasons for this, but one evident reason is variations in temperature. If the furnace is run at a higher heat the coke consumption per ton of burden is lower. Consequently there is less ash to be fluxed and a considerably decreased volume of slag per ton of iron. With this smaller volume persistent variations in the charge will produce a wider variation in the slag than with the former large volume, so that it may easily occur that a swing toward increased basicity or acidity will produce an exceedingly variable composition of slag, which a higher slag volume would take care of without showing as great a change or without difficulty or detrimental results. This liability to the formation of excessively basic slag when a limy slag is carried in low volume on high heat is a deterring factor in the use of limy slag. An insufficient volume of slag to cope with the variations in the burden material will, of course, cause sticking and slipping, even at moderate heat, but even more so on lower slag volume and high heat. Such a condition is not infrequent, and is characterized by the statement that the furnace is too "dry." Trying to keep the slag volume down, when high-sulphur coke is charged, by the use of limy slag is likely to cause hanging, if a variation in materials or charging increases the proportion of basic material in the slag. There are sometimes many perplexing factors to be adjusted in burdening a furnace, especially where the situation is complicated by such problems as abnormally high or low alumina content, excessive sulphur content, the proper proportioning of available fluxes, the relation of the basicity or acidity of the slag to the silicon and sulphur content desired in the iron, or production of slag for commercial purposes. Usually recourse must be had to previous practice, or, if that be lacking, to a series of cut-and-try experiments. The attainment of the correct slag is not always assured, and such uncertainty is not conducive to good work, especially when the slag does not seem to be all that might be desired, and consequently there is naturally a tendency to make changes. Some of the difficulties incident to the use of certain ore mixtures or to the adjustment of practice to operating handicaps is undoubtedly due to the unsuitable composition of the slag. It must be admitted, however, that at times the slag is made the scapegoat for various troubles, such as error in charging, deficient distribution, etc., to which it has not the least relation. To correct such irregularities the slag is made limy or sharp or the alumina or magnesia content is altered, when any of these factors actually are at the most only remotely responsible for the behavior of the furnace.

STOCKING AND CHARGING.

Much can be done toward insuring uniform and regular operation, with freedom from slipping, by care and thought in stocking and charging. The widely varying analyses and fineness of charges from which many of the Mesabi mixes are built up, the fluctuations to which the analysis of so many "old-range" ores are liable, and the certainty that wide variations in quality will be encountered in the ore during a year's run, require as much care in handling ores as in other items of practice.

Furnace troubles are usually more numerous in summer than in winter and at plants having inadequate stocking space for winter consumption. In using ores direct from the cars during the summer months many of the difficulties are attributed to proved variations in the shipments. Plants formerly dependent upon direct shipments have effected marked improvements in practice by providing stocking space sufficient for winter and also summer requirements, the ores being handled through the stock pile. This eliminates the annoyance of frequent changes of burden, spreads cargo variations over a wider period, and removes the necessity of steaming, thawing, and dynamiting in winter. Sufficient space should be insured to avoid any necessity for mixing of ores. The practice of stocking together ores that are similar in physical character but differ in composition or, more frequently, are similar in composition but differ in texture, is often made necessary by the limited stocking facilities. In so doing, the expense and advantage of selected mixing of ore at the mines is lost, and occasional serious irregularity in furnace operation may result.

Narrow stockyards, where capacity is obtained by extension beyond the limits of the space occupied by the stove and furnace, require stocking by dumping on the apex of the heap. When ores are stocked in this way the pile contains a high proportion of coarse material near the floor, grading up to the finer portions on top. Where possible each shipment should be dropped over the surface of the stock pile evenly, so that the grade of ore will be more uniform throughout the season, and also from hour to hour. After uniformity in stocking has been obtained the ore should be taken off evenly and uniformly from the top, rather than removed in deep local sections or cuts.

WEIGHING AND LOADING.

The stock house presents many opportunities for the attainment of the best practice, or for an utter loss of such a possibility. In hand-filled furnaces accuracy in the weighing of charging buggies should be required, on account of the large number of weighings per charge. The use of larry cars may reduce the number of weighings per charge to two, and the less the better, as the chance for error in weighing is reduced and the furnace may be more easily kept full. Utilization of the full capacity of the bins seldom requires urging. When the maximum amount of bin space in proportion to the percentage of ores used has been provided, the superintendent should insist on drawing in turn from the various bins of each grade. Possible sharp changes in quality are thus spread over a longer period and the change made more gradual.

The car operator is more likely to do this work correctly if he has the proper facilities, and in view of the importance of his work every detail should be carefully worked out. The ore and limestone should be under perfect control while being withdrawn from the bin. Chutes should be closely spaced to preclude tendency toward sticking in the bin, and the contour of bins and chutes should be designed to promote movement of the entire contents. Few things are more discouraging to correct weighing than difficulty in getting the ore to run, while the furnace is continually keeping ahead of the stock-house force. Efficiency in weighing is promoted by equipping the plant with larry cars with automatically recording scales, from which the weight of each component of every charge can be checked. It is unreasonable to expect a man to do his best under unfavorable conditions. A dark, cold, windy, dirty, wet, or dusty stock house is not conducive to careful work in weighing.

CHARGING COKE.

The essential feature in charging coke is to obtain the minimum breakage from the cars to the furnace and to avoid charging dust and breeze. For this reason the location of one or two large bins in proximity to the skip is preferable to many small bins from which the coke must be dropped and conveyed to the skip by a larry car. The accumulation of fine coke dust and breeze in the coke pockets, owing to the profile of the bin not conforming to the angle of repose of the coke, is more obnoxious than pockets of fines in ore bins, because delay in spotting coke drags on the trestle, with consequent drawing on the dead pockets, with their accumulation of fines, is certain to cause furnace trouble. Regularity in spotting and dumping coke drags contributes markedly to regularity in furnace work, as was shown at one plant when an attempt to reduce labor costs by eliminating night unloading of coke in pockets which were of inadequate size and poor design led to most unsatisfactory work, and return to smooth furnace work was obtained only by frequent unloading at night as well as by day and by keeping the height of coke in the bin above a fixed limit.

SIZE OF COKE UNIT CHARGED.

The adjustment of the size of the coke unit charged depends on the size of the furnace, character of the burden, blast pressure, distribution of stock in the furnace, limitations of the stock-house system, and also at times upon indeterminate factors so obscure as to lead to the belief that individual furnaces possess characteristics and perversities of their own. The practice of furnaces working on cokes of open structure and rapid combustibility has been at times improved by increasing the size of the coke unit. Increases in volume of the coke unit of up to 50 per cent have effected an increase in pressure of 2 to 4 pounds, thus counteracting the tendency toward a drop in pressure peculiar to fast-burning cokes. Unsatisfactory work, where fast driving was the practice, has yielded in several instances to an increase in the coke unit. Moderate driving, in general, has been most successful with coke units of such size that approximately 85 to 90 units are required per day; in fact, the proportioning of the most advantageous unit of burden may depend more upon the selection of a weight that requires nearly constant charging, than upon any other factor.

The size of the coke unit at furnaces producing 500 tons of iron per day, and of about 22,000 cubic feet capacity, varies from 7,500 pounds up to 16,000 pounds, and satisfactory work is done over this range. The extremely large coke units are in a general way confined largely to furnaces which are more notable for production records than for fuel economy. A coke unit of 9,000 to 11,000 pounds seems to give the best fuel economy and smoothest work on furnaces of the capacity mentioned.

SEQUENCE OF CHARGING COKE, ORE, AND FLUX.

Except with a certain type of distributor, it is not found productive of regular work to dump the coke, ore, and limestone with one drop of the large bell.

In this case a large coke unit is used, about 15,000 pounds, but it is split as follows: Two skips of coke, one of ore, two of coke, one of ore, and two of limestone, making seven skip loads in all on the large bell, which is then lowered. A more common practice at present than dumping all the materials of a charge at one lowering of the large bell is to split the charge as follows: Seventy-five thousand pounds of coke is charged and the bell lowered; next 15,000 pounds of ore and 3,300 pounds of limestone are charged and the bell lowered; then 7,500 pounds of coke, 15,000 pounds of ore, and 3,330 pounds of limestone are charged and the bell lowered. Other plants make two drops of the bell, charging the coke in with one drop, and the ore and limestone in with a second drop. This method of filling places the fuel and the burden in separate strata, and the coke, being comparatively open in comparison to the ore, should allow the gas currents to equalize themselves in each successive layer, and should prevent the formation of chimneys up through the ore. Channeling by gas is detrimental, and the fact that experimental changing from two drops to one drop of the large bell usually results in irregular work and slipping lends a certain plausibility to the theory. As the volume of the charge of ore and stone is roughly one-half that of the coke charge, the minimum size of coke unit is reached when the small volume of ore will not cover the fuel. If the ore charge tends to work toward the wall, the limit in decrease in size of ore unit is reached much sooner than if it were spread out in a level or nearly level layer over the top surface of the coke. On a 16-foot stock line, 16,000 pounds of ore and 4,400 pounds of limestone is about the smallest charge that will work satisfactorily.

Theoretically, the thicker the layers of ore and coke the better stratified are the coke and ore charges. The reason that the limits are narrow for a given furnace is, probably, that a thick ore charge may tend to channel in the deep-ore blanket, or that with an excessively large weight of ore charged as a unit, the annular heap next the wall becomes too thick and dense in comparison to the depth in the center. After the most advantageous weight of ores for a charging unit has been fixed upon, the method of dumping the components of the charge offers many possibilities, and, similarly, the sequence of charging the various ores. The combination of these two factors affords a considerable range and inasmuch as they are among the most obvious means of correcting unsatisfactory operation they are frequently resorted to, often with little effect and to the further detriment of furnace conditions. In general after the operator has determined by previous practice, or by trial during the early period of blast, the best method of operating the bells and the best sequence of ore, coke, and limestone, there is little to be gained by further experiments, and the necessity for the change should be evident before it is made.

