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PREPARATION, TRANSPORTATION, AND COMBUSTION OF POWDERED COAL

BY

JOHN BLIZARD

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PREPARATION, TRANSPORTATION, AND COMBUSTION OF POWDERED COAL.

By JOHN BLIZARD.

INTRODUCTION.

In the following pages the writer has endeavored to give an account of the many methods, advantages, and disadvantages of preparing and burning powdered coal. For much of the information imparted the writer is indebted to various firms in the United States and Canada whose plants he visited, also to the technical press.

Manufacturers and operators of coal-fired furnaces can not afford to disregard the possible advantages of pulverizing their coal before burning it. Hence the purpose of this bulletin will be fulfilled if it leads them, after making careful estimates, either to abandon their present method of burning coal on grates or stokers, and install the pulverizers, conveying system, powdered-coal feeder, and burner best suited for burning powdered coal in their plant, or to reject, as uneconomical, the replacement of their present system of burning coal by a system for pulverizing and burning it.

No research work on the combustion of powdered Canadian fuels has been carried out by the Mines Branch, Department of Mines; but if this research work were carried out scientifically by competent engineers, chemists, and physicists, it would show how powdered-coal furnaces and burners should be designed to give an efficiency higher than they give at present.

ACKNOWLEDGMENTS.

The writer wishes to thank the many manufacturers and power-plant operators in Canada and the United States who, by permitting him to observe their powdered-coal plants, by relating their experiences in using powdered coal, and by supplying many valuable figures and blue prints, made possible the compilation of this report.

CHAPTER I.—POWDERED COAL.

COAL AND ITS GENERAL USES.

Coal is the world's principal source of energy—energy which may be released by burning the coal.

There are many ways of burning coal. It may be burned directly on a grate, or it may be entirely gasified by combustion in a gas producer and the gas carried off to be burned where required, or, again, it may be carbonized in retorts or gas ovens and the gas and coke may be burned separately where required. And there remains another and somewhat more recent system of burning coal, that of burning it, after grinding it to a powder, in suspension in air.

DEFINITION OF POWDERED COAL.

By the term powdered coal, as used in this report, is meant coal subdivided so that it may be conveyed easily by means of a screw conveyer, by compressed air, or suspended in a stream of low-pressure air to the furnace in which it may be burned in suspension when mixed with the necessary supply of air.

WHERE USED.

The above-mentioned properties of powdered coal have led to its almost universal adoption for burning cement in rotary kilns; and in many metallurgical furnaces it has taken the place of coal fired on grates, of gas, and of oil, and, to a more limited extent, it has been used for steam raising in stationary and locomotive boilers.

KIND OF COAL USED.

SIZE.

Since the coal has to be pulverized, it is usually better to purchase slack coal, which is usually cheaper and costs less to pulverize.

COMPOSITION.

The requisite composition of the coal depends upon many factors. Practically all coals from lignite to anthracite, and even coke breeze have been pulverized and burned. But anthracite and coke breeze require more energy to pulverize them than softer coals, and low-volatile coals are difficult to ignite and must be burned in specially designed furnaces.

One of the principal difficulties in burning powdered coal lies in the disposition of the ash; and for this reason it is desirable also to use a coal which contains little ash and that melting at a comparatively high temperature.

The power used to pulverize and convey similar coals to the burner is approximately proportional to the weight of the coal pulverized, and it is clear that the pulverizing and conveying costs will, therefore, be greater per heat unit delivered the lower the calorific value of the coal.

Mr. C. J. Gadd[1] states that coal used in heating and puddling furnaces should fulfill approximately the following requirements:

Composition of coal for heating and puddling furnaces.

	Per cent.
Volatile matter, not under	30.00
Fixed carbon, not under	50.00
Moisture, not over	1.25
Ash, not over	9.50
Sulphur, not over	1.00

And he states that for open-hearth furnaces a still better grade of coal, as follows, should be used:

Composition of coal for open-hearth furnaces.

	Per cent.
Volatile matter, not under	36.00
Fixed carbon, not under	52.00
Moisture, not over	1.25
Ash, not over	6.00
Sulphur, not over	1.00

Frequently it has been necessary at various plants to use coal with a greater ash content than 10 per cent, which means that extra labor is required to remove the ash from the flues and combustion chamber.

CANADIAN COALS SUITABLE FOR POWDERED COAL.

Practically all the Canadian coals can be burned in powdered form in boiler furnaces, though some coals, as outlined above, are to be preferred to others. The only serious obstacle likely to be encountered is that due to the low melting point of the ash, and as an example of this may be cited the rejection of Joggins coal for a Bettington boiler at Moncton, N. B. On the other hand, coals with a high ash content may be burned, as is shown also by the experiences at

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[1] Gadd, C. J., The use of powdered coal in metallurgical processes: Jour. Franklin Inst., vol. 182, 1916, pp. 323–352.

Moncton, where a coal containing 20 per cent of ash is burned, and at Vancouver, where Nanaimo slack is burned.

Even the obstacle due to a coal containing much easily fusible ash will in time be removed, by providing means for cooling the ash below its fusing point before it settles and adheres to other particles, forming a solid mass difficult to remove.

For furnaces other than boiler furnaces, where it is impossible to construct a furnace suitable for any coal, and where coals composed as those stated as being desirable by Mr. Gadd in heating and puddling furnaces are required, many Canadian coals are suitable, as may be seen by referring to the analyses of the coals of Canada.[2]

The approximate analyses and sulphur content of some of these coals, on the dry basis, are quoted below. The moisture content mentioned by Mr. Gadd refers to the powdered coal; the moisture content of the raw coal may be reduced by drying.

Some Canadian coals suitable for practically all purposes when burned in powdered form.

	Nova Scotia.		Alberta.		British Columbia.	
	Stellarton.	Springhill.	Mountain Park.	Yellowhead Pass.	Crowsnest.	Nanaimo.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Ash	9.2	3.4	4.4	8.5	9.0	8.6
Volatile matter	33.7	33.3	31.5	41.4	[1] 26.3	40.4
Fixed carbon	57.1	63.3	64.1	50.1	64.7	51.0
Sulphur	0.6	0.9	0.4	0.2	0.5	0.5

[1] Rather low volatile content.

FUNCTIONS OF POWDERED-COAL PLANT.

A powdered-coal plant consists of apparatus which converts raw coal into powder and conveys it to the furnace, into which it is delivered as required and burned in suspension. The systems used to accomplish this may be divided into two classes: (1) The unit system, in which one machine prepares and delivers the coal to the furnace with the necessary air for combustion, and (2) the multiple system, in which the coal is prepared in one building and transported to another building wherein is situated the furnace in which the coal is to be burned.

The multiple system is by far the more common of the two systems; it consists of many different pieces of machinery and apparatus, which differ considerably in design in different plants. The small-unit systems are all very similar in design. The unit system will be

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[2] Mines Branch Bulletins 23 to 26.

described first, then the general features only of the multiple system, leaving the separate principal parts of the multiple system to be described in later chapters.

SYSTEMS.

UNIT SYSTEM.

The best known unit systems are the Aero system, which is used for various purposes, and the Bettington system, which was developed for firing a boiler specially designed for burning powdered coal. Both systems are similar, each consisting of a single machine, which pulverizes the coal and mixes the powdered coal with a blast of air, propelled by a fan mounted on the same shaft as the pulverizing paddles, and delivers the mixture to the furnace, situated close to the blower-pulverizer unit. The Aero pulverizer unit is shown in Figure 1; the paddles for pulverizing and the fan for propelling the air are shown in Figure 2.

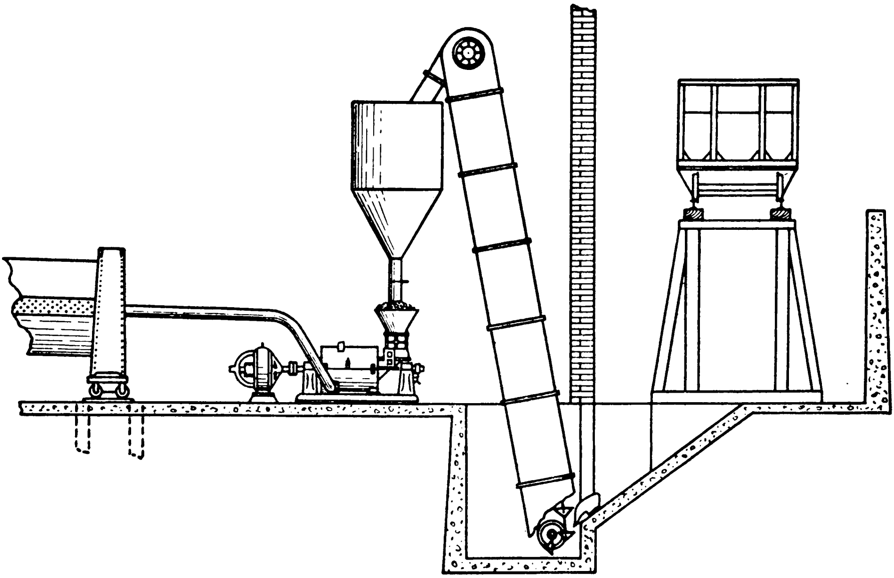

FIGURE 1.—Aero pulverizer supplying pulverized coal to rotary kiln.

Figure 1 shows the elevator delivering the coal to a hopper, from which the coal is fed by a rotary feed to the pulverizer. The air and coal leave the pulverizer by the pipe shown leading from the bottom of the pulverizer.

Figure 2 shows the feeding mechanism at the extreme right, the four pulverizing paddles, the air chamber between the pulverizing and fan chambers into which air passes through an opening at the top, and the fan blades in the left-hand chamber.

These small, compact unit systems have proved very useful where there is room enough to install them near the furnaces and where the quantity of coal used would not warrant expenditure for a separate pulverizing house, coal-dust conveyers, coal-dust storage bins, and coal-dust feeders. A further advantage lies in the ability of this system to use raw coal for many purposes without a preliminary drying in a separate dryer, unless the coal contains a very great amount of moisture. Drying the coal in a drier is unnecessary with this system because there are no bins and feed screws which would clog with moist coal, and because the coal is partly dried by the air passing through the pulverizer. But it is unlikely that this system could be used successfully for many metallurgical operations with coal containing a moderate amount of moisture, unless the coal were previously dried. Some doubt exists also as to the ability of the pulverizer to deliver coal sufficiently pulverized for many operations. The pulverizing blower has the obvious advantage of thoroughly mixing the coal and air before delivering it to the furnace; and in one plant visited by the writer it was possible to reduce or to increase the excess air supply in the products of combustion to any desired degree by merely controlling the flow of air into the pulverizer. With this unit system no powdered coal is stored in bins, which, while obviating difficulties sometimes encountered in feeding coal regularly from the bins and occasional combustion in the bins, makes the continuous operation of the furnace depend entirely on the con-

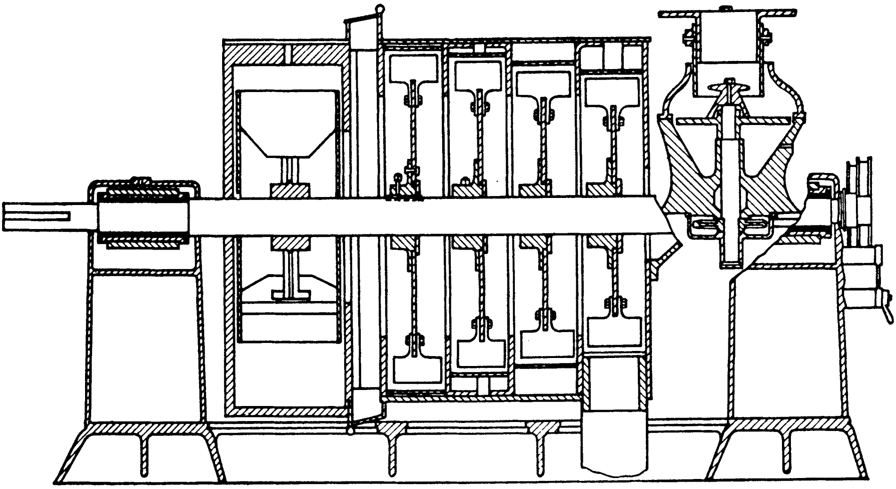

FIGURE 2.—Sectional view of Aero pulverizer.

tinuous operation of the pulverizer. The special field for this system lies in those plants where there are a few furnaces which do not require very dry and highly pulverized coal.

