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THE COKE INDUSTRY OF THE UNITED STATES

AS RELATED TO THE FOUNDRY

BY

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THE COKE INDUSTRY OF THE UNITED STATES AS RELATED TO THE FOUNDRY.

By RICHARD MOLDENKE.

INTRODUCTION.

The investigations carried on at the fuel-testing plant of the United States Geological Survey at St. Louis in 1904–1907 included tests of the steaming and gas-producing qualities of many coals and of the possibility of their improvement by briquetting, together with washing and coking tests and tests of some of the resulting coke in the cupola. These tests were part of a general inquiry into the manner of utilizing most efficiently each of the coals under investigation.

The equipment used in the cupola tests of coke, the manner of conducting the tests, and the essential results have been described in publications of the Geological Survey,[a] and only the more important conclusions to be drawn from the tests are mentioned in the following pages. The tests were made to show the fitness of the cokes for foundry purposes, but an incidental result was to show foundry men and the coke producers the advisability of studying the conditions of foundry practice. The present bulletin, published by the Bureau of Mines because the analyzing and testing of fuels have been transferred from the Geological Survey to the Bureau of Mines, briefly reviews the status of the coke industry, some features of practice in the use of coke in the foundry, the probable happenings of a cupola heat, and the reasons for modifying charging practice so that a particular coke can be used to best advantage.

COKE-MAKING INDUSTRY.

WASTES IN COKE MAKING.

Probably in no other industry, unless in the mining of coal itself, is there so much waste as in the manufacture of furnace and foundry coke. A study of all the coke-making districts of this country and a comparison of the methods used are most convincing in this respect.

[a] Prof. Paper 48, pt. 3, and Bull. 336.

Particularly unfortunate is the fact that this waste is in most instances deliberate, the more economical methods being well known to those most interested. One cause for this condition is the conservatism of the trade, old methods being followed blindly, regardless of improvement elsewhere. Another cause is the necessity of utilizing the enormous investments in coke ovens, a change meaning the wiping out of millions of dollars of capital. Furthermore, the cost of the old ovens as compared with the elaborate by-product installations is comparatively low, and, finally, there is ignorance in the foundry industry in regard to cupola practice. All these causes combined have kept progress in coke making far behind as compared with the advances made in other industries.

For example, in 1907 nearly 62,000,000 tons of coal were charged into coke ovens, yielding more than 40,500,000 tons of coke. Roughly, therefore, more than 21,500,000 tons of the richest part of the coal were driven off. The probable loss involved in present coking practice has been analyzed by E. W. Parker,[a] from whose statement the following figures are taken:

Coke production, 1907.

	Coal used.		Coke produced.	
	Quantity.	Value.	Quantity.	Value.
	Tons.		*Tons.*	
Beehive ovens	54,485,522	$56,956,008	35,171,665	$89,873,969
Retort ovens	7,460,587	15,874,430	5,607,879	21,665,157
	61,946,109	72,830,438	40,779,544	111,539,126

The total value of the by-products from the retort-oven coke was $7,548,071. If it is assumed that the coal coked in beehive ovens was similar to that coked in retort ovens, and that the prices obtainable for recoverable by-products would not have been less than 80 per cent of the average prices for 1907, the value of the recoverable products wasted that year amounted to $44,000,000, or nearly 80 per cent of the value of the coal actually used in beehive ovens.

If it is assumed further that the difference in value per ton of the beehive and the retort-oven coke was due only to difference in freight charges (the beehive ovens being mostly near the mines, the retort ovens near large cities), the total value of the 1907 output of beehive-oven coke (54,485,522 tons) if made in retort ovens close to market would have been $135,750,000; this amount added to $44,000,000, the assumed value of the recoverable by-products, gives nearly $180,000,000. Deducting the difference in assumed value between

[a] Coal fields of the United States, in Papers on the conservation of mineral resources: Bull. U. S. Geol. Survey No. 394, 1909, pp. 17–26.

the coal charged into retort and into beehive ovens ($52,000,000) from the difference in value of the coke and by-products if the coal had been used in retort ovens ($90,000,000) the remainder is $38,000,000, which represents (minus extra expense in operating costs, up-keep, interest, etc.) the approximate net loss due to beehive-oven coke production in 1907.

The change from the old wasteful beehive oven to the modern by-product plant will not come very quickly, for it involves enormous investment as well as a systematic development of the markets to take up the tar, surplus gas, ammonia products, and benzol that will be made as the newer installations are built. We are far behind Europe in this respect; for if we should seriously undertake to bring about the use of these by-products to the extent that is logically possible, by making creosote, the aniline dyes, etc., there would be no further need to burn tar under boilers to get rid of it, and no more importations of ammonium salts, creosote, etc.

Foundry men also are in need of instruction regarding the use of retort-oven coke, which, though giving as good results as the best Connellsville of the old days, requires freedom from prejudice regarding its appearance until the operative force of a foundry is familiar with it. The excellent quality of the coke produced in some parts of the Connellsville region has probably been the greatest hindrance to advancement in coke making. When going over the best plants, one can not much blame the foundry man for wanting just that kind of coke and taking no other. The coal from which the best coke is made is, however, nearly exhausted, and in order to lengthen the life of the mines it should be mixed with poorer grades, the combination making an equally useful coke.

Another source of waste to which attention should be called is the coke breeze. At some of the retort-oven plants the breeze is systematically worked up for special industrial purposes. Thus, coke that is too small for the foundry goes to the domestic markets for household purposes; but the very fine material, corresponding to the cinders coming from a locomotive, is sold to zinc-retort operators. Very little is lost.

In the coke regions where the old methods are used, however, the coke breeze lies in immense piles, unless, indeed, it is burned as fast as made, and a considerable portion of the coal originally used goes to waste in this manner. Now, it is well known that this breeze, often brought into the market for domestic purposes and known as "crushed coke," makes the best kind of fuel for hot-air furnaces in residences; yet in the regions where it is made no one seems to think it worth while to take advantage of fuel that could be had for the mere carting. Coal evidently is still so cheap that the need of a substitute is not felt.

The coming advance in the art of briquetting fuel in this country, which will incidentally open a great market for the tar surplus complained of by some retort-oven coke interests, should also help to solve the coke-breeze problem. Undoubtedly, if this finely divided coke is studied with a view to making it more valuable metallurgically—say, by the neutralization of sulphur—it will some day become a factor of particular interest to the foundry as well as to the blast furnace.

All classes of citizens could help to encourage less wasteful methods of using coal, and our industrial experts in particular should study methods of economizing to the utmost extent, by improved processes of manufacture and use, the resources that seem likely before long to be exhausted.

PROCESSES AND METHODS OF COKE MAKING.

In order to lay a foundation for the later discussion of the proper use of coke in the foundry the processes and methods of producing coke must here be briefly described.

In general coke is made either by the beehive process or in the retort or by-product oven. In the former process all the volatile matter is lost in the atmosphere; in the latter process the volatile contents, except the gas used in heating the ovens, are recovered as surplus gas, tar, and ammonia liquor or ammonium sulphate.