The sequence of ore, coke, and limestone does not seem to have any definite relation to furnace operation over a large number of furnaces, although for a given furnace the sequence is seemingly very vital. For instance, at one plant the coke charge is followed by one-half the limestone, then the ore, and then the other half of the limestone; the limestone and ore being dumped by one drop of the large bell. After a period of irregular working, the limestone was all charged last, following the ore, but this sequence caused such irregular work that the operators went back to the original procedure. One large plant charges the limestone immediately after the coke, following this with the ore. As it was suspected that this method of dumping was causing trouble, the limestone was dumped with the coke, and the ore by itself. Inasmuch as no improvement could be noted, and in fact, the furnace required more coke, the operators went back to the original plan.

As to whether the limestone should be charged ahead of the ore, or after the ore, both being lowered into the furnace with one drop of the large bell, there is the most divergent opinion, the majority of plants charging the limestone after the ore. There have been several instances where dumping the ore, coke, and limestone with one dump of the bell resulted in very poor operation, whereas at another furnace in the vicinity the charge may be split and two or three dumps of the large bell made, each lowering of the bell charging in, say, 5,000 pounds of coke, 12,000 of ore, and 3,000 of limestone, with good results. At most plants each round contains all the components of the ore burden, as follows:

Example of typical charge containing all components of burden.

Constituent.	Number of pounds charged.
Ore A	4,000
Ore B	10,000
Ore C	6,000
Ore D	2,000
Cinders and scale	2,000
Total	24,000

A variation practiced by a considerable number is to alternate "D" ore and "cinders and scale," 4,000 pounds of each being charged in sequence every other round. Another variation is found in setting the scales to charge 7,200 pounds of "C" ore for 5 rounds; on the sixth the "C" ore is omitted and 12,000 pounds of "cinders and scale" is charged. A practice which is somewhat frequent is, assuming that a siliceous ore makes up about 10 to 15 per cent of the burden, to charge the siliceous ore every second, fourth, or fifth round. Obviously a considerable number of similar variations can be worked out for the same mix, and although such variation may seem a very minor factor, or, on the contrary, opposed to regular operation, considerable significance is attached to these small adjustments by the men whose ideas and practice they are. A wide deviation from theoretically uniform charging is represented by the following charge:

Charge showing wide variation from theoretically uniform charging.

Rounds.	Materials.	Number of pounds charged.
First	Coke	12,000
	Ore A	16,000
	Ore D	8,000
	Limestone	6,000
Second	Coke	12,000
	Ore B	24,000
	Limestone	6,000
Third	Coke	12,000
	Ore B	16,000
	Cinder and scale	8,000
	Limestone	6,000
Fourth	Coke	12,000
	Ore C	24,000
	Limestone	6,000

This plan is not actually followed, but is representative of one where successful and uniform work is obtained.

The coke unit, being made up of one component, is subject to little variation. However, many experienced furnace men believe that much better work is obtained if, instead of charging 24,000 pounds of ore and 12,000 pounds of coke per round, 25,500 pounds of ore and 12,000 pounds coke is charged for four rounds and in every fourth round an extra skip of coke, 3,000 pounds is charged.

The general idea behind such variable charging is that the furnace is benefited and hanging prevented, by giving the furnace a periodical "jolt." Another frequent means of "livening" up a furnace is to change the size of the charge or sequence of charging. That in this way scouring of the walls is somewhat promoted is undoubtedly true, and in the event of conditions trending toward slowing up of rate of driving or hanging, some adaptation of the above method works toward elimination of the sticking and stiffness developing into heavy slips. Although these expedients are productive many times of smoother work, it is probable that even the better practice resulting is not as good as could be attained were the distribution, the lines of furnace, and the materials used more closely aligned with the requirements.

INSPECTION OF THE BELLS.

The bells should be inspected at least weekly to insure that sticky or wet ore is not adhering or baking on them. Machined bells with an angle of 53° to 55° give considerable relief, but offer no assurance that a scab is not interfering with distribution. Such lumps can, as a rule, be barred off through the gas-seal doors.

When the bell is hung it should be tested and balanced before placing in the furnace. An unbalanced bell may close off center on account of the underbalanced side coming in contact with the lip of the hopper or hopper extension while the heavier side is still in motion upwards. The result is that there is a horizontal displacement of the bell toward the overbalanced side, with a resulting tendency to side swinging when the bell is lowered. A similar thrust or swing occurs when the bell is off center, either by reason of the point of suspension being shifted relative to the center of the furnace or of incorrect alignment of the bell in placing it. The bell should be exactly centered when it is placed in the top. This is an almost rudimentary requirement, but lack of attention to this point is not unknown, and it usually results in many discouraging irregularities and difficulties during the early part of the blast. Attention to balancing and centering the bell so that it closes simultaneously at every point about its periphery repays many times the time required.

HEIGHT OF STOCK LINE.

The distance the stock line may be carried below the bell has a marked effect on the distribution. Carrying it to the maximum height permitted by the drop of the bell results in an annular ring of finer material with a base toward the wall and in the center of coarse material. Such distribution, which is productive of channeling, may also be caused from the use of too small a bell, and then conditions may be improved by dropping the height of the stock line until the velocity of discharge from the bell carries the material farther out toward the periphery of the furnace. The effect of carrying the stock line too low is to cause excessive abrasion of the lining at the stock line by impact of material and also to shift the apex of the stock discharged from the bell to a point at the walls, or even, theoretically, beyond the walls. Too low a stock line, while affording an increased height in which greater opportunity is afforded for dust to settle before being swept over into the downcomer by the velocity of the gas is prejudical to good work, in that the abrasion of the walls with accompanying breakage of coke, packing of stock by reason of concentration of fine material next the walls, and undue permeability of stock at the center presents too much certainty of scaffolding.

Realizing that the velocity with which the various materials are discharged from the bell will determine the apex of their lodgment upon the stock column, and that this velocity will depend upon their weight, character, and freedom of movement, the aim of the operator should be to select such a height of stock line as will bring the points of lodgment in as close vertical alignment as possible. This can be determined only by inspection of the stock line after each lowering of the bell while filling preparatory to blowing in, and it depends so wholly upon the ratio of diameter of stock line and bell and upon character of ore that no rule of practice is possible. Access to the interior of the furnace while it is being filled should always be provided for. The discharge from the bells should be watched, and as the furnace is filled up and the stock line can be reached with a ladder from a gas offtake or down through between the bell and hopper, the distribution of materials should be examined and the contour of the top of the stock column measured. This information goes a long way toward eliminating questions which come up during the blast, where the furnace gets to slipping persistently. It also helps in determining the height at which the stock line should be carried for the best distribution. To dump large amounts of ore, coke, and limestone into a blast furnace without knowing how it lies in the furnace is leaving too much to speculation and is poor practice. The height of the stock line is sometimes held within such narrow limits by the relative size of the bell and throat of the furnace, the distance between the center line of the gas offtake and the bottom of the bell, the speed of lowering the bell, and the character of materials, that little leeway is allowed, but, nevertheless, there should be a definite idea of the distribution.

USE OF STOCK-LINE INDICATORS.

Keeping the height of the stock line constant is important. The fact that fluctuations in height will be encountered affords no excuse for irregular filling. The location of a stock-line indicator, preferably of the recording type in the stock house, gives the least excuse for intermittent charging. The latest type of rodding devices are worked by air, steam, or water pressure, and these are to be recommended, as they remove any disinclination toward frequent rodding on account of the effort required by older devices. It is a good plan to place one of these rodding devices in the cast house also, so that the blower can keep himself informed as to the condition of the furnace and the regularity of charging. Intermittent charging, varying heights of stock column, and haphazard knowledge of the condition of the furnace not only lead to slips but may make them more serious in results.

SPEED OF OPENING BELLS.

The speed of opening the bells should be kept constant, as the velocity of discharge, the distance to which materials are thrown from the bell, and hence the distribution, depend upon the rate with which coke or ore is made free to move.

IMPORTANCE OF PROPER DISTRIBUTION.

Considerable space has been given to the factors governing distribution of materials in the furnace. This is because correct distribution is a chief factor in the elimination of slips. If the proper volume of blast is used and the contour of the furnace lining is designed for the materials and heat carried, then most of the time, provided the charge is properly distributed, the furnace will work properly, but if the distribution is poor, the furnace will not operate satisfactorily very long at a time.

USE OF COKE BLANKS AND "DOSES."

When a furnace gets to slipping heavily or persistently a widespread practice is to charge a blank of coke. This blank may be accompanied with other materials which are calculated to scour the walls. Examples of various blanks, or "doses," for a 500-ton furnace are given below.

One blank extensively used in the Pittsburgh district is as follows:

60,000 pounds of coke,
10 regular rounds,
10,000 pounds of gravel,
10,000 pounds of converting mill cinder,
5 regular rounds,
50,000 pounds of coke.

Such a blank is in some instances put in a given furnace every four days, whether or not it appears to be needed.

It can be seen that this is an expensive procedure. About 55 tons of coke is charged, which, at $3.50 per ton, gives an additional cost to be carried of nearly $50 per day. There is little iron recovery from the cinder charged in the blank. For the $50 thus expended there is a return in more regular operation, freedom from excessive slipping, and a minimum production of off-grade iron. From comparative practice it is considered cheaper to spend $50 for a blank every four days than to have a "stiff" or slipping furnace, with its accompanying showers of material over the yard and loss in quality and quantity of iron.