Below is a list which gives the standard sizes, capacity, and power consumption of the Aero pulverizers.

Standard sizes, capacity, and power of Aero pulverizer.

Size.	Weight.	Height.	Floor space.	Normal load of soft coal per hour.	Revolutions per minute.	Normal power consumption.	Horsepower of motor recommended.
	Pounds.	*Inches.*	*Inches.*	*Pounds.*		*H. p.*	
A	2,250	28¾	61¾ by 27¾	600	2,050	10	15
B	4,000	45	77½ by 29	1,000	1,750	14	25
D	5,400	46¾	85¾ by 29	2,000	1,550	30	40
E	5,900	50	89 by 33	3,000	1,450	40	50
G	12,000	59	116 by 40	5,000	1,450	65	90

The load may be increased 25 per cent or decreased 50 per cent without material loss of economy.

From the above it will be seen that the estimated power consumption per ton per hour for the above machines is:

	A.	B.	D.	E.	G.
Coal per hour, pounds	600	1,000	2,000	3,000	5,000
Horsepower hours per ton (2,000 pounds) pulverized	33	28	30	27	26

MULTIPLE SYSTEM.

With this system the coal is crushed, dried, and pulverized in a separate building, and from the pulverizer house it is conveyed either by screw conveyers or compressed air to bins near the furnace or in suspension in a current of low-pressure air directly to the furnace.[3] As an example of the multiple system, the following flow sheet of the coal-pulverizing plant at Anaconda is given. This plant has a capacity of 1,000 tons of coal per day.

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[3] Kuzell, C. R., Coal-dust firing in reverberatory furnaces: Eng. and Min. Jour., vol. 101, Feb. 12, 1916, pp. 302–306.

Coal in railway cars:
|
80-ton receiving coal bin.
|
Two 30-inch by 30-inch Jeffrey single-roll crushers.
|
Two vertical chain elevators.
|
36-inch rubber-belt conveyer.
|
1,000-ton crushed-coal storage bin.
|
Two 24-inch conveyers at right angles.
|
24-inch by 26-inch "Ding" magnetic pulley.
|
16-inch chain elevator.
|
Chute to No. 1 dryer and 14-inch screw conveyers to No. 2 and No. 3 dryers.
|
Three 40-foot by 80-inch Ruggles Coles dryers (dust fired).
|
Three 34-inch by 20-inch Jeffrey coal disintegrators.
|
14-inch screw conveyer.
|
Chain elevator (18-inch bucket).
|
14-inch screw-conveyer system.
|
Ten Raymond 5-roller mills (54-inch).
|
Ten No. 11 Raymond special exhausters.
|
Ten 7-foot cyclone dust collectors.
|
Ten 4-foot auxiliary cyclone dust collectors.
|
14-inch screw-conveyer system (also 6-inch conveyer to dryer fireboxes).
|
Nine 50-ton pulverized-coal bins, one at each reverberatory furnace.
|
Warford 4-inch screw coal burners.
|
Supply of air from 16-ounce blowers.
|
Nine reverberatory furnaces.

The flow sheet above is typical of many multiple systems. A good diagrammatic illustration of a similar system is shown in Figure 3. The American Industrial Engineering Co. of Chicago prepared this diagram. From the flow sheet and the diagram (Figure 3) it will be observed that the coal is first crushed to a general size of ¾-inch

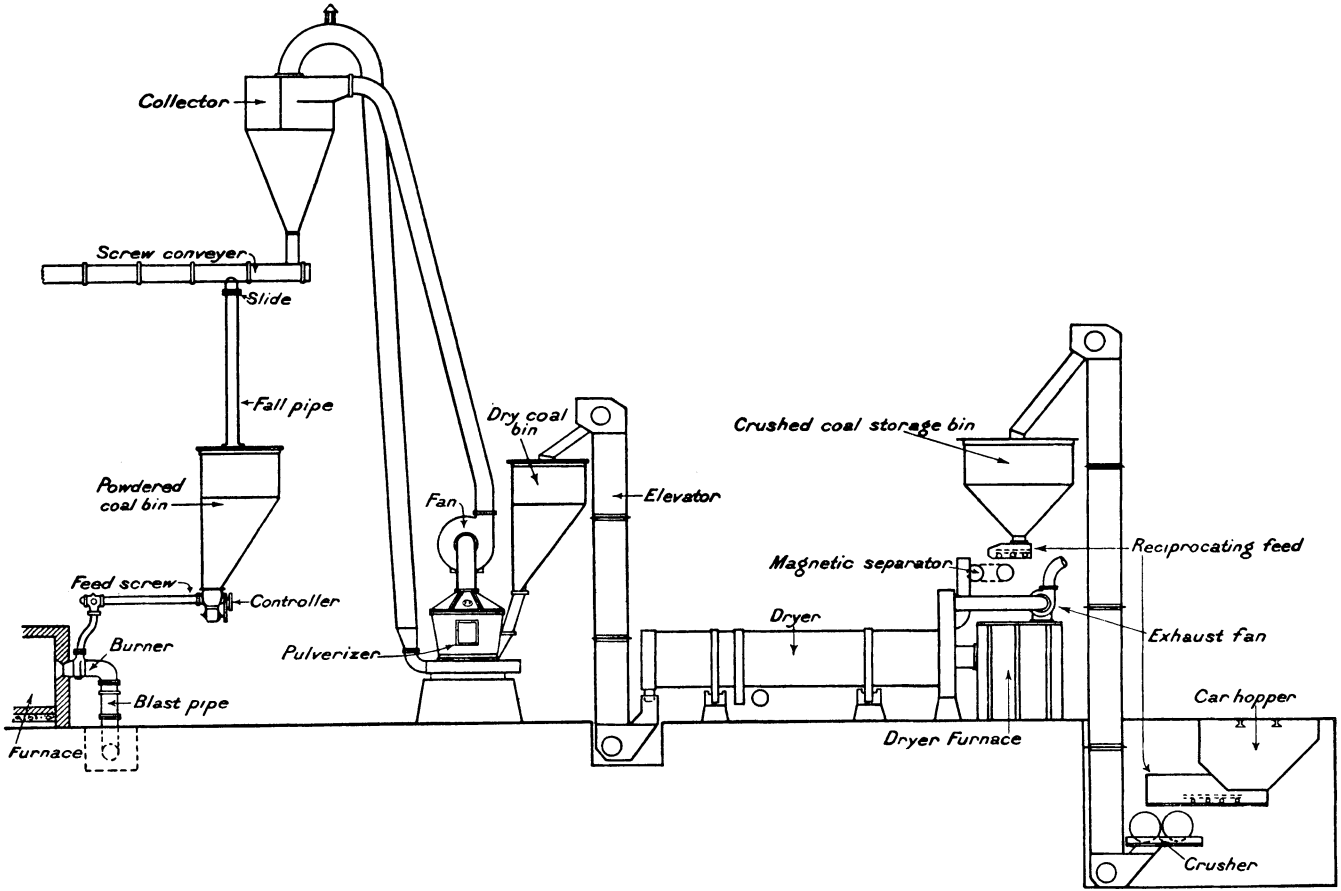

FIGURE 3.—General arrangement of machinery for drying, pulverizing, and conveying coal to burner at furnace.

to 1-inch lumps. It is next passed over a magnetic separator to remove tramp iron, such as bolts, nuts, rivets, nails, and railroad spikes, for if this iron were not removed it would damage the pulverizer and possibly cause an explosion in it. After leaving the magnetic separator the coal passes to the drier, thence to the pulverizer mills, and thence to the distributing system, which delivers it to the furnaces. The various methods of drying, pulverizing, distributing, and burning the coal will be discussed in separate chapters.

CHAPTER II.—PREPARATION OF POWDERED COAL.

DRYING.

When the multiple powdered-coal systems are used, anthracite and bituminous coal are dried until they contain only about 1 or 2 per cent of moisture, while lignite is dried so that it contains only about 5 per cent of moisture. There are three main reasons for drying the coal: (1) Wet pulverized coal packs and arches in storage bins more than dry coal does, (2) it tends more readily to clog in the screws conveying it to the burner, and (3) more power is required to grind it.

DRIERS.

In the usual drier employed coal is fed into the upper end of an inclined cylindrical shell, fitted with rollers, which is rotated slowly by an electric motor. The speed at which the coal moves through the drier may be varied by changing the inclination of the shell and the speed of rotation. The drier shell usually revolves at a constant speed, but occasionally a variable-speed motor is used to enable the coal to be fed at variable rates.

The coal is dried by burning coal in a furnace which is a part of the drier and passing the hot gases from the furnace immediately over the coal to be dried, or passing them first over the shell of the drier and, after being cooled, through the inside of the shell in contact with the coal. The best and safest driers are those of the latter, or indirect, type, so constructed that the flames and burning gases do not touch the coal to be dried until they have been cooled by losing heat to it indirectly through the shell. The gases of combustion and the steam evaporated from the coal leave the drier together. They are exhausted sometimes by a fan and sometimes by the natural draft of a chimney. When a fan is used, it is common to deliver the gas from the fan into a conically shaped dust collector. In this dust collector small particles of coal separate from the gases, fall to the bottom, and are taken into the pulverizer. The gases then pass to the stack.

Figure 4 illustrates an indirectly fired rotary drier made by the Fuller-Lehigh Co., which shows how the gases pass from the ports in the hand-fired furnace over the outside of the shell through the interior of the shell to the stack, and how the coal passes down from the feed inlet through the rotating cylinder to the lower discharge outlet.

SIZE OF DRIERS.

A drier is somewhat cumbersome, and the large, hot, uninsulated cylinder gives out considerable heat, which may render the drying room uncomfortably hot.