In either process the quality and structure of the coke produced depends on the original composition of the coal and on the heat treatment it receives. Thus a coal high in volatile matter will naturally make a light, porous coke, the escape of the gases tending to produce such a structure. The yield of such a coal will also be much less than that of a coal higher in fixed carbon and correspondingly lower in volatile. Coal of the latter kind will make the denser, heavier cokes, which carry a burden well and are therefore more sought after for melting purposes, other factors being equal. Combination in the by-product oven of the two classes of coal, so as to give an average percentage of volatile matter, will probably get the best general results in the future, for coals of the proper composition can be brought from various sources and can be mixed and run so as always to give the same grade of coke, the mixture doing away with any particular defect the coke might have if made from any one of the coals. A good structure can then be combined in a coke with low sulphur and phosphorus for the blast furnace or with low sulphur and ash for the cupola, and a mixture giving a light, porous structure and a high yield of by-products can be used for domestic coke.

In the beehive oven the slack or ground coal (washed, if necessary, to remove excessive sulphur and slate) is dumped through the orifice in the roof and leveled off to the desired depth. This bed may be thin if 24-hour coke is wanted, thicker if the run is to be normal, and heavy if 72-hour coke, left over Sunday, is to be obtained. Only coke of this last kind is supposed to go to the foundries. They pay for such coke, but as a matter of fact the foundry shipments are composed of coke made in twenty-four, forty-eight, and seventy-two hours, special care being taken, however, to select the best looking of each kind. Though foundry men are not hurt in any way by this substitution, as it does not matter how long the fuel was in the oven if it is of proper composition and physical structure, they should be better posted on the coking process, so that if for any reason the brand of coke they regularly use can not be had the introduction of a new one will not demoralize the plant.

The degree of heat, the time of running the oven, and the manner in which the air is admitted, of course, have a great effect on the physical structure, and where the longest time is allowed for making coke the results are apt to be best for foundry purposes. Thus, during the depression at the close of 1907 many ovens in the West Virginia coke districts were run with heavy charges, the heat lasting a whole week. The purpose was simply to keep the ovens hot and make little tonnage. Yet the coke turned out to be exceedingly hard and still of excellent structure for melting purposes. On the other hand, where ovens are hardly given time to complete the coking process the product is necessarily soft, will be high in volatile matter, and inferior even for the blast furnace.

The effect of heat treatment is even more noticeable in the retort oven. Here the coal in properly ground form is dropped into the large retorts or chambers and occasionally is stamped in, or it may be pressed into cakes and forced in from the end. The oven is tightly closed, the heat being supplied through flues in the walls of the oven. The by-products are rapidly given off, practically all of them being recovered during the first two-thirds of the process. Where recovery of these by-products is the primary object and the quality of the coke is a secondary consideration the ovens are drawn as soon as the point of greatest economy has been reached (sometimes in fifteen hours); the result is poor coke, as many blast-furnace men have found, and the result has been a prejudice against retort-oven coke. Where, however, coking is continued for the full twenty-four hours, or even for thirty hours, the coke is of very good structure, provided it has had proper attention and the coal mixture is right.

Consumers of retort-oven coke should therefore make sure that their interests are regarded where it is produced; such insistence has, in fact, so worked out that, particularly in the interest of foundries, certain by-product plants in this country are run on mixtures of coal and under heat conditions that leave nothing to be desired.

The object of this bulletin is not to treat specially of coke making, and it is assumed that the reader is familiar with the beehive as well as the retort-oven process. Another bulletin, which is in preparation by the Bureau of Mines, treats of this subject exhaustively. It is well to say here, however, that cokes of all kinds and compositions can be made by carefully mixing the coals, not all of which need be of coking varieties, and by running the ovens with skill and in accordance with a definite programme. Though considerable improvement has been made, especially in the last few years, in the mechanical part of the beehive process, the method that will ultimately survive must be one providing for by-product recovery; and the sooner the coke industry awakes to this fact the better will it be for all concerned.

USES OF COKE.

Coke is used in the foundry principally for melting iron. This process is carried on almost exclusively in the cupola, where the coke is in direct contact with the metal. It is also used for melting brass and other nonferrous metals in crucibles. Here the heat of the burning coke is imparted to the metal through the walls of the crucible and the fuel and metal are not in contact. Finally, coke has a variety of minor uses about the foundry—in fires for drying cores, heating buildings, skin-drying molds, etc. Recently coke has been introduced with great success for firing boilers within city limits, as it is smokeless, like anthracite. For the same reason it also often replaces anthracite in the annealing rooms of the malleable foundry.

COKE IN FOUNDRY MELTING.

CONSTRUCTION OF THE CUPOLA.

The apparatus used for the cupola-melting process is of the simplest construction. An upright cylinder of boiler plate is lined with fire brick to resist the high temperatures of the interior. The lower end is closed by hinged doors and made tight against molten iron by fire sand mixed with sufficient clay to hold it. A tap hole at the lowest point of the slightly sloping bottom drains out the molten metal, and perforations a little way from the bottom allow air to be driven in to promote intense combustion of the coke. The coke gives up its heat of combustion to the charges of iron, melting them down. The niceties of the process consist in the proper adjustment and shape of the orifices, called tuyeres, the pressure at which the air is forced in, the method of charging the carefully proportioned coke and metal, and the general handling of the process to get the best results.

CHARGING METHODS.

In the early times, when but little was known of the rationale of the process, it was found that when a good bed of either anthracite coal or, later, coke was put in the bottom of the cupola and the top of this bed was a considerable height above the tuyeres, so that the first metal charged was at or above the hottest part of the fire when the blast was on, the metal would melt and could be tapped out and poured into castings. It was only necessary to keep on charging metal and fuel together into this fire, but in such proportion that the melting would proceed steadily at the rate shown by experience to be proper for the cupola.

All that later practice did was to stop the indiscriminate manner of charging and to separate metal and fuel into layers, so that the action would take place with some regularity and the mixture could be changed for different classes of work, and so that the metals could be caught with some degree of certainty during the melt. In view of the work of our early foundry men it is a question whether this change in practice has brought about a real improvement in the quality of the castings. Aside from the achievements of foundry metallurgy in the light of our present knowledge, it may be seriously questioned whether there is much truth in the general complaint of foundry men that pig iron has deteriorated in the last few decades. Pig-iron men hold that pig iron has improved and not deteriorated, and certainly modern blast-furnace practice is vastly improved, at least as to regularity in product. It would seem rather that the foundry man does not get as good results as formerly—that is, the foundry man who has no use for or does not know about the advantages of chemistry—because he can not use the pig iron as he formerly did, judging it by fracture. With the changes in furnace-casting practice the appearance of the fracture is no longer even a reasonably reliable guide.