A so-called "relay dose" or blank is as follows:

"Relay dose."

Material.	Pounds.
Coke	16, 000
Scrap	4, 500
Coke	12, 000
Heating-furnace cinder	4, 500
Scrap	4, 500
Coke	16, 000
Heating-furnace cinder	4, 500

Material.	Pounds.
Sand	2,000
Coke	12,000
Scrap	4,500
Coke	16,000
Heating-furnace cinder	4,500
Coke	12,000
Scrap	9,000
Coke	16,000
Heating-furnace cinder	9,000
Coke	12,000
Scrap	19,000
Coke	16,000
Heating-furnace cinder	4,500
Scrap	4,500
Sand	4,000
Coke	12,000

This so-called "relay dose," which is used in furnaces apparently badly scaffolded, though it appears more formidable than blank 1, in reality contains but 30,000 pounds more coke. In proportion to the coke there is much more unfluxed material, heating-furnace cinder, and sand. The presence of heating-furnace cinder, which is simply a fused silicate of iron, is apt to produce a cast of off-grade iron unless the "dose" comes down very hot.

A third dose is as follows:

Material.	Pounds.
Coke	50,000
Converting-mill cinder, two regular charges	40,000
Coke	25,000
Converting-mill cinder	20,000
White iron (remelt), two regular charges	50,000
Coke	25,000
Converting-mill cinder	20,000
High manganese (6 per cent) ore	20,000

When this "dose" comes down to the bosh, the practice is to lower the heat from 1,100° to 800° F. This "dose" has sometimes proved deficient in coke in the event of its dislodging a heavy scab on the walls.

A dose that is used for a furnace badly scaffolded, and is not used except under very bad conditions of furnace operation, is as follows:

100,000 pounds of coke.

19,000 pounds of siliceous (40 per cent) ore.

One regular charge.

10,000 pounds of coke.

9,500 pounds of siliceous ore (40 per cent).

9,500 pounds of manganiferous ore (4 per cent).

Two regular charges.

35 tons of scrap and remelting iron.

Fifteen regular rounds.
50,000 pounds of coke.
19,000 pounds of manganiferous ore (4 per cent).
Ten regular rounds.
15,000 pounds of coke.
Five regular rounds.
10,000 pounds of coke.

At one plant, when the furnace is very much built up, the following is charged: 33,000 pounds of coke in a blank, followed by 6,650 pounds of coke, 3,000 pounds of ganister, and 3,000 pounds of limestone. This small unit is repeated five times, and is followed by 6,650 pounds of coke, 3,000 pounds of ganister, and 1,000 pounds of limestone. This is also repeated five times, and is followed by 4 regular charges; then 10,000 pounds of coke and 20,000 pounds of scrap and iron are charged, each unit being repeated five times. Then 10 regular charges with 20 per cent less burden, 15 regular charges with 15 per cent less burden, 10 regular charges with 10 per cent less burden, and finally the regular burden are charged. As soon as this blank shows up in the cinder, the engine speed is reduced about 20 per cent and the temperature lowered as much as possible, which is usually about 500° F. The furnace is driven in this way for about six hours; then the blast and temperature are gradually brought up to normal, which takes about six to eight hours' work. Mill or puddle cinder is sometimes substituted for ganister, with good results. This "dose" has proven itself very effective.

Other "doses" that have been used are given below:

Material.	Pounds.
Coke	15,000
Scrap	5,000
Coke	10,000
Converting-mill cinder	4,500
Coke	20,000
Pig iron	5,000
Heating-furnace cinder	4,500
Sand	15,000
Coke	10,000
Coke	10,000
Scrap	5,000
Coke	15,000
Puddle cinder	5,000
Coke	10,000
Scrap	5,000
Coke	15,000
Puddle cinder	5,000
Coke	10,000
Scrap	5,000

Most furnace men use a blank or "dose" from time to time to regulate the working of the furnace, and as each superintendent has his own preferences and carefully worked-out methods of "dosing;" there are almost as many varieties of these as there are plants. Many keep the make-up of the "dose" secret, as they have worked it out by considerable experience, and regard it, properly, as part of their stock in trade. Those "doses" which are presented here are given with the consent of those furnishing the information.

The use of coke blanks is very common, and the amount of coke, at the judgment of the furnace foreman, varies from an additional round up to five rounds of coke in one blank. Many use limestone with the blank to heat up a cold, stiff-working furnace. Sand is not much in favor as a constituent of a "dose," as it is believed to cut the lining. Sandy, rough cast-house scrap is much in favor, but scrap from a granulating pit and steel scrap made up of borings, punchings, etc., is avoided. One furnace man, in attempting to use a considerable amount of wire-nail scrap in a "cleaning dose" had to pull a large proportion of it, unmelted, out from in front of the tuyères. In general, the idea in making up a "dose" is to have it include two materials of different refractory characteristics, so that it will melt over a wide range. Scrap, siliceous and manganiferous cinders, and ore are the essential components. When used as a panacea for all ills about furnaces, the employment of "doses" may be abused, in that their frequent use dulls the need of being continually on the lookout for and determining what actually is causing the hanging and slipping.

Many furnaces operate for months at a time without a dose, as an occasional small coke blank or a frequent adjustment of the burden carries them through without trouble. A stage midway of this type of practice is to substitute twice or three times a day a dose of siliceous manganiferous cinders for the ore burden. Thus, one plant charges, instead of a unit of 20,000 pounds of ore, 15,000 pounds of puddle cinder, gravel, and scrap three times a day. This is simply a development of the idea of charging the siliceous component of a charge every second to eighth round.

As a furnace gets old and the lining cuts out, the number of coke blanks is usually increased. These are often necessary because of slipping, the aim being to replace in larger proportion the coke thrown out by the slip, and also to interpose a blanket of extra coke when filling must be started 10 feet or more below the stock-line level. Often a furnace which has cut excessively above the mantle and sticks and slips persistently has been given a new lease of life by charging an extra round of coke three or four times a day at regular intervals. Instances have been noted where this extra amount of coke enables the furnace to take more burden and a heavier blast, and work with vastly less slipping.

The need for a coke blank or "dose" is not always easy to determine. Often a furnace can be worked out of a period of sticking and slipping by using a cold blast, checking the blast, or lightening the burden for a few rounds. When this can be done, with a good reserve of heat in the stoves, it is undoubtedly better practice than the custom of resorting to a blank or "dose" upon slight provocation, because the use of these may sometimes throw the furnace off. The use of "doses" is perhaps justified under circumstances where excessive slipping must be avoided on account of weak tops or shells, deficient heating, or large explosion doors, or when it becomes necessary to change somewhat frequently from one grade of iron to another.

METHODS OF OVERCOMING SLIPPING AND HANGING.

"BLOWING DOWN."

One old method of removing scaffolds was to "blow down" the furnace until the top of the stock was below the scaffold. A typical method was to start by reducing the amount of ore and limestone charged by about 20 per cent, and at the same time decreasing the limestone content of the burden one-half for every second charge. After 4 to 6 hours the furnace would be allowed to work down slowly. About every half hour a round would be charged in order to keep the top temperature down, though, as a rule, these rounds consisted chiefly of coke. The blast would be reduced gradually until, with about 20 per cent of the pressure off, it was no longer possible to keep the furnace cool on top; then a spray would be introduced. By this means the furnace would be "blown down" till the top of the stock column was alongside of or beneath the scaffold. Sometimes charging would be resumed and the furnace kept at this level until the scab had melted off, or the furnace would be filled with coke, scrap, sand, and cinder and "blown down" again.

These efforts were not always rewarded with success, as the scaffold was not always melted off and several bad explosions have occurred. The method of "blowing down" has not been followed to any extent in recent years, although it crops up at infrequent intervals.

USE OF AUXILIARY TUYÈRES.

A method of combating scaffolds that was formerly much in use, but is seldom resorted to nowadays, consists in inserting an auxiliary tuyère in the lower inwall of the upper bosh. This so-called tuyère consists of a cinder monkey, water cooled, or even a 1-inch gas pipe, which is inserted in a plate opening in the bosh or stack, or in a hole drilled in the shell and lining especially for this purpose. Through this auxiliary tuyère is blown a fairly strong blast of air, which starts combustion of the coke high up beneath the scaffold. The high heat thus generated melts off the scaffold, and if one is fortunate enough to find the right location at the first attempt in placing the tuyère, the furnace quickly clears itself and starts to drive better. Recently a furnace resorted to this means of removing a scaffold which was apparently causing heavy slipping. A stack cooling plate above the mantle was removed and an auxiliary tuyère was inserted, then the tuyère was moved up gradually to each successive plate. This resulted in the scaffold being dislodged and in better work, but the improvement did not prove permanent, as the scaffold soon reformed and such heavy slipping developed that finally an unusually severe slip dislodged the hopper and bell, which was bolted to the top of the furnace.

Some years ago many plants were provided with about six permanent auxiliary tuyères above the mantle, which were put into use whenever the furnace showed signs of sticking. The use of auxiliary tuyères has been discontinued, but at several plants may be seen patches on the lower ring of the stack jacket where auxiliary tuyères were formerly located.

The reasons that the use of these permanent auxiliary tuyères did not prove feasible are that upkeep was difficult, and that the cooling of the walls at this point, so near the inside face of the lining, possibly caused as much scaffolding as the tuyères themselves were supposed to prevent; improvement in furnace lines and in distribution over former standards is an additional cause.