The following table shows the sizes of Fuller-Lehigh driers for drying bituminous coal containing less than 10 per cent moisture:

Tons coal per hour:	Size.
4	3 ft. 0 in. by 30 ft.
6	3 ft. 6 in. by 30 ft.
8	4 ft. 6 in. by 30 ft.
10	4 ft. 6 in. by 42 ft.
14	5 ft. 6 in. by 42 ft.
20	6 ft. 0 in. by 42 ft.
25	6 ft. 6 in. by 42 ft.

FUEL USED FOR DRYING.

The quantity of fuel used per 100 pounds of coal leaving the drier will vary with the calorific value of the coal burned, the initial and final moisture content of the coal, the rise in temperature of the coal in passing through the drier, the temperature of the gases leaving the drier, and the thermal efficiency of the drier.

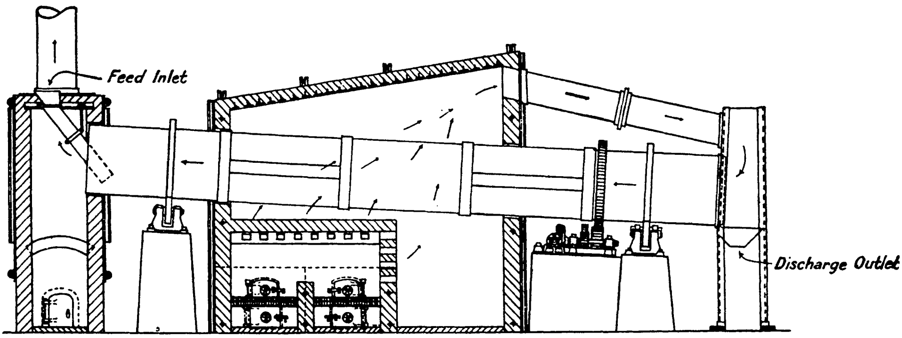

FIGURE 4.—Indirectly fired rotary drier. Fuller-Lehigh Co.

The moisture to be removed from coal containing x per cent of moisture to give 100 pounds of coal containing y per cent of moisture is equal to

$$\frac{100}{100-x}(x-y)$$

The heat used to evaporate 1 pound of water from the coal is equal to $1080+0.48T-t$ where t is the temperature of coal entering the drier and T is the temperature of the gases leaving the drier.

The heat used to heat 1 pound of coal is equal to the specific heat of the coal multiplied by the rise in temperature of the coal in the drier.

In the following table will be found the quantities of undried coal to be burned to dry coal containing 4 to 14 per cent of moisture down to 100 pounds of coal containing 2 per cent of moisture.

The following assumptions are made:

Calorific value of coal, dry basis	B. t. u. per pound	14,000
Temperature of coal entering drier	degrees Fahrenheit	70
Temperature of coal leaving drier	do	240
Temperature of gases leaving drier	do	200
Specific heat of coal		0.24

The thermal efficiency is taken as the ratio of the heat used to drive off the steam and heat the coal to the calorific value of the coal burned.

Heat required and coal burned per 100 pounds of coal containing 2 per cent moisture on leaving drier.

Moisture in coal entering drier ... per cent	4	6	8	10	12	14
Moisture evaporated from coal ... pounds	2.1	4.3	6.5	8.9	11.4	13.9
Heat to evaporate moisture from coal ... B. t. u.	2,300	4,700	7,200	9,900	12,600	15,500
Heat given to 100 pounds coal ... B. t. u.	4,100	4,100	4,100	4,100	4,100	4,100
Total heat used ... B. t. u.	6,400	8,800	11,300	14,000	16,700	19,600
Coal burned 70 per cent efficiency ... pounds	0.68	0.95	1.25	1.58	1.93	2.32
Coal burned 60 per cent efficiency ... do	.79	1.11	1.46	1.84	2.26	2.71
Coal burned 50 per cent efficiency ... do	.95	1.34	1.76	2.21	2.71	3.25

It is usual to fire the coal used in driers by hand, but in some plants it is fired in the form of powder. Very little coal is saved by firing it in powdered form, since it is necessary to feed to the furnace far more air than is required to burn the coal, in order to keep down the temperature of the products of combustion, and so avoid raising the coal in the drier to too high a temperature.

POWER USED FOR DRYING.

Very little power is used to rotate the shell of a drier. The following table gives the estimate of the power used to rotate the shell of a Fuller-Lehigh drier:

Capacity, tons per hour.	Horsepower to rotate shell.
2	2
4	3
6	4
8	5
10	6
14	7
20	8
25	10

PRECAUTIONS IN DRYING.

It is better to choose a drier that is too large than one that is too small. When a drier is too small it dries coal at too high a rate, and the dried coal becomes so hot that it is apt to ignite either before or after pulverizing and may lose some of its volatile combustible constituents in the drier. Further, the higher the temperature at which the coal leaves the drier the greater the quantity of steam in the atmosphere surrounding it, and this steam, on reaching the bins, conveyers, and feeders, condenses on the walls, forming water, which mixes with the coal in a pasty mass and makes the coal difficult to feed.

The elevator or conveyer which removes the dried coal leaving the drier should, if possible, be interlocked electrically with the drier, so that there may be no danger of coal remaining too long in the drier becoming very hot and giving off combustible gases which may mix with air, ignite, and explode. All elevators and bins which handle hot coal should be well ventilated to permit such gases to escape.

PULVERIZING.

After the coal is dried, it passes directly to the grinding mills. In cement plants the coal is often ground in the well-known ball and tube mills, but generally the coal is ground in high-speed pulverizing mills. The four high-speed mills most commonly used are the Raymond, Bonnot, Fuller, and Aero pulverizers. Each of the first three will be described later. The Aero pulverizer has been described already as a part of the unit system of pulverizing.

SIZE OF PULVERIZED PRODUCT.

There is no definite size to which coal must be ground, although it is recommended, generally, that 95 per cent of the pulverized coal should pass through a sieve with 100 meshes to the inch and 80 to 85 per cent through a sieve with 200 meshes to the inch. It has been found possible to operate some furnaces with coarser coal, and found necessary for firing open-hearth furnaces to grind the coal more finely. The more finely the coal is ground the more rapidly will it burn, and the more readily will the smaller ash particles pass off with the gas; but the power required to pulverize coal increases with the fineness of pulverization.

POWER TO PULVERIZE COAL.

A table is here reproduced from the transactions of the American Society of Mechanical Engineers,[4] which shows the horsepower required to drive Raymond pulverizers to pulverize coal at various rates. These figures show that considerably more energy per ton is required to pulverize to 99 per cent through 100 mesh than to pulverize to 95 per cent through 100 mesh. The energy used per ton of coal varies with the moisture content, hardness, and toughness of the coal, and therefore more energy is required to pulverize anthracite than to pulverize bituminous coal.

Power for pulverizing coal.

Capacity of grinding room, tons per hour.	Percentage through 100 mesh.	Percentage through 200 mesh.	Total horse-power required.	Horse-power hours per ton.
1	99	95	45	45.0
2	95	82	45	22.5
2	99	95	60	30.0
3	95	82	60	20.0
3	99	95	85	28.0
4	95	82	75	19.0
5	95	82	85	17.0
6	99	95	170	28.0
10	95	82	170	17.0
10	99	95	255	28.0
25	95	92	425	17.0
25	99	95	680	28.0

The Fuller-Lehigh Co. publishes the following particulars of its pulverizing mills for pulverizing as fine as 95 per cent through 100 mesh:

Size.	Size of feed.	Output per hour.	Horse-power.
24-inch	Through ½-inch ring	1,000 to 1,200 pounds	10
33-inch	Through ¾-inch ring	2 to 2½ tons	30 to 35
42-inch	Through 1-inch ring	4 to 6 tons	45 to 50
57-inch	Through 1¼-inch ring	8 to 10 tons	100

HEATING OF COAL IN PULVERIZERS.

It is often thought that coal is raised to a considerably higher temperature while being pulverized. The actual energy used to pulverize the coal is about three-fourths horsepower-hour, or about the equivalent of 1,900 B. t. u. for every 100 pounds of coal pulverized. Assuming no heat losses from the machine, and that all this heat is taken up in heating the coal, then the temperature of the coal would be raised about 70° F. An actual test with a Raymond pulverizer

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[4] Evans, W. A., Topical discussion on powdered fuel: Trans. Am. Soc. Mech. Eng., vol. 36, 1914, p. 150.

when pulverizing undried coal showed that the temperature of the coal rose from 75° F. on entering the pulverizer to 105° F. on leaving it. Another test with a Raymond pulverizer when pulverizing dried coal showed that the temperature of the coal fell from 238° F. on entering the pulverizer to 170° F. on leaving it. During the latter test the coal lost more heat through the shell of the pulverizer than it gained in the pulverizing process.

DESCRIPTION OF PULVERIZING MILLS.

RAYMOND MILL.

The Raymond system of pulverizing coal is shown in Figure 3. The coal passes from the dry coal bin into the base of the pulverizer, is lifted, when sufficiently pulverized, by a current of air, passes through a separator, where the coarser particles fall back to be further pulverized, and from the separator it passes through a fan to the collector where the air and coal separate. From the collector the coal falls down to the screw conveyer; the air returns from the collector to the base of the pulverizer. Any surplus air drawn in passes to the atmosphere through an opening shown at the top of the bend of the pipe which delivers the air from the top of the collector. In some installations this air-relief opening is not connected directly with the atmosphere, but to a second collector, from which the air passes to the atmosphere, and any coal dust separated from it passes into the powdered-coal system. With this system the coal is delivered to any convenient height by the fan, which takes the place of elevators in other systems not equipped with air separator. The interior of the pulverizer is at a pressure below the atmospheric pressure, and so reduces the coal-dust leakage from the pulverizer, though on the pressure side of the fan the coal and air will tend to pass through any openings in the piping to the collector.

Figure 5 shows a cross section of a Raymond four-roller mill. The coal passes through the spout S and automatic feeder F to the grinding chamber G. In this chamber the manganese-steel ploughs P throw up the coal between the rollers R and the pulverizing ring B. Each roller is keyed to a vertical shaft which is free to rotate on its own axis in a lubricated bearing. The roller shaft and the sleeve surrounding it are supported by a horizontal shaft resting in bearings in a frame keyed to the central vertical shaft. This central shaft is rotated by the bevel gears beneath the pulverizer and carries the rollers round with it. This rotary motion forces the rollers radially outwards against the pulverizing ring and provides the force for crushing the coal.

This mill differs from most other mills because all the moving parts are lubricated. To keep the mill in working order the interior working parts should be lubricated once a day. It takes about 20 minutes to open the mill, pack the rings and journals with grease, and close the mill again.

The air which lifts the coal enters the mill through a series of tangential openings surrounding the base of the grinding chamber and passes upward round the roller R and pulverizer ring B.