Fortunately the introduction of chemistry, or rather metallurgy, into the foundry industry has done wonders, giving us the means to control our mixtures and start the process right, whatever we do to spoil it afterwards. Hence, also, has developed the tendency in this country to test the product not by cutting pieces out of castings, but by pouring test bars under conditions that give the metal as melted and poured into the castings the freest and best chance to show its qualities. It still remains for the foundry man to follow his craft according to his best knowledge and skill, so that the castings shall be the best that can be made with the iron so tested.

UNCERTAINTIES OF CUPOLA MELTING.

It is gradually coming to be recognized that the metal charged, be it ever so good, may be affected by a number of conditions during the melting and may turn out either as a creditable product or as a very inferior one. This is not to be wondered at. Melting depends upon the transmission of heat from the fuel to the metal at such a rate and in such degree that the solid mass of iron becomes liquid.

Iron is not one of the inert metals, such as are uninfluenced in quality by the process of melting. It would not matter whether the heat got into such a metal slowly or quickly, in one hour or five; so long as enough heat got in to do the melting the result would be the same. Iron is very much affected by the speed with which heat above the melting point is imparted to it. Furthermore, gases made intensely hot by the chemical action of burning or oxidizing carbon are also by no means inert. A chemical reaction between unconsumed oxygen and iron, silicon, carbon, manganese, etc., is certain to take place, for such reactions take place most readily at very high temperatures, and so the iron is more or less damaged.

The rate at which chemical changes proceed in the cupola, the intensity of the reactions, and the consequent need of keeping conditions just right throughout a heat are shown by the fact that under ordinary conditions it takes only one-fortieth of a second for a molecule of the oxygen in the air of the blast to pass from a tuyere through the incandescent bed and into that part of the charge too cold for chemical reactions. This brief interval is all the time the oxygen has to combine with the carbon of the coke, and (under certain conditions) with some of the manganese, silicon, or carbon of the metal charged, or with some of the iron itself.

Thus the management of foundry melting, whether in the cupola, air furnace, or open hearth, becomes a continuous struggle to get the valuable result of melting while avoiding the deleterious effect (as shown by defective castings) of oxidation of the metal.

It is no wonder, then, that there are still a few foundry men in remote parts of the world who cling to the ancient but admirable crucible process, in which fuel and metal are not in contact. This process minimizes the harmful effects of oxidation. Commercial reasons have practically eliminated the crucible process for plain cast iron, so those foundry men who want the highest grade of work select the air furnace, or hearth furnace, as it is often called, or perhaps the open-hearth furnace with regeneration of air and gas as fuel. In each of these processes the metal is in contact, not with the fuel, but only with the gases. Therefore, if the processes are carried on properly, there is a smaller chance for oxidation of the iron than in the cupola; moreover, the metal as it rolls down in little drops is not impinged upon by a current of gases containing abundant free oxygen, as it is in the cupola.

These statements do not mean that excellent metal can not be made by the cupola process—metal that will prove just as good under test as air-furnace metal of like composition—but the chances are not in favor of such success; and for the highest grade of product, especially if safety of life and limb may depend on it, such chances should really not be taken.

The few points mentioned above are enough to show that the melting process in the cupola might well be made the object of special study, and if the foundry man knows and has the proper irons and can make the required adjustments in his apparatus his study may be restricted to the coke (if that is the fuel) and the manner in which it is allowed to act on the metal to be melted.

ADJUSTMENT OF PRACTICE TO FUEL.

The writer has had a part in the efforts of associated foundry men from the beginning of what may be called the new era of the industry. He has listened to many experiences related both by veterans and by men newer to the business. All these experiences, including the foaming of enormous quantities of the slag out of the cupola doors on the charging platform and the disappearance of incredible quantities of metal during the melt, have strengthened his belief that troubles laid to the idiosyncrasy or, as some call it, the " innate cussedness " of the cupola (anyone's cupola has it when run by someone else) could really be avoided by changing the melting program to suit the fuel that is used.

Normal coke has 50 per cent cell space and has, pound for pound, practically double the volume of anthracite. Hence during the melt the downward movement of the metal within the range of the melting zone must be twice as fast when coke is used as it is with anthracite. Therefore the difference between the first of the metal to melt and the last, with respect to the influences to which they have been exposed, is greater for a bed of coke as compared with a bed of anthracite of like weight. That is, the first metal to melt is likely to be the same on either the coke bed or the bed of anthracite, but the last metal, especially if the charge is very heavy, melts much lower down in the coke-charged cupola and is necessarily subjected to greater oxidizing influences, because the blast low down in the cupola contains more free oxygen. When anthracite is used the part of the bed where the melting is actually done varies least in position.

This advantage is still retained by many foundry men in the East, where anthracite, as it is still available and no dearer than coke, may be used for the fuel bed and often mixed with coke in the subsequent charges, or even used altogether.

A study of the downward movement of the metal, as just stated, is important, as it suggests the way to make use, in regular casting practice, of practically every variety worthy of the name of foundry coke. Anthracite and coke, being practically identical in composition—that is, containing the same percentage of ash, fixed carbon, sulphur, etc.—differ radically only in physical structure. Thus, if the cell space of a coke is 50 per cent, as mentioned above, the coke has twice the volume of an equal weight of anthracite. Now, not all cokes have the same cell space, and, moreover, cokes differ in percentage of ash, etc. Hence a given weight of coke varies greatly in volume, and consequently the behavior of charges of iron melted with it also varies. The foundry man when changing his brand of coke makes the mistake of believing that the new kind ought to be handled in the same way as the old. It may be possible to do so if the two cokes have the same characteristics, but if they have not the foundry man is certain to get differences in results, which he usually ascribes to sulphur, high volatile, black ends, and what not. His coke dealer then hears from him. This difficulty is so marked that even when the same brand of coke is bought the year round and trouble results, investigation of the shipments often reveals substitution of coke from different companies located in the same general region. Furnaces have this difficulty to contend with more particularly.

It is therefore highly important that the foundry man get his coke from the same ovens and the same coal mines—in fact, have it as nearly the same as it can possibly be made; if a change is desirable or necessary he should be informed, so that he can adjust his work to the changed conditions.

In this respect the retort-oven coke has a great advantage. After the coals have been contracted for and the proper mixture has been established, the result will continue to be even as long as the coking process is carried out uniformly; and as the highest scientific skill is available at retort ovens, there should be little variation from the standard if the management honestly wishes none.

Another advantage of retort-oven coke is the size and shape of the lumps. A retort oven is narrow, and the coking of a charge proceeds from the walls toward the middle; the result is a mass of coke that, when quenched, breaks into short, thick pieces. The absence of thin fingers is decidedly noticeable. In comparison, the lumps of standard grades of beehive-oven coke are generally longer and thinner. Moreover, makers of retort-oven coke have carefully sorted the product before shipment, so that it has contained little breeze and the lumps have been of good shape. The size of the lumps of fuel in a cupola charge has much to do with the progress of the heat, and the absence of thin fingers accounts in a measure for the remarkable success of retort-oven coke when it was first used in foundries. Charges of coke having lumps that are uniform in shape and size give results similar to those obtained by using anthracite, which is marketed in screened sizes, because the uniform sizing of the fuel permits an even and regular penetration of the bed by the blast.