The fact that the temporary auxiliary tuyère is only infrequently used is probably due to the difficulty of locating the proper place to insert it, the questionable expediency of cutting a series of holes in the $\frac{5}{8}$-inch, or thicker, steel shell, the possibility that any relief will be only temporary, and the much lessened tendency toward severe scaffolding.

USE OF EXPLOSIVES TO DISLODGE SCAFFOLDS.

At present the chief use of explosives at blast-furnace plants is in removing hearth bottoms at relining, and this has been discussed in detail on pages 175 to 182. In former years the use of dynamite to dislodge scaffolds was frequently resorted to, and considerable mention of the method is to be found in issues of the Transactions of the American Institute of Mining Engineers as far back as 1881. At that time many of the blast furnaces had no steel shells inclosing the brickwork, but were simply banded, much as the modern bosh is banded. This left a considerable space of uncovered brickwork, through which holes could be drilled where the scaffold was suspected to be, and then a charge of dynamite could be inserted and fired. The dynamite was sometimes inserted in the body of the scaffold, and sometimes in the empty space beneath the arch, and fired. This method was very successful, but the development of the modern thick steel shell has obviated its use almost completely, and in several years of practice with Mesabi ores the writer has never seen it used. The method was in use in Germany up to a recent date, and is described by Schöneweg[a] as follows:

A tube welded together at one end, 2½ inches in inside diameter and 8½ to 12 feet in length, is used as a protecting tube; and another snugly fitting tube of the same length and of 2 inches inside diameter is used for the charge. Into this inner tube is drilled a hole for the fuse at a distance of 3 feet from the mouth, when one does not want to use electric ignition. After the inner tube has been closed at one end with a wooden plug and the charge has been introduced into the tube, the upper empty space is filled with sand and the mouth is closed with a wet clay plug. The empty protecting tube is introduced at the proper place into the furnace, where brickwork must be provided with a sufficiently large hole; the fuse is ignited and the loaded tube with the burning fuse is shoved into the protecting tube. Every explosive may be used. If we use dynamite and the protecting tube, on being introduced into the furnace, has become red-hot, it must be cooled by allowing water to flow into it from a hose before shoving in the inner tube. Otherwise it may happen that the nitroglycerin may melt, explode, and throw out the charge. One may also use any of the explosives that are safe to handle, the pulverized as well as the gelatinous. As a charge one may safely take 2¼ to 2¾ pounds, only the charge must be at a distance of at least 1 foot from the brickwork.

A furnace had not been driving well for five days. Through the opened tuyère one could see clearly an arched, closed scaffold, and a space 23 feet in height in the lower part of the furnace was entirely empty. During the stoppage 25 tons of coke had been thrown into the lower part of the furnace. We had eight holes drilled into the bottom of the scaffold. After the firing of the eight shots the furnace began to draw well. After two hours we noticed that the furnace did not work as well in its upper part. It was stopped once more, and we found that the holes had been drilled too high. New holes were drilled; 15 tons of coke and 2,000 pounds of tap cinder were thrown in, whereupon we blasted. This time the scaffold collapsed, the furnace descended uniformly, and after 24 hours it yielded iron for the steel works.

In all, 12 descriptions of the use of dynamite are given in the article from which the above extract is taken.

OTHER MEANS OF PREVENTING SLIPS.

By far the most common means of preventing slips from assuming a violent character or of preventing hanging and sticking from working into protracted and heavy slipping are lowering the temperature of the blast or reducing the volume of blast momentarily

[a] Schöneweg, Herman, Das Schiessen in Hochofenansätzen: Stahl und Eisen, Jahrg. 34, 1914, pp. 1333–1336.

(checking); other expedients resorted to are increasing the slag volume and increasing the amount of limestone in the burden. Some operators decrease the revolutions about 5 per cent for an hour or so at the first indications of the furnace becoming stiff or tight. The avoiding of soft, punky coke and fine, easily reducible ores is frequently urged as a means of avoiding slips; but from the fact that most furnace operators are allotted a given variety of ores at the beginning of each season the range of adjustment of burden to include more refractory ores is limited. The given allotment must as a rule be consumed during the ensuing year, so that practically the only alternatives are, with certain furnace lines and distribution, to adjust the size of the charge and method of charging, the tuyère length or area, the volume and pressure of the blast, and the blast temperature to the best average practice, and to meet the occasional wedging and scaffolding of the stock by the use of coke blanks, "doses," and the manipulation of blast pressure or temperature in emergencies to bring any abnormal stiffness to an end. These represent the available means, after design, construction, materials, and average practice have been fixed and the problem of regular operation is at hand.

MANIPULATION OF BLAST PRESSURE AND TEMPERATURE.

As a general rule, if hanging develops it is considered advisable not to check the furnace, if this can be avoided. If the furnace will slip of its own accord within 30 to 60 minutes, many prefer to allow it to do so, because if the blast is partly or completely shut off to induce a slip the falling column is apt to pack tightly, and by wedging itself against the walls cause high pressure, repeated hanging, and heavy slipping; but if it falls against a strong ascending gas current its descent is obviously somewhat checked. If in one hour's time a hanging furnace does not settle voluntarily, then it must be made to settle. The longer a furnace hangs the larger is the cavity formed and the greater is the risk of an explosive slip, particularly if the furnace should slip with the blast on. As the cavity enlarges and the pressure of the gas within it increases, there is increasing probability of a violent eruption as the gas bores its way through or about the falling material. Therefore after 30 to 60 minutes steps are usually taken to slip the furnace, it being flushed before check to prevent cinders coming back in the blowpipes, unless there is hanging directly after the cast.

Reducing the blast temperature, say, from 1,050° F. to 900° or 800° F. will often loosen the furnace—that is, cause it to slip. However, it is not always desirable or possible to reduce the blast temperature, and the use of too much cold air, repeated too often, may result in off-grade iron.

If using a colder blast does not cause the furnace to slip, then the furnace must be checked. As a matter of fact, except after casting or in case a furnace is hanging stubbornly in the bottom, checking is resorted to more frequently than the use of cold air. The first check is almost never made sooner than 30 minutes after hanging develops, and then the furnace, if it is necessary to check repeatedly for some hours to keep it moving, is checked at not less than 40 or 60 minute intervals. Checking at 20 or 30 minute intervals almost invariably stiffens the furnace, and if it becomes necessary to check as frequently as this, it is a sign that emergency measures will soon be or are necessary.

Reducing the blast pressure at the tuyères 3 to 6 pounds is usually effectual in slipping the furnace. If it does not slip, the blast is usually turned fully on for perhaps 20 minutes and then checked again, and a second or even a third check may follow in close succession, provided each preceding check does not slip the furnace; the second check is usually all that is necessary, although if hanging persists, a third check, the pressure being reduced 5 or 6 pounds, frequently becomes necessary, or the snort valve may be opened, thus taking the blast off altogether.

The degree to which checking is resorted to always depends upon the judgment of the furnace man, as many furnaces and types of hanging require different treatment and amount of checking. When more than one check has been applied to the furnace the top and tuyères are watched carefully to determine the instant the furnace slips, as it is essential to turn the blast on as quickly as possible to prevent jamming and packing of the material inside the furnace, thus making it stiff. This is especially essential when the snort valve has been opened.

When hanging and sticking prove so stubborn that even opening the snort valve will not cause the furnace to slip, about all that can be done is to resort to cold air at low volume. This usually causes the furnace to slip. Another option is to take the blast off suddenly by first notifying the engine-room force to stand by the engines, then signaling a check, and immediately throwing the snort valve open. This treatment, repeatedly applied at quick intervals has been known to cause the furnace to slip but is hard on blowing equipment.

A practice which is sometimes resorted to is to let the furnace stand with the gas drafted back. This method is seldom successful, the net result being apparently only to make the furnace tighter, and it is usually resorted to only when all other methods have failed. A better final method is to speed the engines up, push the blast pressure up to the limit, and thus break up the hanging column. This method and the use of cold air have been most successful, but the use of high blast pressure is sometimes prevented by weak stove shells, blast mains, blowing equipment, or furnace.

PROCEDURE WHEN CINDER IS AT THE TUYÈRES.

Sometimes neither cold air nor a check can be applied to slip the furnace. This happens when the tuyères are "sloppy"; that is, banked up with a boiling mass of liquid cinder which is kept from running back into the blowpipes only by the full pressure of the blast. In this event, the furnace man is in a dilemma. Sometimes he has to let the furnace go, perhaps for two hours, until it slips itself, when it will usually fill the tuyères and blowpipes. Sometimes he will try to "dry the tuyères" by using all the heat available and flushing continually. Although this makes the furnace stick tighter than ever for the time being, the high heat may cause the cinder to disappear from in front of the tuyères, when the furnace may be checked. Sometimes he takes a chance, checks the furnace, and permits the cinder to run back in the pipes, trusting that they will not be cut or burned. The peculiar feature about this condition is that although the cinder notch may be open, and the furnace apparently drained, cinder may lie persistently at the tuyères.

VARYING THE BURDEN.

Increasing the amount of limestone charged is usually beneficial in old furnaces, both by increasing the slag volume and in increasing the concentration of CO_2 in the top part of the furnace. In one furnace with a badly eroded lining, an increase of 600 pounds of limestone, about 10 per cent, virtually eliminated an incessant series of top slips of long standing.

An extra round of coke and a slight lightening of the burden for 8 to 12 hours is usually efficacious in stopping a proneness to work stiff; that is, slipping about 8 to 10 feet at regular hourly intervals.