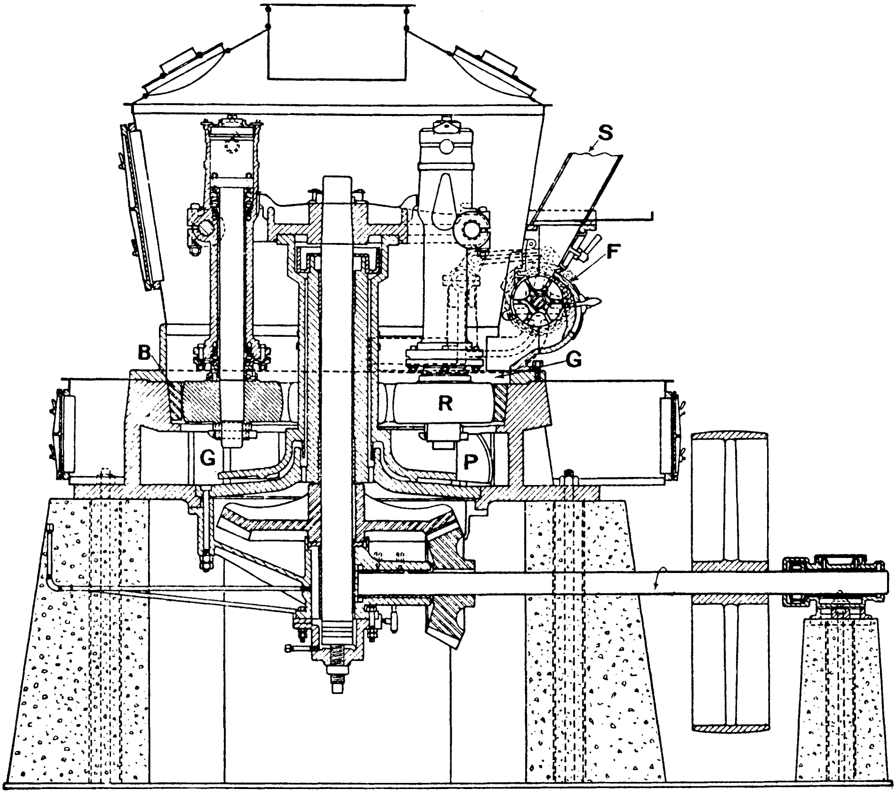


FIGURE 5.—Cross section of Raymond Bros.' four-roller pulverizing mill.

This mill will pulverize coal varying in size from $\frac{1}{4}$ inch to $1\frac{1}{2}$ inches to a fineness of about 95 per cent through 100 mesh. When it is necessary to grind coal more finely than this, Messrs. Raymond Bros. recommend a mill with a similar pulverizing system, but a more elaborate separating system.

BONNOT PULVERIZER.

Figure 6 shows the Bonnot pulverizer. The coal is pulverized between four rollers, which are free to move radially in slots in a driver mounted on a horizontal shaft, and an inclosing ring. When the driver rotates, the rolls are forced by centrifugal force against the ring. The pulverized coal is then thrown upward from the pulverizing chamber into a distributing compartment, where a stream of air meets it and carries it up through flues where it meets adjustable deflectors, which return the heavier particles of coal to the center of the separator and pulverizing compartment.

The fineness of the coal may be controlled by varying the flow of air through the separator. There is considerable wear and tear between the rollers and drivers in this machine, and in some plants both drivers and pulverizers have been renewed frequently. The coal and air pass through an opening in the top of the Bonnot pulverizer to a fan which delivers the mixture to a collector. The coal leaves through an opening in the base of the collector and the air through an opening in the top, from which it returns through a pipe to the pulverizer.

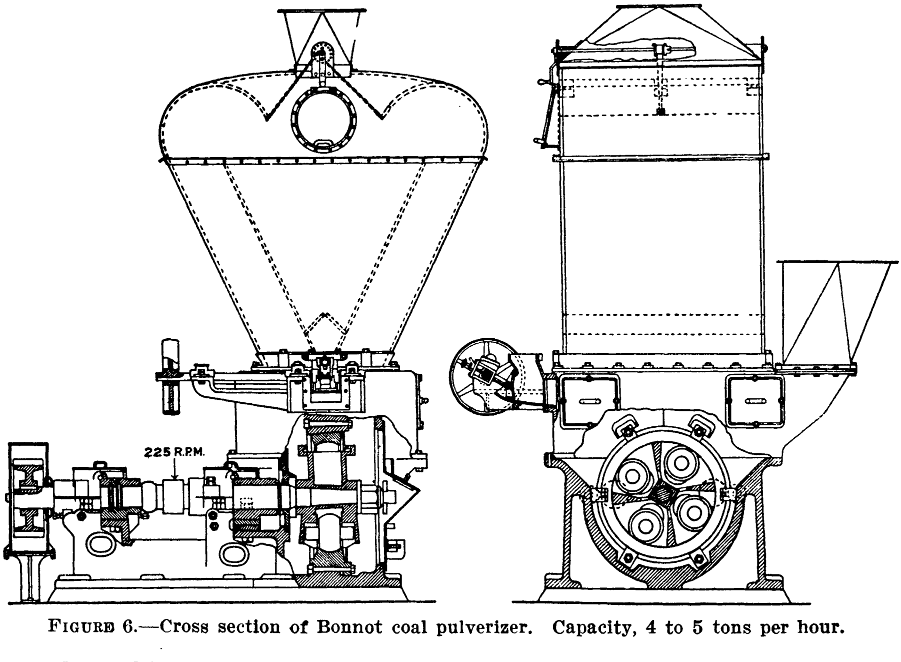
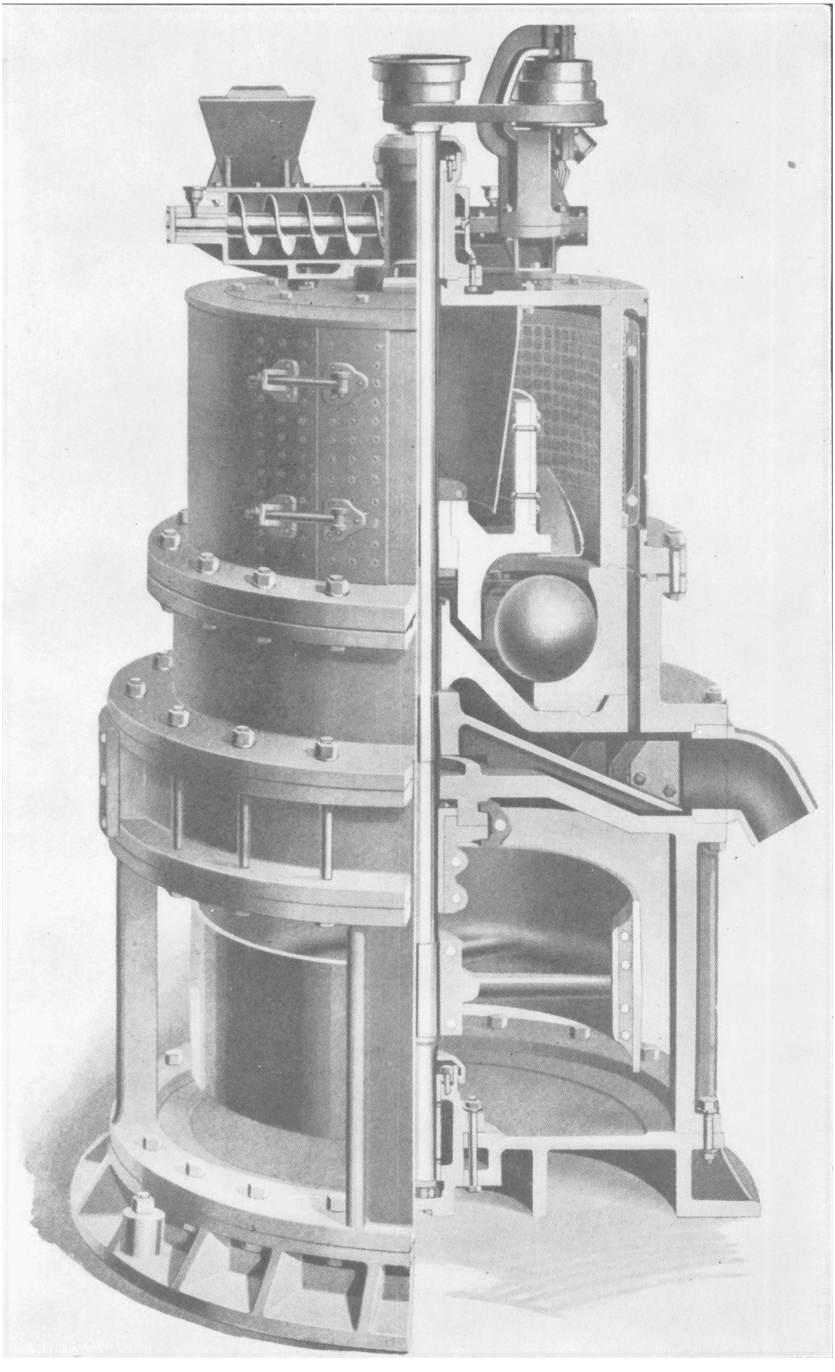


FIGURE 6.—Cross section of Bonnot coal pulverizer. Capacity, 4 to 5 tons per hour.

FULLER-LEHIGH PULVERIZER.

Plate I shows the Fuller-Lehigh pulverizer mill. The coal is fed to this mill by means of the feeder shown on top of the mill. It is pulverized by four unattached steel balls rotating in a horizontal plane, which are forced by centrifugal force, many times their own weight, and by their own weight, against a concave-shaped driving ring. Four pushers propel the balls. These mills have two fans—one in the separating chamber above the balls and the other in the chamber below the balls. The upper fan lifts the fine particles of coal from the grinder into the chamber above it, and there holds them in suspension. The lower fan draws the finer coal through the protecting and finishing screens on the outside of the separating chamber and discharges it through the spout shown at the side of the mill. From the spout the pulverized coal passes to a conveyer, which should be ventilated to permit the air leaving with the coal to pass to a separator where any coal dust suspended in it is separated. These mills are operated entirely through the single vertical shaft, and do not require, like the Bonnot and Raymond mills, an additional fan mounted on a separate shaft. When the screens clog with wet coal, or when in time they are pierced by pieces of foreign matter, they should be removed and replaced with others at regular intervals. The balls wear with usage and assume an ellipsoidal shape when the mills become very noisy. The balls wear more rapidly when the coal is fed irregularly. The Fuller-Lehigh Co. manufactures another mill, which differs from the one described in that the fine coal is selected by an upward current of air instead of by screens.

Vertical-shaft motors usually drive Fuller mills by means of a belt, but they are also driven by horizontal-shaft motors, either through gears or a twisted belt.



42-INCH FULLER PULVERIZING MILL, FAN DISCHARGE, PULLEY DRIVE, CAPACITY 4 TO 6 TONS PER HOUR.

CHAPTER III.—DISTRIBUTION OF THE POWDERED COAL.

INDIRECT AND DIRECT SYSTEMS.

There are two main systems of distributing powdered coal from the powdered-coal bins in the grinding room to the furnace, namely, the indirect and the direct. In the indirect system the coal may be distributed, by screw conveyers or compressed air, to bins situated near the furnaces, whence it is fed by a screw or other means to the furnaces. In the direct system the coal may be blown directly to the furnaces, from the grinding room, in a current of low-pressure air. With the indirect system separate bins and feeders are required for each furnace, but the extra expense involved is offset by three factors, namely, (1) less danger from explosion, (2) greater control over the rate of feeding the coal to the furnace, and (3) greater reliability, since with the direct system the whole plant will be shut down should the central distributing fan break down. Each system will be described in detail.