In order to adjust the process to the varying character of the coke used for melting in the cupola, it is necessary not only to change the melting conditions, for instance, by using a milder or stronger blast according as the coke is light or heavy, but also to change the relative weight of the metal and coke charges on the bed. A foundry man using heavy charges, though he may not know why, avoids coke with a large percentage of volatile matter. Such coke is necessarily underburned and light and ignites rapidly, spreading the melting through too large a volume. Very light charges will obviate much of this trouble, as the bed of coke will be kept more nearly uniform in height, and the melting will be done at the proper point. A coke in which the volatile matter is too high is virtually a gas coke and is too troublesome for use in the foundry, at least for cupola melting. It will serve well enough for all the other purposes.

Before the question of charging is taken up it will be of interest to review the original tests made by the United States Geological Survey at St. Louis, in the exposition foundry, where a collection of cokes such as never had been got together before was tested under identical conditions of melting.

COKE TESTS BY THE GEOLOGICAL SURVEY AT ST. LOUIS.

METHODS AND RESULTS.

Foundry men will remember that several years ago an elaborate series of cupola melting tests was made at the fuel-testing plant at St. Louis on cokes made from coals sent in from all parts of the country. These cokes were made under the direction of A. W. Belden, of the United States Geological Survey, and the melting tests themselves were made under the direction of the writer, assisted by Mr. Belden as executive. By being present at nearly every test, the writer was able carefully to gage the behavior of the several cokes and to determine their merits for the foundry. The cokes were naturally selected for their probable fitness for foundry purposes; that is, those having excessive sulphur and ash were barred.

The series of tables subsequently published [a] gave information of direct value to the owners of the coal and demonstrated many things impossible to ascertain in ordinary foundry practice, because no individual could afford to burn up valuable iron, even if the time could be taken to do it.

In all about 190 tests were made. Three thousand pounds of metal were melted in each test. To have uniform conditions in the coke bed for each test and at the same time to suit the average coke made, the height of the bed above the tuyeres was fixed at 14 inches as the standard, and this height was kept for every test. The upper tuyeres of the cupola were not used. A melting ratio of 7 to 1 was adopted, as the diameter of the cupola was small. The coke for the bed was weighed and put in up to the proper point, as measured by a weighted wire. The weight of the several cokes for this constant bed varied from 180 to 230 pounds, showing a considerable range in specific gravity—from the very light to the heavy cokes.

[a] Moldenke, Richard; Belden, A. W.; and Delamater, G. R., Washing and coking tests of coal and cupola tests of coke: Bull. U. S. Geol. Survey No. 336, 1908, pp. 48–76.

Metal weighing four times this weight of coke was charged on this bed, to conform to the general custom of foundries, and the remaining successive charges of metal and coke were divided into four parts, so as to preserve the total ratio of 7 to 1, the coke charges varying from 50 to 62 pounds and the metal charges correspondingly.

The blast was kept at about 7 ounces, and the time when the first iron appeared at the spout was noted. This time, which was five to fifteen minutes, was interesting as indicating how the coke behaved in burning and in allowing the iron to come into the melting zone. With the best results the iron came in seven to ten minutes.

Necessarily for the extremely light and very heavy cokes such melting practice would mean disaster, and in fact the melting loss did point very markedly to such a result. Possibly this may also convince many foundry men who still think it impossible to burn up iron in the cupola. The results showed the melting losses to be from 3.2 to 52.5 per cent of the metal charged. The cupola was continually slagged off, but in the worst case so much slag was made that it flooded the tuyeres and effectually stopped operations. When the bottom was dropped no metal was found remaining. It was evident that the lighter varieties of coke burned away so rapidly that the metal came to the lower portion of the melting zone much faster than it should have come. Moreover, as the original bed went down unduly for the melting of the first charge the subsequent coke charges did not bring the bed up to proper level again, and hence a Bessemerizing of the metal took place almost from the very beginning.

In tests of the very heavy cokes it was necessary to wait a good while before the bed had burned low enough to begin melting. Necessarily at the fixed ratio of 4 to 1 the first charge of metal on the heavy coke bed was very heavy. In this case also there was an undue lowering of the bed by the heavy metal charge after the surplus coke had burned off to begin melting. What was worse, however, was that the heavy coke bed took so large a part of the total amount to be used that the upper coke charges were necessarily very small, and the practical result was not only burned metal, but an insufficient amount of coke toward the end to continue the heat, so that the bottom had to be dropped. The general result of these heats with very heavy coke was burned iron for the beginning and unmelted iron in the cupola drop.

It may be seen, therefore, that when the melting process with a normal coke gives good results it does not necessarily follow that every other coke will do likewise; yet this is what the foundry man practically assumes when he changes his coke without making trial heats to see how to use it.

VALUE OF MELTING TESTS.

Perhaps the custom that is just beginning to be introduced into this country by coke companies of sending out experts to teach foundry men to use their particular brands of coke may obviate many of these difficulties. The retort-oven coke people were simply forced to adopt this plan, the appearance of their coke being so bad, as compared with the magnificent Connellsville product, that it took great argument to sell it at all. It should be understood that the clean, silvery appearance of beehive-oven coke as compared with the dull black cast of the retort-oven product results principally from the manner of quenching. In the beehive the quenching is done within the oven, and as little water as possible is used. In the retort oven the red-hot charge is forced out and deluged with streams of water as it drops into the receptacles for the coke. Consequently the retort-oven coke contains much more water than the beehive product. The formation of steam in the cells and the condensation and consequent drawing in of the water seem to hold it tight within, and when once water is thus included it remains. Coke exposed to rain will drain off the water to a great extent, but the occluded water of quenching stays. Sellers of retort-oven coke are therefore rather sensitive on the subject of "moisture" in the specifications, though it is hard to understand why they should expect coke prices for water. In practice, coke with a little moisture does no great harm in the cupola, although the bed coke must be dry. There is, of course, a thermal loss in driving moisture off, just as there is a great saving in the blast furnace in the use of artificially dried instead of natural air. Specifications for coke should therefore fix a maximum limit for moisture, with a penalty for any above it, to insure reasonable care in the oven practice, but this upper limit should be such that good retort-oven coke can readily keep within it.

Coke producers should therefore be urged to make thorough melting tests with their coke, so that when selling it they can advise foundry men how to get the best results with it. This plan would save enormous trouble, as there are about 6,500 foundries using coke in the United States and Canada, and but a very small percentage know how to make comparative tests of coke and draw conclusions therefrom that will guide them in its proper use. There are, on the other hand, comparatively few coke producers, or selling agents for coke producers, and it would pay these firms well to have a central testing station, or a sort of "trouble bureau," for coke tests.

BURNED IRON IN THE CUPOLA.

CAUSES OF TROUBLE.