Stubborn hanging and frequent checking and slipping can usually be most effectually stopped by a large coke blank, or "dose." At a few plants where the furnace is mechanically strong, has a tight top, and ample stove equipment, there is sometimes a disposition to make the furnace relieve itself, without the use of coke blanks, a lightening of the burden being the only aid given. This is possible only where equipment is in first-class condition, plenty of stove heat is available, and there is little disposition toward being critical as to sulphur and silicon in the iron.

USE OF STEAM IN BLAST.

A few plants have used steam, admitted with the blast, to loosen hanging furnaces, but there does not seem to be much enthusiasm for this method.

EXAMPLES OF ACCIDENTS CAUSED BY SLIPS.

Descriptions of slips and the accidents caused by them follow:

A foreman and helper were on top of a furnace inspecting the condition of the bell when the furnace slipped violently. Flames from the explosion doors and from inside the gas seal burned both men so severely that they were disabled for more than six months.

Two top fillers were caught in a slip which blew the bell out of the furnace and enveloped the top of the furnace in a cloud of burning gas and dust. The time lost was 7 and 13 weeks, respectively.

Two bottom fillers were sent up to oil the sheave wheels on top, and were caught in a slip, the flying dust settling on their faces and arms. Lost time, 10 days each.

Two top fillers and one rodding man were burned by flying dust and flame ejected by furnace slips, resulting in a loss of time of 21, 30, and 37 days, respectively.

A dust man was dumping a dust catcher, when the furnace slipped and gas blew out from the bottom of the catcher, through the open bell, burning his hands and face and resulting in 2 days disability.

A dust man was standing alongside a car, playing water on the dust which had just been dumped, when the furnace slipped. To escape the falling material he jumped off the wall into the dust car beneath the catcher and burned his feet, ankles, and legs severely with the hot dust. He suffered 26 days' disability.

A dust man was cleaning up dust beneath a downleg which had just been emptied when the furnace slipped. The pressure blew the bell on the leg open, and the dust and flame burned his scalp and neck, resulting in 35 days' disability.

A dust man was beneath a dust catcher stopping up the doors on a hopper car, when the furnace slipped, opening the dust bell and sending a shower of burning dust and flame over his hands, wrist, face, neck, and ears. He lost 41 days' time.

A track cleaner was underneath a dust catcher, the base of which was entirely inclosed except at the track, cleaning the track immediately after the car had been withdrawn. The furnace slipped and knocked the dust bell off the lever, and the man was killed.

A stove tender was adjusting a burner nose shield when a slip caused the burning gas to puff back about the door frame and burner, burning his head and neck, he lost 8 days' time. Another stove tender opened a door to see how the gas was burning, just then a slip occurred and gas ejected from the door, burned his face, ears, scalp, neck, wrist, and hand. Another tender was struck on the head by a small piece of falling coke, causing 4 days' lost time.

In three separate instances when cleaners were cleaning the wells of stoves in which the gas had been left burning, gas blew out of the doors on account of the furnaces slipping and burned the men's hair, face, and hands, involving losses of 29 to 48 days.

In four instances boiler-house firemen were tending fires or blowing tubes, when gas was driven from the doors by the furnace slipping and caused burns resulting in disability of 2 to 63 days.

In six instances when men were working about the furnace front changing tuyères, blowpipes, or caps, the furnace slipped, blowing gas, coke, and cinder from the opening over the men, causing disabilities of 16, 17, 25, 50, 97, and 210 days, respectively.

Several men were about the front of a tapping hole. The furnace was badly scaffolded and the men were putting an oil burner in to burn out a cavity in the hearth, when the furnace slipped, throwing a shower of cinder, dust, and flame over them.

A cinder snapper received burns of the abdomen in a similar manner, causing a loss of time of 21 days.

Two laborers, engaged in unloading coke from a flat-bottom high-side coke car were fatally burned by being caught in a shower of coke thrown out of an adjacent furnace by a heavy slip.

A boiler cleaner was standing on the combustion chamber of a boiler sealing tubes, when the furnace slipped. There being no roof over the boiler house, some red hot coke hit him, setting his jacket afire. He thereupon jumped off the boiler to the ground, and in consequence of burns and bruises was severely injured.

A slip threw the bell and hopper out at a furnace, killed one man and injured several seriously, the falling ore, coke, and limestone being blown a great distance.

A slip caused the dust catcher to burst, and the escaping gas formed a sheet of flame which fatally burned five men and injured four others.

Several accidents have occurred in former years, none recently, in which a scaffolded furnace slipped and the impact of falling material on the sloping walls burst the bosh. (See p. 22.)

The most numerous type of accidents is comprised in men being struck by falling material thrown from explosion doors and bleeders. Six instances are known in which riggers and millwrights working on elevations or platforms difficult of escape, were struck by material thrown out by a slip, and were injured, losing 2 to 4 days' time. In another instance a man jumped from a hot-blast valve head to escape from a slip, fracturing his leg, and in another case a man leaped from the top of a stove to escape a slip and was killed.

Other accidents from the same cause are cited below:

Coke thrown from the furnace struck a man's leg, burning and bruising it and causing a loss of 2 days' time.

A man was working on trestle and coke thrown from furnace by a slip cut his scalp, causing a loss of 15 days' time.

The furnace slipped and a man running for cover was struck on the neck by hot coke and bumped his head in crawling under a car, losing 17 days' time.

A piece of brick thrown out in a slip fractured a yard cleaner's rib, causing a loss of 30 days.

A laborer was digging a ditch near the furnace, when it slipped. A lump of ore fell from the top and broke his arm, causing a loss of 42 days.

A laborer stepped outside the cast house as the furnace slipped and instead of jumping back, attempted to run to a near-by office. He tripped and hot coke burned his legs and body; loss of time, 42 days.

The furnace slipped, throwing hot coke on man cleaning up cinder on the tracks near the furnace. The man was burned about the scalp, neck, ears, and arms, and lost 68 days.

In four different instances men who were standing near a furnace watching the top to see the furnace slip were injured. In some of these it was necessary for the men to note the starting of a slip, so that they could signal for the blast to be turned on; in others the injured men were not obliged to stay in a hazardous position, but did so out of curiosity. The lost time was 15, 28, 29, and 105 days, respectively.

Eight men were severely burned and bruised by material expelled from a furnace by a slip falling upon them while in an adjoining cast house, from which the roof had been removed.

Two men engaged in cleaning the roof of a cast house were caught by a slip and burned by the hot dust, causing disabilities of 27 and 30 days, respectively.

A slip broke the shell of the furnace and ejected a shower of red-hot coke and ore over seven laborers, causing disabilities of 8 to 245 days.

CHARACTER OF INJURIES.

By far the most numerous class of employees suffering accident from slips is comprised in the laborers about the plant. These men, for the most part unacquainted with the obscure indications of an impending slip, and engaged in tasks singly and in gangs about the plant, in the yard, on the trestle, and at the cast house, make up the bulk of men injured. The possible severity of various injuries and the amount of time lost is indicated in the following tabulation.

Thirteen typical accidents at blast-furnace plants, showing time lost.

Kind of accident.	Period of disability, days.
1. Lacerations of forehead, burns of neck, face, and hands	3
2. Burns of neck	3
3. Burns and cuts on face and neck	5
4. Burns of face, laceration of scalp	7
5. Burns of hand and forearm	12
6. Burns of body	14
7. Burns of face and neck	16
8. Burns and cuts on face and hands	18
9. Laceration of scalp	25
10. Contused and burned shoulder	25
11. Burns and cuts on arms and hand	27
12. Burns on back of hands, also bruises	52
13. Burns on limbs, also cuts and bruises	195

SEVERITY OF SLIPS IN PRESENT TYPES OF FURNACES.

Frequent mention of tops being blown off furnaces, shells bursting, and boshes collapsing as the result of slips may be found in the trade journals of this country up to 1909, and even at the present time in foreign trade journals. These disasters often resulted in considerable loss of life, as many as 3 to 12 men being killed or injured. The lack of mention of such accidents in American journals during the past six years is partly due to the reluctance of those concerned to discuss the trouble or to invite publicity, but more especially to elimination of such accidents. With the exception of a number of furnaces having weak shells and disadvantageous lines and distribution, it may be said that most blast-furnace plants are free from the possibility of such accidents as occur from failures of tops, boshes, or shells.

Terrific slips still take place, however, and the effect of these is confined to the interior of the furnace, if it has a tight top, or shows up at the gas burners and bleeders. The net result of such slips is largely confined to property damage and decrease in tonnage. For instance, at a furnace with a tight top a heavy slip forced open the bell on a dust catcher, and the gas rushed out through a dust chute into the hopper of a railroad car with such velocity that the car rolled over and over until it brought up against a boiler-house wall.

A much-dreaded type of slip is one where the falling column of material shears off a number of bosh plates and admits large quantities of water into the hearth and crucible. When this occurs, unless the leak is discovered immediately, it may require one to three days' hard work to get the furnace in condition again.

Occasionally, although no water reaches the hearth, a pasty mass of unsmelted material fills the hearth and part of the bosh. This also requires a long period of hard work before the mass can be melted up and the tuyères cleaned so that smelting and driving begin again. When the material dropped down into the hearth is loose the cinder-notch cooler is sometimes removed and the material blown out. One case has been seen where many tons of cold material, coke, raw limestone, and unreduced ore was blown out.

Occasionally the iron and slag is just barely fluid and when the tapping hole is opened the sluggish iron runs and chills, builds up, and forms a small crater, out of the top of which iron is flowing and chilling, thus continually building it higher. A case was seen where this crater or accumulation of frozen iron and slag with a liquid core had built up almost to the blowpipe level.