INDIRECT DISTRIBUTION SYSTEMS.

SCREW CONVEYERS.

The oldest system of distributing the coal from the central storage bin to bins near the furnaces consists of screw conveyers for moving the coal horizontally and bucket and chain conveyers for raising it vertically. In Figure 3 (see general arrangement, p. 8) a screw conveyer is shown immediately below the collector, which receives the coal from the Raymond mill. Below this screw conveyer is shown a pipe through which the coal may be allowed to pass to the bin near the furnace by opening a slide. Care should be taken to see that it is impossible to cause this bin near the furnace to overflow, for the falling powder may touch a hot body and ignite. The troughs for the screw conveyers should have a well-fitting cover to prevent the leakage of dust. A section of a trough for a screw conveyer is shown in Figure 7. Packing is placed between the cover and the trough to make it dust proof. Screw conveyers are a very reliable means of conveying coal, seldom need to be repaired, and are largely used; but they are comparatively heavy, require rigid supports, and often a walkway for inspection, and while they are very suitable for conveying large quantities of coal horizontally through compara-

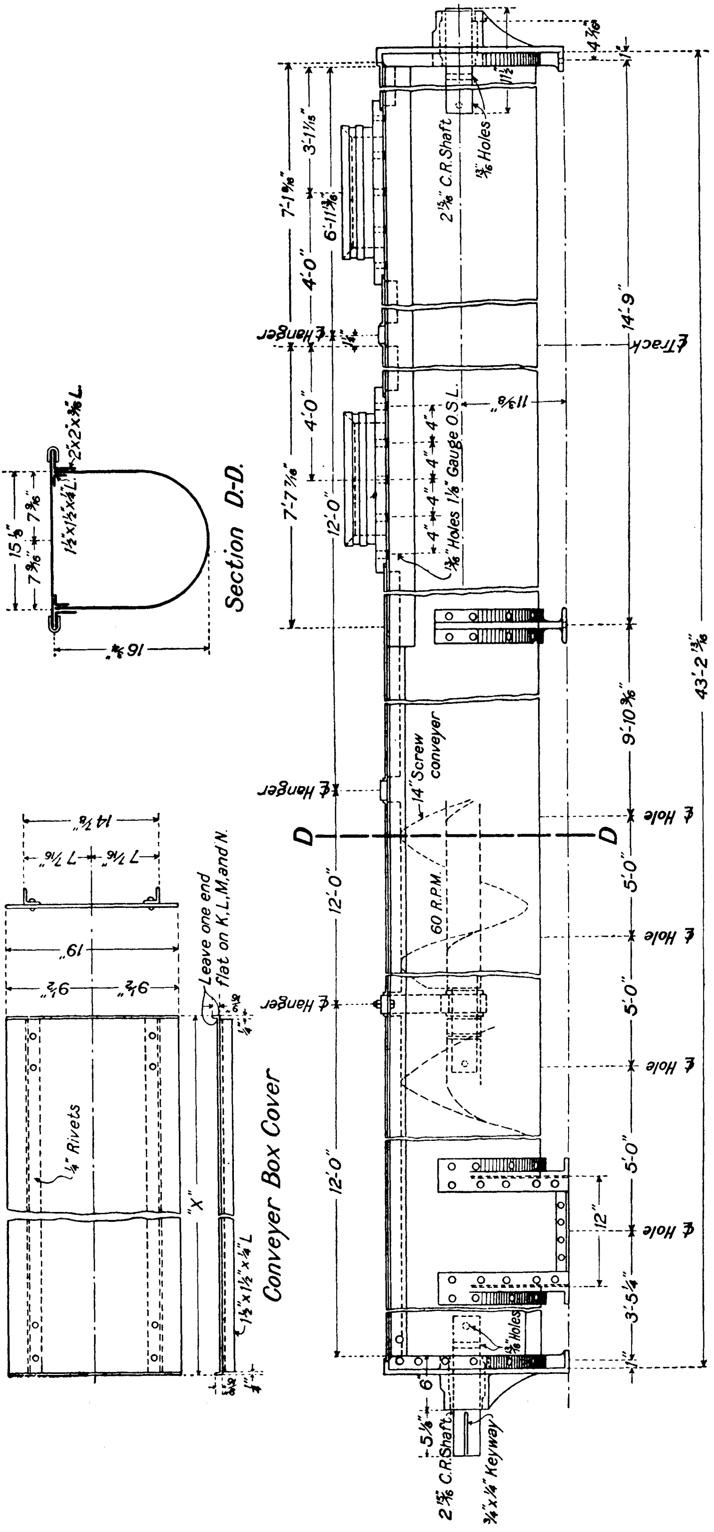


FIGURE 7.—Screw conveyer for powdered coal.

tively short distances in one straight line, they are gradually being superseded by less cumbersome transportation systems, whereby the coal is transported in a pipe, which takes up little room, requires little support, and contains no mechanism.

About 1 horsepower is required to rotate the screw to propel a ton of powdered coal per hour 300 feet.

HELICAL PUMP (FULLER-KINYON SYSTEM).

The Fuller-Lehigh Co. has developed a system whereby coal, after being aerated slightly, is forced through pipes by a small helical pump. This pump consists of a worm mounted on a heavy horizontal shaft which is rotated in a cylinder, coaxial with it, by an electric motor. The coal falls from a storage bin through a pipe onto the worm in the pump casing, is forced axially through the pump by the rotating worm, and leaves the pump through an opening concentric with the worm shaft. In passing through the pump the powdered coal is compressed slightly, and as it leaves the pump it meets a small jet of compressed air, which mixes with it, aerates it, and renders it so fluid that it may be propelled through the distribution pipes.

The quantity of air mixed with the coal is so small that neither cyclone separators nor dust collectors are required at the end of the delivery line.

A 6-inch pump (that is, a pump with a worm 6 inches in diameter) will propel 9 tons of powdered coal per hour a distance of 350 feet and 4 tons per hour a distance of 1,250 feet. About 1 horsepower is required to propel 1 ton at the rate of 9 tons per hour 350 feet, and 5 horsepower to propel 1 ton at the rate of 4 tons per hour 1,250 feet. The pressure of the aerating air is 45 pounds per square inch for transporting the coal 1,250 feet, and 15 pounds per square inch for transporting the coal 350 feet. From 4 to 8 cubic feet of air at atmospheric pressure are mixed with 1 cubic foot of pulverized coal.

The Fuller-Lehigh Co. says this system has been used successfully both to convey coal horizontally and to lift it vertically as high as 65 feet. This company states also that the initial cost of the system is no greater than the initial cost of chain bucket elevators and screw conveyers.

COMPRESSED-AIR CONVEYING.

Quigley installations.—Another method of conveying coal in bulk is by means of compressed air. With this system, which has been installed in several plants by the Quigley Furnace Specialties Co., the coal is blown along a comparatively small pipe from a bin in the pulverizer house to the bins near the furnace. Mr. W. O. Renkin, of the

Quigley company, states in the Blast Furnace and Steel Plant for February, 1919:

> In installations using the compressed-air transport system the pulverized coal is fed into a cylindrically shaped blowing tank, from which it is driven, not as a mixture but as pistons of coal alternating with pistons of compressed air.
>
> This is a novel feature which greatly reduces the amount of air needed to transport the powdered coal. The average is, in properly designed apparatus, about 1½ to 2 pounds of coal to 1 cubic foot of free air when compressed to 30 pounds. With this system 2,800 pounds of powdered coal has been transported 600 feet through a 4-inch pipe in one minute, with an air pressure averaging 15 pounds per square-inch gage.

The writer saw this system of air transport working successfully at the plant of Dilworth, Porter & Co. (Inc.), Pittsburgh. At this plant the powdered coal is blown from the Raymond pulverizers to a cyclone separator, from thence, after separation from the air, it falls into powdered-coal bins of 8 tons capacity each. From the powdered-coal bins the coal is permitted to pass as required through a gate and flexible pipe to each of the blowing tanks, which are placed on weighing scales. Each tank is 6 feet diameter by 18 feet high, and can hold 5 tons of coal. From the tank the coal leaves through two 4-inch pipes.

The system of operation is as follows: The operator has before him a blackboard on which the contents of every bin in the mill near the furnaces is indicated. When required by signal to send coal to a particular bin, he reads the scale showing the weight of the blowing tank and its contents, then delivers coal to that bin until the new scale reading shows him that he has delivered the desired amount of coal.

Figure 8 shows this system. The powdered-coal transport tank is shown on the extreme right. The three furnace hoppers and the switching valves for the first two hoppers are shown to the left of the tank. Above each furnace hopper is shown the cyclone dust and air separator. The air used to propel the fuel through the pipe escapes through the vent on the top of the separator. Alongside the 4-inch supply pipe is another pipe (not shown in Figure 8) which is connected to it at suitable intervals. When the coal clogs in the supply pipe, compressed air from the pipe alongside is admitted to move it. The compressed air for delivering the coal is compressed in a two-stage motor-driven compressor, which delivers the air into two air receivers. Before the air is stored it is cooled, and in cooling it loses some of its moisture. The method of admitting coal to the supply pipe leaving the tank is as follows:

The 4-inch supply pipe extends from within about 1 foot of the bottom of the tank vertically up through the roof of the tank, and

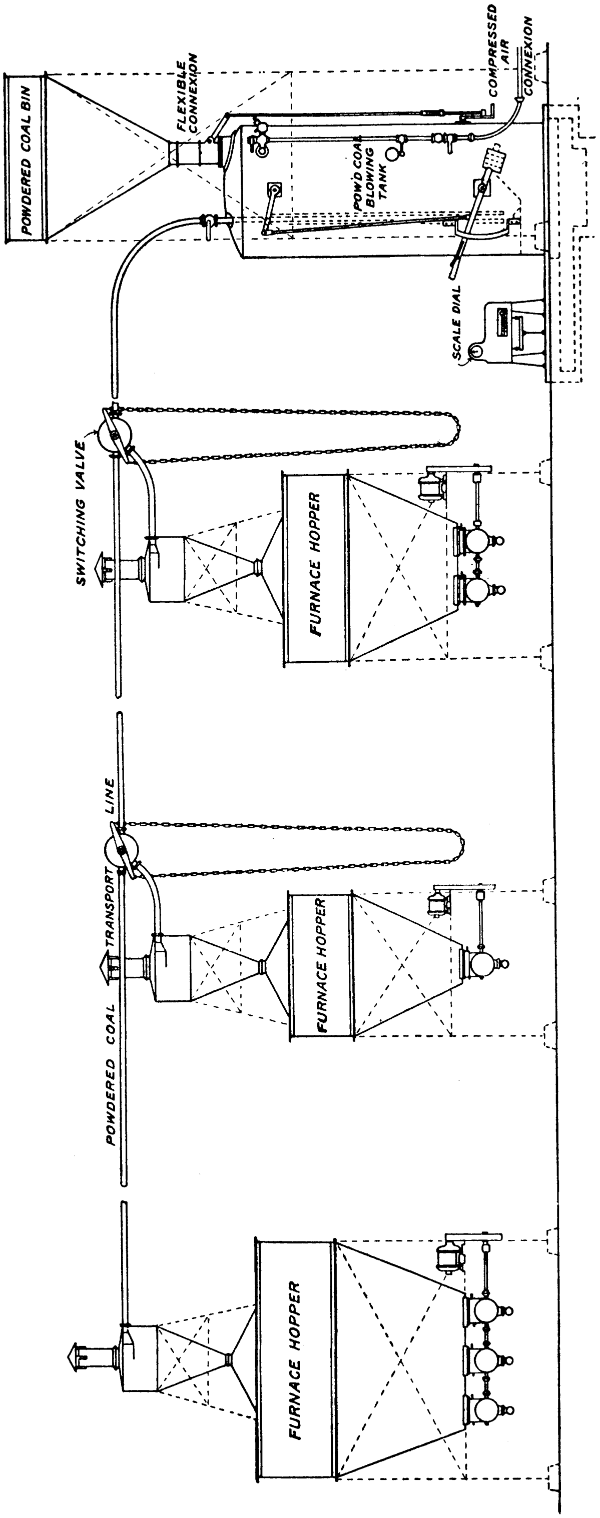


FIGURE 8.—General arrangement of powdered-coal transport system, manufactured by Quigley Furnace Specialties Co.

has a valve placed in it just above the tank top. Inside the transport tank an 8-inch pipe surrounds the 4-inch pipe for about three-fourths of its length. This 8-inch pipe rests on a lead ring when it is not desired to blow coal. When it is desired to blow coal the pipe is raised from its seat on the ring by means of levers controlled on the outside of the tank.