The burning of iron in the cupola process, and in fact every melting process to a greater or less extent, is now becoming better understood. In years gone by no one could be made to believe that such a thing was possible. But anyone having to do with making the iron silicates can realize how very little silica can carry great quantities of iron to make a thin black slag. The process can be watched very nicely in heating and forging shops, where billets of iron and steel are made ready for the hammers. The modern regenerative heating furnace keeps things at an extremely high temperature, and hence a billet once up to heat must be removed and worked quickly, as otherwise it will "waste away" very rapidly. In fact, if the furnace is too hot the outside of the billet will often be ready when the inside is still too cold, so that wasting from the surface takes place and can not then be avoided.

The surface of the billet becomes oxidized or scales heavily. The scale drops off, and on touching the white-hot sand of the bottom unites with it as a silicate of iron in the form of a thin slag that runs off. Careful operators try to keep this wasting action down to a minimum, and they collect the slag in pots, selling it to blast furnaces. It contains over 60 per cent of iron and is therefore rich, though it requires much limestone for treatment if large quantities are used.

In the bottom of the open-hearth furnace pools of iron often remain after the heat is drained out. These pools oxidize rapidly, burning away with a fine display of sparks, the oxidized material uniting with the sand bottom and making a temporarily dark spot. This action is observed especially in the malleable process with the open-hearth furnace. In the Bessemer process the burning of iron is so obvious that one has only to stand near the blow to be spattered with pellets rich in iron. In making pig iron one has only to note that the same size of furnace that makes a given quantity of good, "honest" pig iron for the foundry man is made to yield very much more pig iron when forced. Iron made thus must be oxidized slightly and produces castings weaker than they ought to be. Even in the cupola the scintillations can be seen as the drops of metal find their way to the bottom. The exact degree to which the oxidation thus brought about affects the product depends on the rapidity of the stream downward, the condition of the blast as regards unconsumed oxygen at the point where the iron is melted, and the consequent condition of the metal itself. If the metal is oxidized even slightly, its melting point is raised, and it will drop more sluggishly and receive more damage from the blast farther down. Hence the importance of nicely balancing melting conditions by proper attention to the coke and charging.

EFFECT OF BURNED METAL ON CASTINGS.

In the coke-melting tests at St. Louis another matter carefully watched was the quality of the metal cast. In every test that showed high melting loss the castings were observed to be full of pin holes near the surface, and in some tests the metal was like a big sponge. Though the silicon necessarily ran low with repeated remelting, enough remained to keep the body of the metal gray; but whenever the iron was burned the fins on all the castings were white.

Long experience in the foundry business has taught the writer that whatever cause may be put forward for such defects in castings as pin holes, excessive shrinkage, draws, and cracks, and for others due to the metal and not to the molding, practically all of them can be traced back to burned iron. Whenever steps have been taken to correct the cupola practice, these troubles have disappeared. Pin holes are due, not to the inability of the air to get out of the molds fast enough, but to the yielding up of dissolved gases in the iron at the moment of set. The first thing that happens in the mold, if the iron poured is not much overheated, is the setting of a thin skin of metal against the sand, and hence these gases in going upward and outward to escape strike the thin shell that has set and stay there. When the casting is put on the planer and the skin is removed the pin holes make their appearance and the casting is condemned. Such an outcome is particularly annoying with respect to fine varieties of rolls, on which an unblemished surface is absolutely necessary. When the metal is badly burned, as, for instance, in low-silicon heats for malleable castings, the formation of gas is so strong that the casting is honeycombed, not with pin holes as in the high-silicon iron, but with blowholes half an inch across, and the interior surface is black from oxidation.

As a further difficulty, if the metal is oxidized even very slightly its melting point is raised considerably, so that it readily freezes or, as the foundry man has it, loses its "life," and the ladles "skull." As a consequence, in pouring the gates freeze up and the castings are short poured. If the casting has been poured, the molten metal may be cut off so quickly that interior shrinkages are more than likely to occur, as no feeding can take place.

Finally, burned metal is very weak. It seems as if a coating of oxide gets between the several crystals, so that their tenacious grip on one another is lessened. Hence casting strains find the metal unprepared to resist and a crack is the result.

A little oxygen can do an immense amount of damage. The very worst burned iron ever seen by the writer contained only a few hundredths of 1 per cent. The evils of high sulphur are as nothing compared to it. Hence only a very small amount of aluminum or titanium is necessary to make the correction, more than 0.1 per cent seldom being required for addition to the ladle to produce the desired deoxidation.

All the facts outlined above show how important the subject is and why the ferro alloys are becoming such a factor in casting practice. However, prevention of this burning or oxidation is better than its correction afterwards by means of alloys of iron with titanium, aluminum, manganese, and silicon.

CUPOLA CHARGING AND ITS RELATION TO QUALITY OF METAL.

PROCESSES NOT UNDERSTOOD.

Unfortunately, we are still in the dark regarding the actual processes in the cupola. Until means are provided to take accurately temperatures as well as samples of the gases formed at every point within the active part of the working end of the cupola we shall have only theories. It is to be hoped that some day an experimental cupola will be erected and specially arranged for such tests, so that deductions based upon determined facts may be made. In the absence of the necessary data only conjecture is possible; nevertheless, the processes described in the following paragraphs seem actually to take place.

DEPTH OF FUEL BED.

All melting occurs above the tuyeres, for the blast can find an exit only up the stack. The coke below the tuyeres is therefore only a filling and serves no other purpose, as it is not even so hot as the molten iron that collects around it before being tapped. The tuyeres are placed high or low, as the exigencies of the shop may require. Where a continual stream of very hot metal is wanted, as, for instance, in light casting work or in the molding of stove plate, the tuyeres are placed about 6 inches from the bottom and the coke filling is least in volume and height. For melting pig iron before it is Bessemerized for steel the tuyeres may be a few feet above the bottom, because a rather large tonnage of metal has to be kept between blows. In European practice the forehearth does the work of a deep crucible in the cupola, serving as a big ladle or catch-basin for the molten metal running unchecked out of the cupola spout. The forehearth, however, is intended to be heated as part of the blast arrangement; but unless the regenerative system is used it is doubtful whether high enough temperatures are obtained to do this heating to any considerable extent. The proper method would be to use a mixing furnace, such as may be seen in steel practice. This is merely a tilting open-hearth furnace, in which the metal is kept continually up to the proper temperature.

Between the least and greatest depth of the bed below the tuyeres there are of course depths adapted to various classes of work, some foundries preferring a height of 20 inches between the bottom and the tuyeres and others 14 inches, 10 inches, or whatever height gives them the space they want for the storage of metal. The quantity of coke thus used, especially in small heats, naturally affects the melting ratio; if this fact is forgotten and a high ratio is arbitrarily selected, the heavy bed often leaves too little coke for the upper charges, as, for example, in the tests at St. Louis with heavy cokes. In long heats this factor is not so apparent.

SMALL CHARGES.