Another condition much dreaded is when the stock slips, falls into the hearth, and jams down into the bath of iron and slag, forcing it up above the level of the tuyères, where it sooner or later runs back into a blowpipe, burns it, compels the blast to be taken off, and then completely fills the other tuyères. Another variety of slip is illustrated by the following incident: A furnace was working stiff but not slipping markedly, and immediately after a cast was finished a large amount of black scaffolding material with much cinder slowly descended to the tuyères. Tuyère after tuyère filled until when only three were available and no cinder could be obtained at the monkey, braces were hurriedly placed against the stocks, the bridle rods were removed, and then the braces were pulled from a safe distance. A large amount of cinder ran over the cast-house floor, but after it was cleaned up three tuyères were easily gotten into blast again and the furnace worked into condition. At the present day, and at most plants, this and similar varieties of slips are the most dreaded.

EXAMPLES OF EXPEDIENTS USED TO CHECK SLIPPING.

Some idea of the work entailed by severe slips, a glimpse of the occasional difficulties of furnace work, and the expedients tried are shown in the following descriptions supplied to the author by blast-furnace superintendents:

The blast on both furnaces had been very regular and the furnace became very hot with a very basic cinder. The burden increased 2,400 pounds in two days on one furnace and 2,900 pounds in the other. The latter furnace became "lime cold," filled the tuyères in a slip, and "skulled up" the cinder notch with a limy iron-bearing cinder. After holding the furnace 10 hours the cinder notch was finally opened and the furnace was flushed, the cinder filling the ladles and running all over the yard. On Sunday the furnace filled its tuyères again from a slip, getting "cold on the lime" and "heavy burden" (too much limestone for flux and too much ore), and making no gas to speak of, a new stove showing only 800° F. By adding considerable extra coke, lightening the burden, and reducing the lime the furnace was gradually worked into good condition.

The other furnace, becoming very limy, was also getting cold and hanging continually. Finally the monkey was taken out to flush out the cold cinder. During the flush the furnace slipped, filling the tuyères and burning several blowpipes and stocks. As soon as four tuyères could be gotten the blast was turned on and attempt made to drill the cinder and iron notch. After several hours the blast had to be taken off, for neither tap hole nor iron notch could be gotten. Preparations were then made to cast through a tuyère about 2 a. m., and an oil burner was put in both the iron and the cinder notch and was set going, taking the blast from the other furnace. The water was then taken from the tuyère, after a runner had been made, and for 15 minutes iron and cinder flowed from the tuyère. The tuyère was then plugged with clay and brick at 7 p. m. in the evening, the iron notch was opened, the wind having been off in the meantime, and four ladles of iron obtained. The notch was plugged with sand, coke dust, and clay, but hardened again, requiring a blowpipe. It was finally opened at 5 p. m. the next morning, the burden lightened, the lime taken off, and several blanks of coke charged, and the furnace was gradually gotten into condition.

Another example is as follows:

The furnace had gotten cold. At 10 a. m. it was reported to have been hanging for two hours, and shortly after it slipped to the 40-foot line (this would be a 25-foot slip). It was filled, and made a slight slip a half hour later. At 4 p. m. it had been hanging two hours and slipped to the 45-foot line, blowing off the top and filling the blowpipes and tuyères. After the hopper and bell had been replaced the furnace was given 300,000 pounds of coke with limestone flux, with the result that the cinder showed up limy and filled the tuyères again. By this time the cinder notch and tap hole were tightly frozen, and a burner had to be put on both. The cinder notch was easily opened with the burner, and after several flushes a runner was made and a cast taken from the cinder notch. At the iron notch, however, the burner was in 6 feet, and no iron could be gotten, so a charge of dynamite was put in, well tamped with clay, and set off. This opened the hole to some extent, but after a while it froze up again. The burner was put on once more, and the notch finally opened, and the roof broke above the hole, making a good cast. By using extra coke and light blast the tuyères were gradually opened and the furnace was worked into condition.

These notes are typical of the work required when violent slipping occurs, and, with the exception of the blown-off top, represent the emergencies for which furnace men must be prepared, even nowadays. The oxygen burner has made the work much easier, but experience is still the requisite in determining the steps necessary to get a furnace into condition again after the tuyères and notches have frozen up.

The general rule is to get at least one tuyère, adjacent to the cinder notch, on blast, and more than two are not considered desirable at the start. In some cases the tuyères have had to be abandoned and the furnace started with a monkey inserted in the bosh.

PRECAUTIONS AND SAFEGUARDS.

Practice, design, and materials may be adjusted to a considerable extent to give a certain freedom from slips. In view of the many handicaps to attaining a minimum amount of slipping and the certainty that slips will occur, protection of the force from injuries by these causes is essential. The most vital step in eliminating slips and the injuries resulting therefrom is an improvement in design.

THE USE OF TIGHT TOPS.

The improvement that has resulted in the greatest diminution of accidents is the application of the tight top to furnace construction. Formerly a man virtually took his life in his hands when he ventured on top of a furnace, or on any elevated place, difficult of escape, in range of explosion doors. The tight top, with no explosion doors and with a positively closing bleeder, or bleeder which allows only fine dust to escape, has practically eliminated the chance of injury by flying material, flame, or hot dust.

On furnaces of modern construction, having heavily armored boshes, three-fourths inch double and triple riveted shells, dome, or strongly braced tops, and strongly constructed downcomers and dust catchers, explosion doors have been eliminated with impunity, and automatic bleeders have been replaced with bleeder valves that opened only by hand, high pressure from slips either forcing them against their seat or balancing any tendency to open. At furnaces of questionably strong construction, so that a slip may burst the shell unless prompt relief of pressure is afforded, explosion doors at the gas off-take can usually be eliminated with no danger of the shell bursting, provided that bleeder valves of ample capacity are installed. By eliminating the explosion doors and providing four bleeder valves instead of the usual single valve, adequate relief is afforded, and placing the valves at the top of bleeder pipes 20 to 40 feet above the furnace top lessens somewhat the amount of material ejected by the rush of gas when minor slipping occurs.

REINFORCING THE BOSH AND STRENGTHENING THE TOP.

Frequently more radical steps are necessary if the furnace shell or bosh construction seems too weak. Heavier and wider bosh bands, wide enough to fill the vertical distance between the bosh-plate boxes or openings, may be provided, and the old bosh bands placed inside the furnace stack in a series of reinforcing bands at 3 to 5 foot centers, a few bands of similar material being used to supply any deficiency. The top may require further strengthening by additional braces from the shell to the top ring, and also better provision against displacement of the hopper and hopper extension. Such modification enables the use of bleeders that afford relief of gas pressure, but not the escape of large pieces of limestone, coke, or ore.

EXPLOSION DOORS.

The presence of explosion doors on gas offtakes has not sufficed, regardless of their size and number, to prevent slips from throwing the bell and hopper out of the top, splitting the shell, and wrecking the base. Furthermore, the difficulty of maintaining tight seats owing to erosion by dusty gas or warping of the door or seat introduces the possibility of air sucking in during shutdowns or slips, thus causing so-called "top shots" occasionally.

The uselessness of explosion doors in preventing danger from explosions, the annoyance they cause by ejection of material on even trivial slipping, the cost of keeping the yard clean, and the danger of ejected material falling on men about the yard and furnace top is sufficient cause for their elimination. Some plants having four to six explosion doors have found it safe to eliminate half of them. The door is left in place and is fastened down on its seat by a so-called "safety" bolt, three-eighths or one-half inch in diameter, which supposedly will break in the event of a violent slip and permit the door to open. At one plant where this arrangement is used none of the bolts have ever broken. Another practice is to provide hinged explosion doors with heavy chains, which prevent the door from opening more than 12 to 18 inches. Sometimes a heavy structural beam is fastened over the top of an explosion door, so that a horizontal door can not lift more than a few inches when the furnace slips. Hinged explosion doors may be provided with a shield in front of them, which prevents material being thrown, sometimes hundreds of yards, over the furnace or adjacent property.

BLEEDER VALVES.

Bleeder valves are of two types—valves seated at the outlet of the bleeder pipe and valves contained within the pipe, the outlet being above the valve and a continuation of the pipe. Both types may be arranged to permit the passage of solid material carried in the gas or to prevent it from escaping with the gas. When possible such valves should be designed to permit only fine material to escape, thus eliminating the showering of heavy lumps on the roofs and yards, while affording relief from gas pressure. Interior valves permit gas to escape without the noise that characterizes the other type and are less liable to burning of the control levers for closing the valves against high pressure.

NECESSITY OF STRONG CONSTRUCTION.

If the use of explosion doors and bleeders that permit free escape of material is required, then safeguards should be provided. However, the fact that the jacket is considered so weak that the throttling of the release of gas pressure would present hazardous conditions, should justify serious consideration of strengthening the bosh, shell, top, and downcomers at the first opportunity. Such weak construction, if it exists, is inimical to the safety of employees and may cause serious losses in production and investment in the event of heavy slipping.

SIGNALS AND WARNINGS.

SIGNALS BETWEEN CAST HOUSE, BLOWING ROOM, AND SKIP OPERATOR'S STATION.