The combination of the air-transport system, the control, and weighing of the coal delivered has been designed by the Quigley company, so that not only is the system simple to operate, but it enables a valuable record of the coal used in different parts of a plant to be easily kept.

Heyl & Patterson installation.—Heyl & Patterson also install a compressed-air transport system. Mr. E. C. Covert, contracting engineer for Heyl & Patterson, has designed and installed an air-transport system at the Oliver Iron & Steel Co.

The writer saw this installation, which conveys 60 tons a day through a 3-inch diameter trunk line to eight stations, the farthest station being 1,670 feet from the pulverizing plant. Mr. Covert states that it takes about 5 or 6 minutes to deliver a ton of coal in this plant, and about 2 cubic feet of free air per pound of coal is used to transport it. The air pressure is 80 pounds per square inch.

Installation of the International Nickel Co.—The International Nickel Co. has constructed an air transport system for powdered coal at Copper Cliff, Ontario. Messrs. E. P. Mathewson and W. T. Wotherspoon refer to this system in a paper on the application of pulverized coal to blast furnaces.[5] They say that with compressed-air transport 2½ tons of coal could be transported in five minutes through a 3-inch standard wrought-iron pipe, 1,100 feet on the horizontal, and with an elevation of 50 feet.

Bonnot compressed-air transport (combined with direct-delivery system).—The Bonnot company has installed a plant for transporting powdered coal in bulk by compressed air at the Pressed Steel Car Works at McKees Rocks, Pa. At this plant the coal is delivered to substations from ejector tanks in the pulverizing house. Each ejector tank holds 5 tons of powdered coal. It has been possible to fill a tank and deliver the coal to a substation in 8 minutes, with a compressed-air pressure of 35 pounds per square inch. Figure 9 illustrates the Bonnot installation at McKees Rocks, and shows the path of the coal from the track hopper through the pulverizing house to the substation and the method of distributing coal in suspension in air from the substation bin. The details of the flow of coal to the furnaces are indicated below.

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[5] Mathewson, E. P., and Wotherspoon, W. T., Application of pulverized coal in blast furnaces: Bull. Canadian Min. Inst., July, 1919, pp. 737–760.

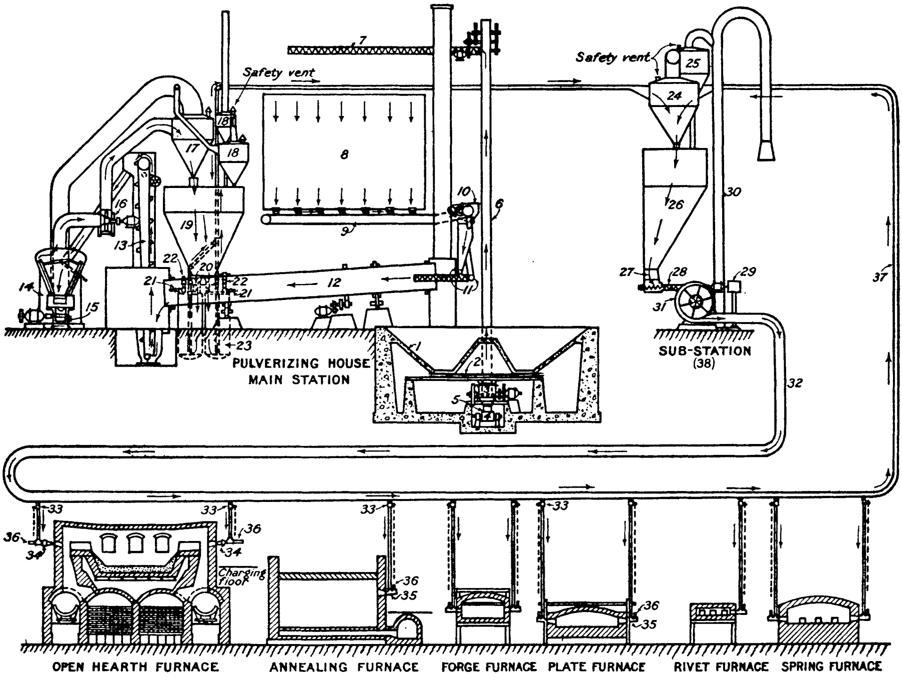

FIGURE 9.—General arrangement of a powdered-coal system with substation. Installed in plant of Pressed Steel Car Co., by the Bonnot company: *1*, track hopper; *2*, reciprocating feeder to feed coal from the track hopper to coal crusher; *3*, coal crusher to receive coal from the reciprocating feeder; *4*, belt conveyer to deliver coal from the coal crusher to the bucket elevator; *5*, stationary magnetic separator over the belt; *6*, centrifugal discharge bucket elevator; 7 distributing screw conveyer with casing and flights, to receive coal from the elevator and distribute it in the coal bunker; *8*, 3-ton coal bunker divided into two parts, so as to store two kinds of coal; *9*, belt conveyer to deliver coal to the automatic scale; *10*, automatic scale; *11*, screw conveyers, to receive coal from automatic scale and deliver to coal drier; *12*, rotary drier; *13*, centrifugal discharge bucket elevator to deliver coal from drier to dried-coal storage bin; *14*, 5-ton dried-coal storage bin; *15*, Bonnot coal pulverizers, complete with vacuum separator; *16*, mill exhauster to exhaust pulverized coal from the separator and deliver it to the collector; *17*, pulverized-coal collector above 25-ton bin; *18*, auxiliary pulverized-coal collectors; *19*, pulverized-coal storage bin; *20*, special outlet castings with valves to let pulverized coal into ejector tanks; *21*, compressed-air line; *22*, vent line; *23*, ejector, which delivers pulverized coal to the various substations through a 3-inch pipe line by means of compressed air; *24*, pulverized-coal collector at substation, which receives pulverized coal from the ejector; *25*, auxiliary collector; *26*, 25-ton capacity pulverized-coal storage bin; *27*, special outlet casting to support feed screw; *28*, special feed screw for feeding coal to the distributing system; *29*, automatic regulator, which automatically controls the speed of the variable-speed motor that drives the feed screw, in order to feed the pulverized coal in proportion to the amount of air flowing through the distributing system; *30*, vent pipe with top bent down to prevent its acting as a flue and thus producing suction on the system which might draw flame into the pulverized-coal main if blower should be stopped for any reason; *31*, high-pressure distributing blower, to furnish the necessary air for distributing the pulverized coal to the furnaces; *32*, pulverized-coal main to furnaces with branch lines to burners; *33*, valve for regulating the flow of pulverized coal to the burner; *34*, special burner for open-hearth furnaces; *35*, cast-iron water-cooled burner; *36*, air-blast line to deliver secondary air to form the proper mixture for burning pulverized coal; *37*, return main to take surplus pulverized-coal and air mixture to pulverized-coal collector, which deposits the unused coal into 25-ton pulverized-coal storage bin.

NOTE.—At the McKees Rocks plant there are five substations, which are substantially the same as shown, one for annealing furnaces at foundry and one for open-hearth furnaces at foundry, one for forge plant, spring, and rivet shops, one for the miscellaneous order department, and one for plate-heating furnaces in the pressing department. The mixture of air and pulverized coal in the coal-distributing main is 1 pound of pulverized coal to 63 cubic feet of air. The mixture of air and pulverized coal when burning in furnaces is 1 pound of pulverized coal to about 230 cubic feet of air.[6]

DIRECT DISTRIBUTION TO THE FURNACES OF COAL IN SUSPENSION IN AIR.

BONNOT INSTALLATION, HOLBECK SYSTEM.

The distribution of powdered coal in a current of air differs radically from the system of distributing it in bulk by compressed air to bins. This system is shown in Figure 9, and is used to distribute the powdered coal directly from the substation bins *26* directly to the burners at the various furnaces. That is to say, only one powdered-coal bin is required to supply many furnaces which may be widely scattered, and the air that carries the coal in suspension delivers it to a valve near the burner. The opening and closing of this valve is all that is necessary to regulate the flow of coal from the distributing main to the furnace.

This scheme of distribution is carried out as follows: The coal falls from the storage bin *26* into the feeder box, which is fitted with a gate, and is extracted by means of a double-flight feed screw *28*, driven by a variable-speed motor, whose rate of rotation is controlled automatically by a regulator *29*. This feed screw delivers the coal into a current of air; both coal and air drawn through a high-pressure blower *31* pass through the circulating main *32*, from which it may be allowed to pass by opening valves *33* through branch pipes to the burners, and the residue of coal and air which does not pass to the burners returns through the main *37* to the cyclone separator in the substation, whence the coal passes back to the storage bin and the air to the atmosphere.

When a valve admitting coal and air from the trunk line to a furnace is opened, the momentarily reduced pressure in the trunk line causes an automatic valve in the Holbeck air indicator to open; and in opening, it operates a mechanism which increases the speed of the feed screw that delivers coal from the bin. On the air indicator is a scale which shows the rate of flow of the air to the system. The air indicator thus supplies, automatically, a quantity of air and coal, mixed in constant proportions, commensurate with the demand of the furnaces. Should all the furnaces be shut down for a short time a sufficient quantity of coal and air is kept in circulation by the regulator to insure an immediate flow of air and coal from the distributing main on reopening a valve between the main and a furnace burner. At the Mansfield Sheet & Tin Plate Co.'s plant an additional blower

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[6] Longenecker, Charles, A diversified application of powdered coal: Iron Age, vol. 102, 1916, pp. 619–623.

was installed at about the farthest point from the pulverizer house, having about one-half the capacity of the main blower in the pulverizer house, to assist in maintaining the required velocity of coal and air in the delivery pipe.