The portion of the bed above the tuyeres is next to be considered. Here the actual work of melting is done. The cold air entering the cupola at once attacks the coke and delivers up its oxygen, which, by the time it is all consumed, has traversed a certain distance inward and upward. This distance probably limits the melting zone, the shape of which no one can tell until experiments such as were referred to above have been made. The effect of this zone is seen along the lining, and the more defined and the narrower it is the better are the results. If the zone, as shown by the cutting action on the lining, spreads over a considerable height, the melting is irregular. The lining should be fairly clean throughout, easily chipped out, and quickly daubed up. Otherwise practice has been defective.

This melting zone may be in the shape of a parabola flaring upward along the sides or, if Mr. West's center blast is used so that the blast pressure is more nearly equally distributed, its upper limit may approach a flat plane; in either case the highest temperature is reached at a point somewhat above the entry of the air, and above that point the heat diminishes. It is in the melting zone that the reaction between the oxygen of the blast and the carbon of the coke bed is most intense, and it is here, probably, that the formation of carbon dioxide is greatest. Here, too, the cupola temperatures reach a maximum, probably about 3,500° F. Below the narrow limits of the melting zone the temperatures are less because the combustion of the carbon, its reaction with oxygen to form carbon dioxide, is incomplete. Above the melting zone the temperature falls because, if the coke bed is thick enough, the carbon dioxide formed in the melting zone has to pass through incandescent fuel, and the glowing carbon reacts with the carbon dioxide to form carbon monoxide, the gas that may be seen burning in the upper part of the cupola. This reaction takes up heat, and hence within a distance of 3 feet, if the coke bed is so thick, the temperature falls to about 2,100° F.

It is evident that if the thickness of the coke bed is so proportioned that all melting takes place within the melting zone, the melting will be done quickly and well, for the melting point of the iron ranges between 1,900° and 2,400° F. If, however, the coke bed is excessively high, some iron will begin to melt as soon as the coke bed has burned away enough to bring the temperature above the melting point, and will melt slowly. As a result, cold metal will drop into the crucible of the cupola, causing the many annoyances of cold metal in pouring. The best economy is naturally had if the metal is just at that point of highest temperature, and not much below or above it. As the heat progresses the coke is rapidly burned away. Hence the bed is lowered and the metal sinks; the next charge of coke is intended to restore the bed to its original height so that each successive charge of metal may melt in the same position in the cupola. Under the best conditions the lower part of the metal charge melts in the upper part of the melting zone, and the upper part of the metal charge melts in the lower part of the melting zone. Hence if a metal charge is too heavy some of the iron is melted below the normal limits of the melting zone, and if a charge is unnecessarily light all the iron is melted in the upper part of the melting zone. If each charge melted at the same level there would be no more to say on the subject; and the fact that it did happen in former times, when no attempt was made to charge in layers, shows that perhaps we have not progressed so much as we suppose.

If, as there is reason to believe, the melting is best done at the point of highest temperature, the point at which the last portion of the usual heavy first metal charge must melt, owing to the sinking of the bed and the metal, is considerably too low in the cupola. The heat may be high enough there, but the gases in the cupola near the tuyeres are not yet free from uncombined oxygen. As a result the metal must suffer somewhat by contact with this free oxygen at so high a temperature. If this statement of conditions is in any degree true, the remedy is to make the charges as small as possible, so that the fluctuation in position of the effective part of the coke bed may be as slight as possible, and the cutting action in the cupola limited to a height of a few inches instead of feet.

UNIFORM CHARGES.

Inasmuch as only the very top of the coke bed is effective for proper nonoxidizing melting if it was made right at first, the question arises why it is the prevailing practice to make the first lot of metal several times as heavy as those succeeding. The obvious reason is plausible enough at first glance—namely, that a lot of metal ought to go on top of a lot of coke in the bed. It is forgotten how little of that big bed of coke really does the work of melting.

The damage caused by the big first charge of iron may best be shown by figures. Let us assume that every 1,000 pounds of iron in melting uses up 1 inch of the coke bed. If the first big charge of metal is 6,000 pounds, 6 inches of the coke will have been burned away when the metal is melted. If iron is really damaged by oxidation, the last 3,000 pounds of that charge is not quite so good as the first 3,000. Now, the first intermediate charge of coke comes down. Does that restore the 6 inches of the bed? By no means. It is merely enough to melt the next and much smaller charge of metal. Let us say it restores the bed 3 inches and disposes of a succeeding charge of 3,000 pounds of metal. The bed, restored only halfway up to its original position in the melting zone, burns down 3 inches again in melting the second charge, nearly all of that iron being melted at a point where it is affected by unconsumed oxygen in the blast. This restoration and melting is repeated until the end of the heat, and the practical effect of the big first charge is to give an inferior grade of iron for the entire heat, unless extra coke between the charges brings the bed up to proper level.

Many foundry men have recognized this point, and now run their cupolas with charges of metal alike from first to last; and the writer has persistently advocated this method as the first step in solving the problem of using all kinds of foundry coke successfully.

But if there is any advantage in keeping the fluctuations of the bed uniform, there is additional benefit in making this fluctuation as small as possible; hence the writer's second recommendation is to make the charges so small that the layers of coke are only thick enough to cover the layers of metal, unless definite knowledge regarding the range of the melting zone of a cupola permits heavier charges.

ADJUSTMENT OF BED.

Another very important point remains for discussion. The bed must be of the right height to start the melting properly; otherwise all subsequent care is useless. Many foundry men have adopted the method outlined above of melting by small charges, most of them successfully from the start, but others have not succeeded until attention was called to the height of their bed. Practically the only way to know when this height is right is to observe the time between "blast on" and "first iron." Every foundry man knows that when this time is about seven to ten, preferably eight, minutes he gets his best results. So in determining the right height of bed, if iron comes at a time within these limits it is safe to continue to charge as in that heat. If the iron comes, say, in fifteen minutes, the bed is too thick; if it comes in four or five minutes, the bed is too thin. Thus this matter can be attended to at first. In a new cupola the bed can purposely be made too thick in the first heat and reduced subsequently until the proper time of "first iron" is reached. This "first iron" means the first metal running continuously just previous to "stopping up," and not the few random drops that often come in five minutes. Where in practice the tap hole is closed when the blast is put on, it had better be left open, for a few days, until the action of the cupola in this respect is known.

In making the estimate of the correct time from "blast on" to "first iron," it was assumed that the charging was done on a fuel bed well burned through, with all the wood consumed. The writer has noted instances in which about a third of the bed coke was put on and burned through. Then the remaining two-thirds was added, the cupola charged, and the blast turned on. In such instances the first few minutes of the observed time to "first iron" were taken up by the fuel bed burning through and did not form any part of the melting time. Iron in eight minutes was really iron in four or five minutes, consequently the results were disappointing.

Too heavy a bed has nearly as bad an effect as one too thin. The thin bed, as has already been explained, has just the same effect as a very heavy first charge. The entire process of melting throughout the heat takes place too low down and in a more or less oxidizing atmosphere. If the intermediate charges of coke used were not as a rule slightly heavier than necessary, thus causing the fuel bed gradually to rise, a low bed together with a heavy first charge of metal would give serious trouble throughout the heat. As it is, these conditions may account for much of the badness of the "first iron," commonly laid altogether to sulphur.