Unnecessary hanging of the furnace may often be avoided by the use of a telephone, speaking tube, or signal bell and light between the skip operator's station and the blower's office and the cast house, or by a system of regular half-hour card reports, showing the height of stock line and furnace condition, whether "hanging," "stiff," "regular," "out of reach," "slipped," "number of charges," etc. The simplest type of signal from the skip and bell operator to warn that the furnace is hanging is a blast from a special whistle, used only for this purpose. More in favor is a signal-light system, of which possibly the simplest type is a red light in the cast house, which in event of the furnace hanging is turned on by the skip operator. This is supplemented by a similar red light at the skip operator's station, which the foreman or blower lights from the cast house when he is checking or stopping the furnace. Sometimes this signal system is elaborated by having two lights, one white and one red; in the cast house red indicates "hanging" and white indicates "slipped," whereas at the skip operator's station red indicates a "stop" or "check," with notice to report the condition of the furnace, and white indicates "blast one" or "start charging." Occasionally a gong is used to supplement the light in order to attract attention. Instead of the foreman having to notify the skip operator that he is checking the furnace, a "buzzer" is sometimes relayed from the engine-room whistle circuit so that the skip operator is automatically notified in case of a check or stop. Two plants have installed an electrically lighted signboard in the cast house, at which the height of the stock line and the words "hanging" and "slipped" are illuminated as required by punching in a plug at a miniature panel in the stock house.

The use of an automatic recorder located in the blower's office, showing the movement of the skip or hoist, bells, rodding device, and the distributor, if any, is an invaluable means of noting any interruption to regularity of charging. A similar knowledge of interruption of filling is afforded by a sensitive top temperature or top pressure recorder. Frequently, if a daily analysis of furnace gas from samples representing an 8 or 12 hour period are made, water leakage may be indicated by the abnormally high hydrogen content.

In order to avoid mistakes in checking the furnace at the blowing room, the whistle should be as dissimilar in tone as possible from other whistles, and the furnace from which the signal is blown should have a light of different color, or its number, displayed in the engine room by the circuit operating the whistle. The use of electric power for operating the whistle is preferable to other means, as a light may be placed at the cast-house switch which is flashed at each contact. At one plant, to insure thorough understanding of signals, each engine is provided with a switch at the engine throttle, whereby the engineer is enabled to relay the blower's signal back to the cast house. One plant, in order to be sure that the electric-signal system is always in working order, has it so arranged that the telltale light on both the cast house and the blowing room are in circuit at all times, and lighted, except when the switch is thrown for the signals.

GENERAL METHODS OF WARNING WORKMEN.

There are three general methods of special warning to workmen about the yard, stoves, trestle, or cast house. Some plants provide a whistle at the skip operator's station, as already noted, or at the cast house. When placed in the cast house it is blown by the man checking the furnace, and is preferable to the other location, in that the blower can often tell when a furnace is about to slip when the skip operator will not have any intimation from the filling or rodding that such is the case. Also, if the blower gives the signal he can time it more closely to the actual danger point than can the skip man, who is in ignorance of when the furnace is to be checked.

Another method, used at but few plants, however, consists in having a number of red lamps at points commanding a wide range of yard or working places. In event of the furnace being due to slip, these lights are thrown into circuit. They really supplement the whistle at the blowing room. Inasmuch as this whistle is blown for a shutdown, for making a cast, or for changing a tuyère, it soon ceases to have any particular significance as regards indicating a slip. If it is supplemented by red lights about the cast house, men in hazardous positions can readily determine whether the furnace is about to slip by glancing at the lights when the signal at the blowing room is heard.

A similar safety provision is in force at four plants, where in event of a slip signs are displayed which read "Danger—furnace slip." These signs are covered when the furnace is running smoothly, and are displayed only in event of an impending slip.

When a signal is needed for men at the stoves, boiler house, yard, trestle, in cars or in ditches, on top of the furnace, or in any exposed place, a whistle is the simplest and most urgent warning. It should be loud and of distinctive sound and not smaller than 2½ inches in diameter. It should be sounded as a warning when the furnace is discovered hanging and repeated before the furnace is checked.

PROTECTION FROM FALLING AND FLYING MATERIAL.

The roof over the cast house should be of at least three-sixteenths inch steel plate, as roofs of corrugated iron are likely to corrode rapidly and permit material to fall upon men in the cast house. The walls of the cast house, if not continuous from roof to floor, should extend down far enough to prevent material from rebounding from stoves or adjacent furnaces and buildings into the cast house. The roof should be continuous about the whole diameter of the furnace. Boilers, hoisting machinery, cinder-crane operator's cabs, hoist houses, and offices and shanties in proximity to furnaces should be similarly provided with strong roofs of fireproof material.

The windows should be provided with strong wire-mesh screens. One plant has installed a series of canopies or coverings over walks and steps about the base of the furnace, where it is frequently necessary for men to walk to and from their work in range of flying material from slips. Where oil, steam, or air cylinders for operating the bell cylinders are in range of flying material, many plants have installed steel roofing over the cylinders to protect repair men from injury. Several plants have installed small shelter houses at the top of the furnaces, generally on the top platform adjacent to the bridge from the stoves to the furnace top, to provide shelter to men caught in a slip while working at the top of the furnace.

PRECAUTIONS TO PREVENT ACCIDENTS FROM SLIPS.

To prevent accidents from slips, aside from the hazards from falling material, which may be quite remote, or absent, or guarded against as described above, certain precautions are necessary in the work about the cast house, stoves, boilers, and top.

PRECAUTIONS IN GOING ON FURNACE TOP.

When it is necessary for men to go on top of a furnace they should report to the blower, regardless of whether routine or special work is to be undertaken. Before the blower permits the men to go he should take all possible precautions for their safety. If the furnace is hanging, men should not be permitted to go on top under any consideration or circumstances. It is best always to check the furnace and keep it on check until the men are off the top. If necessary, the blast should be taken off altogether.

PRECAUTIONS IN WORKING ABOUT THE CAST HOUSE.

If the furnace is known to be hanging, warning should be given by means of the whistle, signs, or lights, so that men about the yards will have time to get out of the way.

Men watching the tuyères when the furnace is hanging should not hold their eyes near the eyesights, as slag or coke may be thrown against the glass and break it; also, they should wear goggles or hold a hand glass between the sight and their eyes.

Before a tuyère, plate, or cinder-notch cooler is changed, or the last shift goes on the drill in opening the iron notch, or the crew begins work on the notch after a cast, or caps are to be removed from tuyère stocks, or the blowpipes dropped to clean them, the blower should be sure that the furnace has settled and that it is not hanging. While work of this character is being done the skip and bell operator must not dump the large bell, as hot slag, coke, or flame may be ejected through the open tuyères or plate openings, as if the furnace had slipped.

PRECAUTIONS IN WORKING ABOUT DUST CATCHERS AND STOVES.

When stove-well bottoms are being cleaned the gas burner should be shut off completely or sufficiently closed so that if the furnace slips gas will not flash out of the cleaning door.

Whenever a signal is given that the furnace is about to slip, the stove cleaners and hot-blast men should keep away from the cleaning doors, and they should never for any reason open the doors of stoves on gas until the furnace has slipped.

Dust men, stove cleaners, and stove tenders should keep from under gas legs, and away from stove burners, and under no circumstances dump a dust catcher when the furnace is hanging.

PRECAUTIONS IN THE BOILER ROOM.

Tube blowers and firemen should keep away from boiler-setting doors upon receiving warning that the furnace is hanging.

GENERAL PRECAUTIONS.

Foremen in charge of men working in places where they are exposed to slips should be on the lookout for any signs of a slip. When a warning is given, any men in cars or ditches or on elevated places should be immediately ordered to a safe place. Other men in places from which escape is more easy should be warned not to remain so far from shelter that it will be difficult to quickly get under cover.

No workman should be permitted about any place where he is in danger from slips unless he is actually employed there. If a man is assigned work in such places, his experience about furnaces should be ascertained, he should be warned of the dangers, and whenever the furnace is hanging the blower should particularly warn him.

One type of accident which occasionally occurs when the furnace slips heavily, is the ignition of oil in the cold-blast main by burning gas surging back from the furnace through the mixing valve. However, it is only through a poorly seated valve, or gross neglect in closing the valve, that such accidents can occur. **Before a furnace is checked, the mixer valve on the by-pass between the cold-blast and the hot-blast main must be closed.** Two minor accidents from fire in the cold-blast main caused by the furnace slipping and burning gas rushing back into the cold-blast main through an open mixing valve on the by-pass have been noted; in one case a cast-steel elbow in the main was cracked, and in the other three cold-blast valves on the stoves were put out of commission.

Inasmuch as it is always possible for a mixing valve to be imperfectly closed or to be forgotten and not closed at all when the furnace is checked, the use of automatically closing valves should be earnestly considered. Such valves are of various designs, either closing by weight of the valve itself when the blast is slackened, or being actuated by auxiliary air cylinders in which the piston opens or closes the valve in the cold-blast mains or mixer pipe, according as the blast is turned on or taken off the furnace. In using such auxiliary valves in the by-pass an indicator should be provided to show the positive working of the valve; also the valve should be inspected at intervals to see that it does not become warped or broken.

Watchfulness is necessary to insure positive and effectual working of automatic valves, for the use of such safety appliances as apparently eliminate the need of personal responsibility invites similar accidents by mechanical failure. The installation of such valves is of the greatest value if they are considered as supplementing the personal responsibility for the prevention of fires and explosions in the cold-blast main, but the stove tender should be held to his former obligation of closing the mixer valve when the furnace is checked, the millwright supplementing the stove-tender's duty in this regard by conscientious care of the nonreturn valve; otherwise such a valve is worse than useless.

CONCLUSION.

The furnace type, or features of construction, or methods of practice that will give absolute assurance of immunity from blast-furnace slips, hot-metal breakouts, or gas explosions have not yet been developed. So far as improvement and progress in these matters is concerned, the past 10 years shows an advance that is to the great credit of operating men and engineers, and if future improvements in this respect can be estimated from the advances of the past, it is apparent that accidents of the above types, although they will never be eliminated, will in frequency and seriousness become an even less serious factor than at present, as regards regular and safe operation.