The Bonnot method of controlling the flow of air and coal from the distributing line and mixing it with a supply of secondary air delivered by a blower through the secondary air line is shown in Figure 10. A portion of the coal and air mixture passes through a gate, butterfly valve, and vertical pipe to a Y, where it meets the secondary air and the combustible mixture passes on to the burner. Figure 11 shows details of an adjustable baffle, for deflecting the coal and air from the trunk to the branch line, and of the gate and butterfly valve in the branch line.

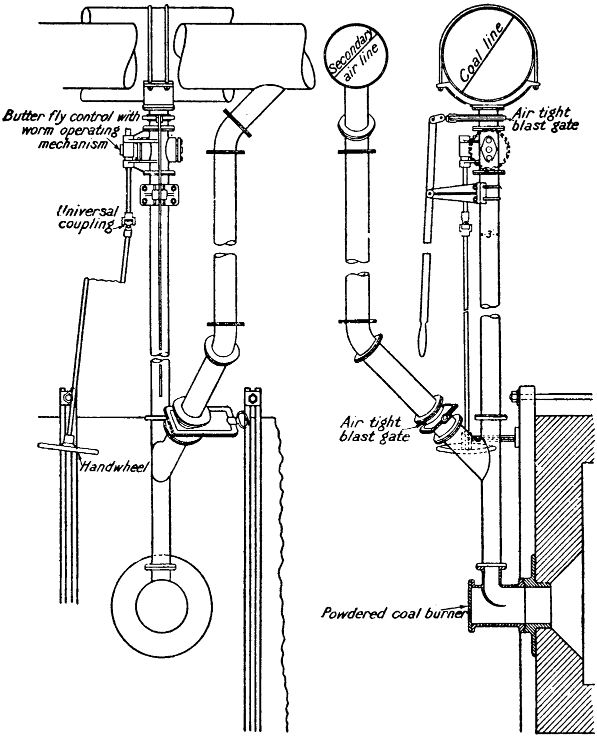

FIGURE 10.—Coal and air control, Holbeck system, Bonnot company.

Figure 12 illustrates a type of water-cooled burner commonly used with the Holbeck system. The primary air and coal enter the feed section at B, the secondary air at A, and a combustible mixture enters the furnace at C from the water-cooled section. A blank flange is placed at D. Usually this blank flange is left hanging on one bolt, so that it may easily be turned to permit view of the burning coal.

The Bonnot Engineering Co. seems to use entirely the coal in suspension system, and usually distributes the coal by this system directly from the powdered-coal bin in the pulverizer house. With it no bins are required near the furnace nor separate motor-driven feeding

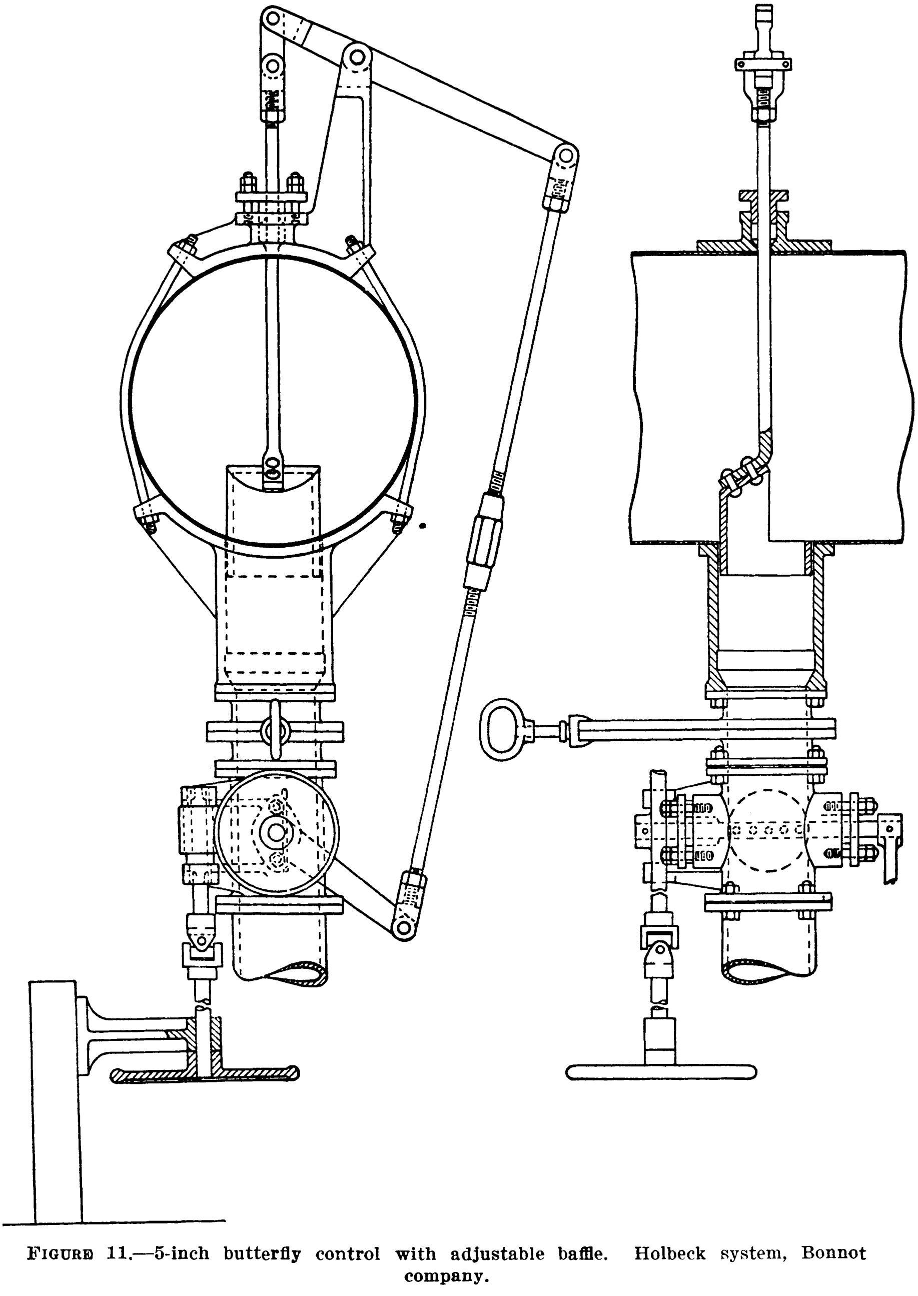

FIGURE 11.—5-inch butterfly control with adjustable baffle. Holbeck system, Bonnot company.

devices for each burner. But the whole system is entirely dependent upon the air and coal circulating fan and distributing main. Should the fan stop or the coal plug the circulating main, the whole plant must shut down, for there are no bins near the furnace containing a reserve supply of powdered coal with a separate mechanism for feeding it to the furnace.

The fan has to keep air and coal in continuous motion; and though the larger portion of the air is used to burn the coal, it has traveled an unnecessarily long distance before reaching the furnace. The coal and air mixture erode the fan impeller and casing, and in several plants the impeller has had to be renewed or repaired frequently.

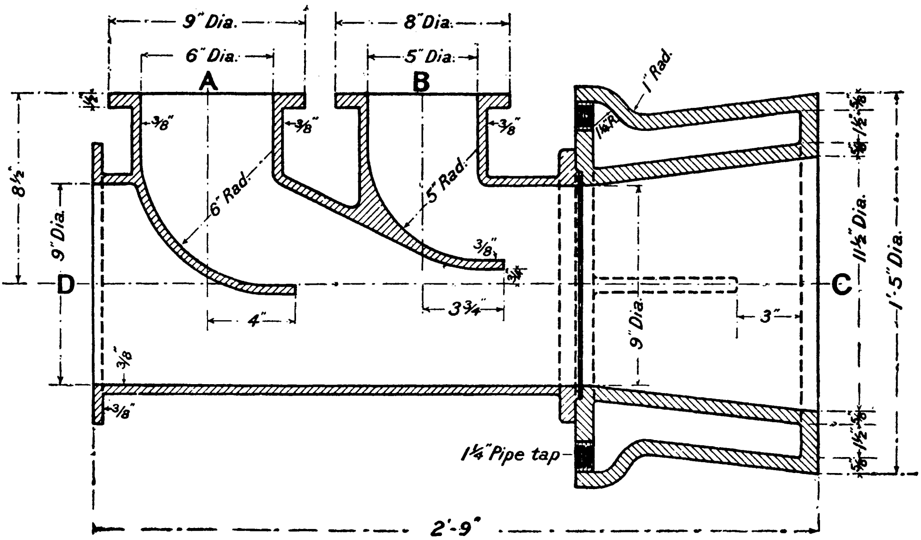

FIGURE 12.—Longitudinal section of 5-inch standard water-cooled burner. Holbeck system, Bonnot company.

At the plant of the Bethlehem Steel Co., Steelton, Pa., the following results were obtained from a test on a Holbeck system supplied by the Bonnot company, which delivered air and coal from the pulverizing house through a 12-inch pipe to a 14-inch by 16-inch mill continuous heating furnace.

Results of a test of the Holbeck system.

Horsepower used to drive conveying fan		26.55
Air discharge per minute	cubic feet	3,826
Quantity of coal delivered with air per minute	pound	29.68
Air discharged into furnace per minute	cubic feet	3,082
Coal discharged into furnace per minute	pound	23.91
Air used per pound of coal	cubic feet	129
Mean velocity of air in 12-inch pipe	feet per minute	4,900
Velocity head for mixture of coal and air	inches of water	1.4
Pressure of mixture leaving fan	do	10.2

In this test the power consumption to deliver 2,000 pounds of coal per hour and most of the air required to burn it was 37 horsepower—a greater expenditure of energy than would be required to move the coal by screw conveyers or air transport to bins and to feed the coal from the bins. The ratio of power used to distribute the coal and air mixture per ton of coal used will increase with the distance the mixture is transported and decrease with the load factor on the plant. This system is, therefore, better adapted for supplying a plant which requires a fairly constant supply for furnaces not too widely scattered.

At many plants the transport of coal in suspension in air has been found to give mixtures of coal and air which differ from time to time and furnace to furnace. At one small forge furnace a heater told the writer that he had had less trouble in getting correct heats with hand firing than with the air and powdered-coal transport system, since with the powdered-coal system he needed constantly to open and close his valves a little. But at this plant the management was well satisfied; the substitution of powdered coal for hand firing had reduced the coal consumption considerably and enabled the use of a cheaper coal than had been used with hand firing. At another plant, using coal in air transport, some small furnaces were changed at the request of the heaters from powdered coal to hand firing, only to be changed back to powdered coal again at the request of the heaters.

A good description of a Bonnot powdered-coal installation appears in Mining and Metallurgy, February, 1920. In that article Mr. R. E. H. Pomeroy,[7] describes the coal-pulverizing plant at the Nevada Consolidated Copper smelter, McGill, and states that after 14 months' continuous operation the plant proved entirely satisfactory. At that plant a mixture of about 50 cubic feet of air to 1 pound of coal is blown through the distributing main. The returning air from the circulating system after being relieved of most of its burden of coal dust passes from the auxiliary return-line dust collector through a header pipe to the main suction pipe.