On the other hand, too thick a bed unduly delays the metal. The bed has to burn away, and while it burns some of the stock melts slowly too high in the cupola and hence is exposed too long to the influence of the cupola gases. The melting is therefore slow, and the iron may be slightly burned and is apt to be cold. Slow iron nearly always means inferior iron. The evils of too heavy initial charges are perhaps most noticeable in air-furnace and open-hearth practice, where a slow heat is an abomination.

If the bed is too thick, a heavy first charge of metal keeps the succeding charges of iron from melting too high in the cupola and reduces the danger from burned iron. The writer, indeed, has observed a number of instances of excellent results obtained, with a thick bed and heavy first charge, with very small intermediate charges. Such practice does not seem good, however, as some of the "first iron" will be dull. Better have a proper bed and uniform charges.

In changing from the current practice of high fuel bed and heavy initial charge of metal, it will be noticed that a little while after the start the melting always becomes slower; that is, of course, if the same ratio of coke to iron is used for the intermediate charges in the two methods. This is because some of the coke which was used up under the old conditions to make slag and cut the lining becomes available for melting, less fuel is needed, and the fuel bed rises. This thickening of the fuel bed and slow melting is easily remedied, when observed, without doing harm anywhere and with a saving of coke by changing the melting ratio; that is, cutting down the intermediate coke charges slightly.

It is but natural that the system of cupola charging above outlined, which has been before the foundry public for several years, should have been tried out by many foundry men with varying success. Among the hundreds of instances of trials in large and in small cupolas that have come to the attention of the writer, whenever failures or indifferent results were reported, investigation always indicated something wrong with the bed charge, or a lack of care in the charging itself. Melters object to the extra labor of weighing out small charges, preferring their comfort to clean, sound iron. In some instances, indeed, melters have deliberately added extra coke in order to show that melting became slower by the small-charge method. However, no matter what the cupola or what the class of castings made, a reduction in the size of the charges always works to advantage, and wherever slower melting has been noticed a slight reduction in the intermediate coke charges has always restored the proper rate of melting. Naturally, it takes more care to get an even distribution of small than of large charges, but the reduction in scrap castings is surely worth some effort.

Again, it does not follow that burned iron always results from very heavy charges. When the conditions become such that the molten iron is attacked by oxygen, the iron may be protected by the manganese in the charge. Silicon gives similar but less protection. The foundry man merely has to remember that when the metal is slightly too low in the melting zone of the cupola the same conditions obtain, though in far smaller degree, as in the Bessemer process, in which manganese, silicon, and carbon, and with them more or less iron, are burned out. What the foundry man should look to is that his cupola does not become a sort of converter during any part of the melt.

In conclusion, it may be said that the logical method of cupola charging after the bed is in would be to do away altogether with separate metal and coke charges, and yet keep the proper ratio of iron to coke. This ratio can be maintained by weighing out metal and coke in separate piles on the platform and charging a small quantity at a time from each pile, after the manner of proportioning sand and facing materials. The claim has been made that this method, the one used by our foundry-men forefathers, means slower melting, but careful trial has shown that such is not the case. However, the discomfort and cost of the method will preclude its use.

The writer has advanced another suggestion, that to reduce the cost of charging a cupola to a minimum the charges should be made up in the yard. They should be carefully laid in special charging buckets with swinging bottom doors to drop the charges exactly as laid. If the cupola is cut off at the platform, one man in the yard with a reversible hoisting engine and a revolving jib crane can handle the charges. This plan has been tried at a large foundry with excellent results. A suitable hood and stack above the cut-off cupola will carry off escaping gases.

SUMMARY.

The probable processes of a cupola heat have now been considered, and the lessons derivable therefrom if the assumptions are correctly made. In this description of a cupola heat the foundry man may find suggested a method by which he can make use of practically any kind of coke. If the coke is heavy—almost like anthracite—he can use fairly heavy charges, as the fluctuations of the melting zone will be slight. If the available coke is light, he absolutely must take small charges, the smaller the better, for large charges would result in too strong combustion and perhaps in red-hot coke near the charging doors. The limit for lightness is set only by coke so light that combustion takes place too rapidly and the iron can not take up the heat fast enough. This limit is quickly found in practice. The methods of making all varieties of coke, and particularly those made in retort ovens, are now fairly well settled, and hence foundry coke is made a specialty at only those plants that can obtain the right kinds of coal for the purpose; that is, these coke makers have coals of various kinds available, which when ground and mixed give the desired result.

As retort-oven coke, it is to be hoped, will be the foundry fuel of the future, the coke makers, by careful study of details, will probably bring about a very uniform product, with so slight variations in composition and physical structure that a method of operation in the cupola such as that outlined above will give uniform satisfaction to the user. In the meantime, however, we have to do with existing conditions. We have coke with low and with high sulphur, coke with low and with high ash, and occasionally coke so soft as to be very near the danger limit. By the very nature of the process of making it coke can not be uniform in structure, and only careful selection from the ovens as they are discharged gives the foundry man what he is paying for. In brisk times this selection is likely to be made less conscientiously, coke forks being discarded or their prongs made closer. Many coke tests have shown conclusively that much can be done to improve a coke by adapting the process of making it to the requirements. This matter will be treated more fully in another bulletin of the Bureau of Mines.

COKE DISTRICTS OF THE UNITED STATES

GENERAL STATEMENT.

Fortunately for the foundry industry it is possible in practically all the important centers of the industry to get good cokes at reasonable prices through competitive rates from the several coal fields. The foundry man, however, who is so placed that he can get, for example, a Clinch Valley coke cheaply, but insists upon having Connellsville coke at a dollar or two higher, incurs a direct and avoidable loss.

Coal-washing methods have now progressed so far that it is possible to make very creditable foundry coke out of what was formerly considered almost too poor material for the blast furnace. Hence, if the producers give proper attention to the wants of the foundry and the users of coke take into account the differences in its structure and composition, with existing facilities for shipment, there should be little trouble in the marketing of coke from any part of the country. It will be well, therefore, to describe briefly the coking districts of the country and point out some of the characteristics of the coals to be found in each.

Coal from five of the seven great fields of the country is used for the manufacture of coke. These fields are the Appalachian field, embracing Pennsylvania, Virginia, West Virginia, Ohio, Tennessee, Georgia, Alabama, and eastern Kentucky; the eastern interior field, in Illinois, Indiana, and western Kentucky; the western interior field, in Iowa, Kansas, Missouri, Nebraska, Arkansas, Oklahoma, and Texas; the Rocky Mountain field, in Colorado, Montana, Wyoming, Utah, and New Mexico; and the Pacific coast field, in Washington.

DESCRIPTION BY STATES.

ALABAMA.