In the attainment of this end, it is probable that, as in the past, improvements in design, construction, and practice evolved from operating experience and experiments will be of greater value than inventions and technical investigations, and that furnace men will look to small but gradual improvements in the distribution of stock within the furnace, the preparation of the materials of burden, the lines of the furnace, and advances in practice and construction rather than to studies of the chemical, physical, and thermal actions taking place in the furnace. Much advance has been made along practical lines, and the writer believes that it is in further development along the same practical lines by the men engaged in furnace practice that the greatest advance is to be expected in the minimizing of the types of accidents discussed in this report.

NEED OF FURTHER INVESTIGATION.

It is believed, however, that with the improvements effected in progress, and to be expected along these lines, most furnace men would welcome experimental work along certain lines, and that such work, if undertaken in cooperation with men or concerns operating furnace plants and auxiliary operations, would repay the time and effort expended. In suggesting the following studies, it should perhaps be mentioned that although they do in fact approach more nearly questions related to regularity and economy in operation than to safety in operation, it is virtually impossible to separate safety in operation from regularity in operation when the subject of blast-furnace slips or blast-furnace breakouts is being considered. Without qualification, safety is here a corollary of regularity in operation. The possibility of explosions is not related to operation in this close manner; here the personal element enters and the possibility of errors of judgment, omission, and commission play a larger part. But in the work suggested, the successful working out and application of the problems would result in better regularity of practice (which means reduction of the coke consumption per ton of iron produced, a decreased production of off-grade iron, less loss of iron per ton produced, and less interruption to the process from irregularities) quite as much as in the possibility of improvement in decreasing the probability of excessive slipping or dangerous breakouts, a possibility that has already been reduced within the bounds of reasonable if not exceptional security to men employed about blast-furnace plants.

The investigations the writer has in mind are:

(1) An investigation as to the relation of the physical properties of coke to its combustibility in the furnace and its solution loss in the upper part of the furnace, the preparation of specifications for blast-furnace coke to be based upon these properties rather than upon the chemical constituents (see page 223, Part III); (2) an investigation of the resistance of hearth and bosh fire brick to the attack of slag, iron, and the intrusion and disintegration by graphite and alkaline salts (see page 48, Part I); (3) an investigation of the free-flowing temperatures, the temperature of formation, and sulphur eliminating properties of slag (see page 235, Part III); (4) an investigation of sintered, briquetted, nodulized, and agglomerated flue dusts and fine ores, as to strength, state of oxidation and reducibility, porosity and glaze, density, and purity (see page 227, Part III).

GLOSSARY.

AIR TUB. The cylinder on blowing engine which pumps the blast or wind or air.

BLEEDER. An escape valve for gas at top of furnace or along the gas line, to relieve excessive pressure or flow of gas.

BLOWING ON THE MONKEY. Blowing air through the cinder notch at flushing.

BLOWING ON TAPPING HOLE. Blowing air through the hole at casting, to clean the hearth of iron and cinder.

BOIL. Occurs when molten iron runs over a cold or damp spot or object in runner. The sudden generation of steam often causes an explosion, whereby molten iron is scattered about.

BOSH BREAKOUTS. Breakouts of the blast, gas, or coke through the bosh brickwork.

BOSH JACKET. Reinforcing jacket to hold brickwork and platework of bosh in place. Employed mostly in eastern and southern furnaces.

BOT. A cast-iron or forged-steel plug, that mounted on a long steel rod, fits inside the monkey.

BOTTING. Thrusting bot into monkey to stop run of cinder during a flush, or when the furnace begins to blow on the monkey.

BOTTOM FILLERS. Man who fills barrow with ore, coke, or stone, weighs it and places it on cage, or elevator, to be hoisted to top of furnace.

BREAKOUT. Escape of gas, coke, slag, or iron from the bosh, tuyère breast, or hearth of a blast furnace.

BRIDLE ROD. A wrought-iron rod employed to hold the stock or "bootleg" in place against the blow pipe.

CAST HOUSE. The roofed (and sometimes inclosed) space in front of and about a blast furnace in which molten iron is run or cast.

CHANGING BRONZE. Changing tuyères, plates, monkey, etc.

CHECKING. Reducing the volume of the air blast on a blast furnace temporarily in order to make furnace "slip" or "move." Also in sense of first "check," second "check" at casting time to stop iron notch.

CHIMNEY VALVE. Valve on hot blast stove open at base of chimney or at flue when stove is on gas; closed when stove is on blast.

CINDER BREAKOUT. The slag within the furnace comes through the brickwork and escapes. Caused by erosion, softening of brick by heat, or corrosion and penetration by slag.

CINDER NOTCH. The hole, about 5 or 6 feet above iron notch, and 3 feet below tuyères, through which slag is flushed two or three times between casts.

CLAY GUN. *See* Mud gun.

COOLING PLATES. Hollow plates in furnace wall, through which water circulates to cool the wall.

"CRACKS" OF GAS. Puffs or explosions of gas.

DISTRIBUTOR. Device for distributing charge when dumped into blast furnace.

DOG HOUSE. *See* Fore chamber.

DOSE. Special charge used in blast furnace, designed to cure furnace troubles.

DOWNCOMER. Gas main from furnace top to dust catcher.

DOWNLEG. Leg or boot of a dust catcher.

DRILLING UP. Preliminary digging out of the clay in the tapping hole. This is done usually with hand, air, or electric drill.

DUST CATCHER. Primary chamber for settling dust out of blast-furnace gas.

Dust man. Man who dumps dust catcher or loads the dust.

Dutch oven. *See* Fore chamber.

Explosion door. Door to relieve pressure in gas mains in event of a gas explosion; also valves at gas offtakes at furnace top to relieve pressure when the furnace makes a heavy slip.

Explosions from molten iron. Caused by molten iron escaping and coming in contact with water or wet material.

Fore chamber. Auxiliary construction for gas-fired boilers, provides incandescent surface for lighting gas instantly when turned on after being shut off for any reason. Also called "Dutch oven" and "Dog house," and is of benefit further in enabling combustion of gas to be complete before boiler tubes are encountered.

Furnace holding iron. Furnace gives much less than normal amount of iron at casting, although the charging may have been regular. The tap hole runs iron slowly, and amount of slag is somewhat scanty. Compare "furnace losing iron."

Furnace losing iron. Escape of iron from the hearth of a blast furnace into the foundation beneath, indicated by decreased quantity of iron at casting, and abnormally large appearance of slag at tapping hole.

Gassed. Overcome with gas.

Green hole. Tapping hole in which clay is not properly set, and through which the drill may break and let iron out unexpectedly.

Hanging. Sticking or wedging of part of the charge in a blast furnace.

Hard hole. Tapping hole difficult to open, usually one in which stopping clay is short and drill encounters cold skull of iron.

Hearth breakout. Breakout of molten iron through the hearth wall or bottom.

Holding iron. *See* Furnace holding iron.

Hot spot. A small portion of the furnace shell that is warmer than the rest. It indicates a thin lining at this place on account of erosion of brickwork by gas and stock.

Losing iron. *See* Furnace losing iron.

Mantle plate. Plate that supports the mantle.

Mess. Masses of cinder, slag, iron, etc., about the furnace or yard, from burned tuyère or blowpipe, bad tapping hole, breakouts, burned ladle, or boil.

Monkey. Small water-cooled bronze casting in cinder-notch cooler through which cinder runs from cinder notch when bot is withdrawn.

Monkey boss. Man in charge of flushing furnace and of claying up monkey and coolers. Helps on tapping holes also, and at cast.

Mucky hole. Tapping hole from which the iron is so pasty that it does not run freely.

Mud gun. A steam cylinder operating a plunger inside steel tube 6 inches in diameter. Clay is fed into hopper tube as plunger is worked back and forth and is thus forced into tapping hole, at end of cast.

Plate box. Box for cooling plate.

Pricking bar. Bar used in opening tapping hole.

Rid up. Cleaning up period after cast, when trough and runners are prepared for next cast.

Ridding up. Cleaning up after a cast.

Sand valve. An old type of arrangement in gas mains used to shut off flow of gas, superseded by water seal valves.

Short hole. Tapping hole with a short stopping, may break out unexpectedly when drilled into.

Skull. Iron that has solidified on the interior of the furnace.

SLAG BREAKOUT. Breakout of slag or cinder through the brickwork between plates, tuyères, and top of hearth jacket.

SLIP. Sudden descent of a hanging or sticking charge in a blast furnace.

SNORT VALVE. A butterfly valve opening from cold-blast main to atmosphere. Allows casting at the furnace without shutting down blowing engines. Operated by large wheel or lever in cast house.

STOCK. Term applied to the mixture of ore, coke, and limestone charged into the furnace, or stored in bins at stock house. Also applies to connection between blowpipe and gooseneck attached to bustle pipe.

STOCK HANGER. Hanger for tuyère stock.

SUBJACKET. An auxiliary jacket about the lower part of the hearth.

TOP FILLER. Man who dumps charges into furnace top.

TOP KICK. *See* Top shot.

TOP SHOT. Explosion or puff of gas at furnace top.

TUBE BLOWER. Man who cleans tubes of boiler.

WELSHMAN. A heavy steel ring about 3 or 4 inches inside diameter, used in withdrawing a bar which is stuck or frozen in a skull of iron. The ring is placed on the bar, a wedge inserted, and the bar backed out by sledging on the wedge.

WILD GAS. Blast-furnace gas that does not burn steadily or properly.

WORKING ON THE WALLS. Eroding of furnace linings or channeling of gas through burden next to the lining.

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