Alabama is one of the large producers of coke and has an advantage in home markets. Its coal is rather high in impurities, and nearly all the slack and more than half the run-of-mine coal used for coking is previously washed. Probably the chief cause of objection to Alabama coke is the rather high sulphur content, which is injurious for stove castings and similar articles. Otherwise the coke of Alabama is used satisfactorily for the foundry. Alabama coke has about the following composition:

Average composition of Alabama coke.

	From run-of-mine coal.	From washed slack.
Moisture	1.34	0.75
Volatile matter	1.03	.75
Fixed carbon	83.35	86.00
Ash	14.28	11.50
Sulphur	1.30	.90

The analyses show up better for coke made from washed coal.

COLORADO.

Practically all coal from Colorado used for coke purposes is washed. Average analysis is about as follows:

Average analysis of Colorado coke.

Moisture	0.44
Volatile matter	1.31
Fixed carbon	82.18
Ash	16.07
Sulphur	.44

The coke should be improved with respect to its high ash by better development of the washery practice.

GEORGIA.

Very little coke is made in Georgia, but that little is good. The industry is confined to the extreme northwestern corner, in Dade County; "Durham" coke is known, in the market which it reaches, as a good low-sulphur foundry coke, easily operated.

ILLINOIS.

In Illinois much foundry coke is made in by-product ovens from coals drawn from West Virginia. This coke has become standard for foundry practice in northern Illinois and tributary regions. The Illinois coal itself gives a rather poor coke even when washed, though doubtless it can be used to advantage by mixing with other coal possessing better coking quality. An analysis of a coke made from a washed Illinois coal follows:

Analysis of a coke made from a washed Illinois coal.

Moisture	2.78
Volatile matter	.74
Fixed carbon	83.35
Ash	13.13
Sulphur	2.49

In spite of its quality this coke has its uses, though probably one would do well to keep clear of it for ordinary foundry work. Foundry men will recognize in the above analysis a material much like that which they sometimes get during coke famines.

KENTUCKY.

Kentucky draws its supplies of coal from two of the great coal fields. Most of the coke is made in the western part. The analysis of Kentucky coke shows normal components except the sulphur, which runs above 1 per cent and sometimes nearly to 2 per cent. The sulphur in the coal is chiefly in the form of pyrite, much of which is eliminated by washing.

NEW MEXICO.

New Mexico is becoming an important factor in the coke production of the West, as one sees on visiting its coal regions. The coal is so dirty, however, that for coking purposes it must be washed, and when it is so treated some analyses still show over 10 per cent of ash. The sulphur content is rather low, being between 0.60 and 0.70 per cent.

The great coke plant at Dawson, N. Mex., is interesting. The gases from the modified beehive ovens are used for raising steam for the plant, but the other by-products are lost.

OHIO.

Ohio is coming up as a coke-producing State, though not so rapidly as it should, probably on account of the proximity of the Pennsylvania fields. Many of the coals have to be washed, and the sulphur and ash are generally a little high.

PENNSYLVANIA.

Pennsylvania is, of course, the banner State for coke. Coke is made in ten districts that are geographically distinct. The amount of slack that is washed before coking is considerable, but not so large as in other coal fields. Nearly all of the coal mined in the Connellsville district is used for coke making, and most of the coal so used is unwashed run-of-mine. As detailed statements of the statistics can be found in the volumes of Mineral Resources annually issued by the United States Geological Survey, it will suffice here to give the range in composition.

Range of composition of Pennsylvania cokes.

Moisture	0.23	to	0.91
Volatile matter	.29	to	2.26
Fixed carbon	92.53	to	80.84
Ash	6.95	to	15.99
Sulphur	.81	to	1.87

The upper limits for ash, sulphur, and volatile matter denote nearly extreme cases either of imperfectly made coke or of coke made from coal that is not generally used for the purpose. As the foundry man is liable to have such coke sent him, it is included in the statement.

TENNESSEE.

The bulk of the coal used to make coke in Tennessee is washed. In fact, all the slack is so treated before coking. Washing is necessary on account of the bone and the occasionally high sulphur. The coke analyses, which reflect these properties, are as follows:

Range of composition of Tennessee cokes.

Moisture	0.22	to	1.67
Volatile matter	.11	to	1.60
Fixed carbon	92.44	to	76.87
Ash	7.23	to	19.86
Sulphur	.61	to	2.45

This statement shows plainly the necessity for washing, but also the fact that very good coke is to be had.

VIRGINIA.

The southwestern portion of Virginia is rapidly becoming an important coke center. The coals are high grade, producing a coke comparable with those from the Flat Top and New River districts of West Virginia. The range of the following analyses indicates what excellent material the State produces:

Range of composition of Virginia cokes.

Moisture	0.16	to	1.52
Volatile matter	.80	to	1.67
Fixed carbon	93.24	to	88.52
Ash	5.80	to	8.29
Sulphur	.42	to	1.02

WASHINGTON.

The coke industry of Washington, though not large, is important, not so much for its quality as for the fact that metallurgical coke is made at all on the Pacific coast. The coal for coke making is all washed. The importance of this treatment is shown by the following analysis of a Washington coke the coal for which had not been washed.

Composition of a Washington coke from unwashed coal.

Moisture	1.02
Volatile matter	2.10
Fixed carbon	77.53
Ash	19.35
Sulphur	.44

Everything in this coke will pass except the ash and the volatile matter, the first of which can be reduced by washing and the second by suitable changes in the coking process.

WEST VIRGINIA.

West Virginia is the second largest producer of coke in the country. Th quality of the coal of this State is shown by the fact that the greater part of its coke is made from slack, but little of which has to be washed. Hence the following range of analyses is interesting:

Range of composition of West Virginia cokes.

Moisture	0.07	to	0.60
Volatile matter	.46	to	2.35
Fixed carbon	95.47	to	84.09
Ash	4.00	to	12.96
Sulphur	.53	to	2.26

VALUE OF A STANDARD COMPOSITION.

It may be useful to give a desirable composition for foundry coke, so that a foundry man can compare it with the analyses given above for the several States and with the coke that he purchases. This function really should be performed by a standard specification, and the fixing of such a standard, it is hoped, will some day be carried out in a manner acceptable to all interests concerned. The following composition, however, would be considered excellent—better, in fact, than is actually required:

Desirable composition for foundry coke.

Moisture	0.50
Volatile matter	.75
Fixed carbon	89.75
Ash	9.00
Sulphur	.70

PUBLICATIONS ON FUEL TESTING.

The following publications, except those to which a price is affixed, can be obtained free by applying to the Director of the Bureau of Mines, Washington, D. C. The priced publications can be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.:

PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

BULLETIN 261. Preliminary report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, in St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1905. 172 pp. 10 cents.

PROFESSIONAL PAPER 48. Report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1906. In three parts. 1492 pp., 13 pls. $1.50.

BULLETIN 290. Preliminary report on the operations of the fuel-testing plant of the United States Geological Survey at St. Louis, Mo., 1905, by J. A. Holmes. 1906. 240 pp. 20 cents.

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