In one portion of the plant no return line is used, but the air and coal are fed directly through a pipe, tapered to maintain the velocity required to carry the coal to the furnaces. This nonreturn system, while working less smoothly than the return-line closed system, gives little trouble if enough burners are used to keep the line from choking with coal dust. The power consumption for the entire operation at this plant has amounted to about 35 kilowatt hours per ton of raw coal pulverized.

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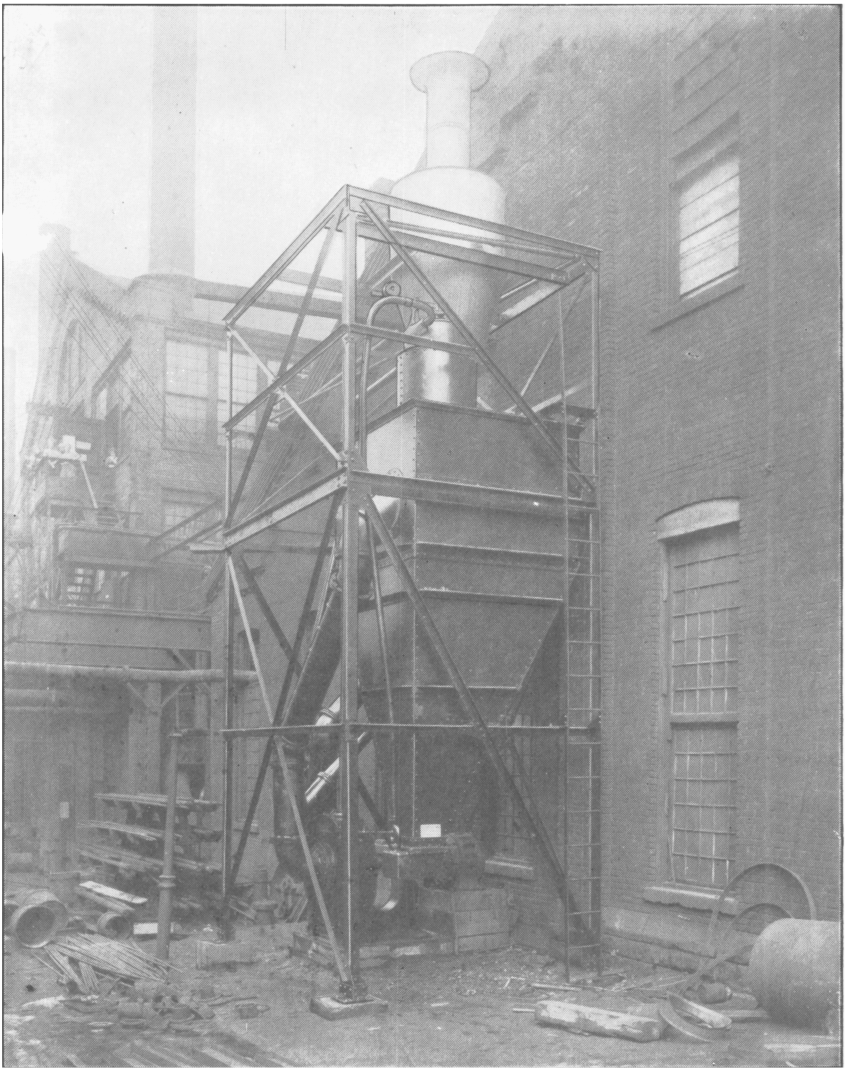
[7] Pomeroy, R. E. H., Coal-pulverizing plant at Nevada Consolidated Copper smelter: Min. and Metal., vol. 63, 1919–1920, p. 13.



SUBSTATION FOR COVERT SYSTEM (HEYL & PATTERSON).

Mr. Longenecker,[8] of the Bonnot Engineering Co., says in the Coal Trade Journal that with the Holbeck distribution system a pressure of about 20 inches of water is used in the circulating line at the fan and about 60 cubic feet of air are used in the circulating line per pound of coal.

HEYL & PATTERSON INSTALLATIONS.

Mr. E. C. Covert, of Heyl & Patterson, has developed an automatic air and coal circulating system. With this system the coal is stored in a hopper near to the furnace building, from which it is delivered by a pressure blower through an endless pipe circuit. The unused coal and air mixture, after passing round the circuit, returns to the suction side of the fan, where it is augmented with an additional supply of air and coal as required. Plate II shows the bin, blower, return, and delivery pipes on one of the Heyl & Patterson installations.

EXPLOSIBILITY OF COAL—AIR-TRANSPORT MIXTURES (DIRECT SYSTEM).

It is important to note that the mixtures of coal dust and low-pressure air used for transporting the coal directly to the burners may explode, and that with this system bad explosions have occurred in the fan, cyclone separators, and the circulating main. Great care must be taken with this system to prevent the ignition of the circulating mixture of coal and air, either from coal left in the pipe after shutting down and ignited by spontaneous combustion or by sparks carried back from the burners by the secondary air supply which inadvertently may be allowed to continue to flow after the main coal-circulating fans have stopped running.

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[8] Longenecker, Charles, Powdered coal winning out in special fields: oal trade Jour., vol. 51, 1920, p. 354.

CHAPTER IV.—FEEDERS, MIXERS, AND BURNERS—BIN AT FURNACE SYSTEM.

IRREGULAR FLOW OF COAL FROM BINS.

When the powdered coal is not delivered directly to the furnace in a current of air it is delivered to a bin near the furnace, from which it is fed to the furnace by a screw conveyer and air or by high-pressure or low-pressure air. To feed coal from a bin at a definite rate is not as simple as it may appear. Powdered coal, even under a constant head, will flow at rates which vary considerably with the dryness, aeration, and fineness. It will frequently adhere to the sides of the bin, arch, fall down, and inclose air, which renders it very fluid and causes it to rush from the bin past the controllers into the furnace.

METHODS TO OBTAIN CONSTANT FLOW FROM BIN.

To minimize this irregular flow of powdered coal, the bins from which it is fed have steep sides, and many ingenious mechanical devices have been tried both for feeding the coal and for preventing the formation of an arch in the bin. Among the devices tried to prevent the powdered coal from resting on the walls of the bin are electrical vibrators, mechanically rotated paddles, and compressed air. Though the vibrator and rotating paddles have been somewhat successful, blowing compressed air into the bin failed to regulate the feed, because the compressed air cooled the steam-laden air in the bin so that the steam condensed on the walls of the bin and caused the coal to adhere to the walls. The most practical remedy for preventing the coal from hanging to the bin sides, and almost the sole remedy used, is to dry the coal sufficiently and cool it in such a way as to remove the steam-laden atmosphere which surrounds it when at a high temperature. The walls of the bin should also be kept at a temperature higher than the dewpoint of the atmosphere inside the bin to prevent condensation on the walls.

BIN AND FEEDER, ANACONDA COPPER CO.

Figure 13 shows a general assembly of the powdered-coal bin, feeder, and air main used for supplying powdered coal and air to five burners for a reverberatory furnace in the dust-treating plant at Anaconda. The coal is brought to the plant on rails in the specially constructed coal-dust car. From the car it falls through flexible detach-

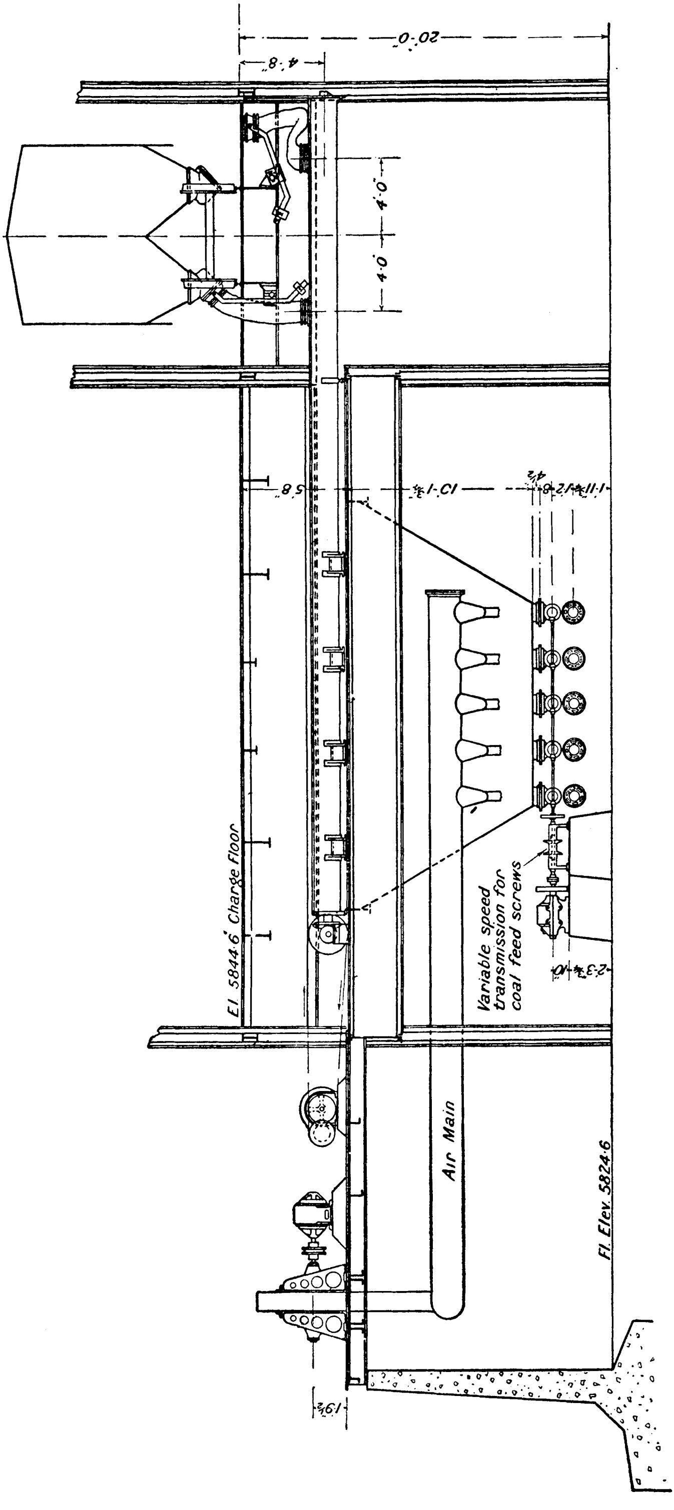


Figure 13.—General arrangement of coal feed from special powdered-coal car to reverberatory furnaces at dust-treating plant. Anaconda Copper Mining Co., Anaconda, Mont.

able pipes into two 14-inch screw conveyers. A 10-horsepower motor rotates these screws through reduction gears, belt, and bevel gears, and the coal falls through four openings in the trough of each conveyer into the storage bin.

At the bottom of the bin are five openings through each of which the coal falls into a specially constructed screw conveyer, which propels the coal forward until it falls through an opening into the mixer, where it meets a current of air delivered by two blowers, each driven by a 75-horsepower motor. A 10-horsepower motor drives the five screw-conveyer feeders through a Reeves' variable-speed transmission of pulleys and bevel gears. Figure 14 shows the coal-feeding screw and the air and coal mixer in a chamber beneath

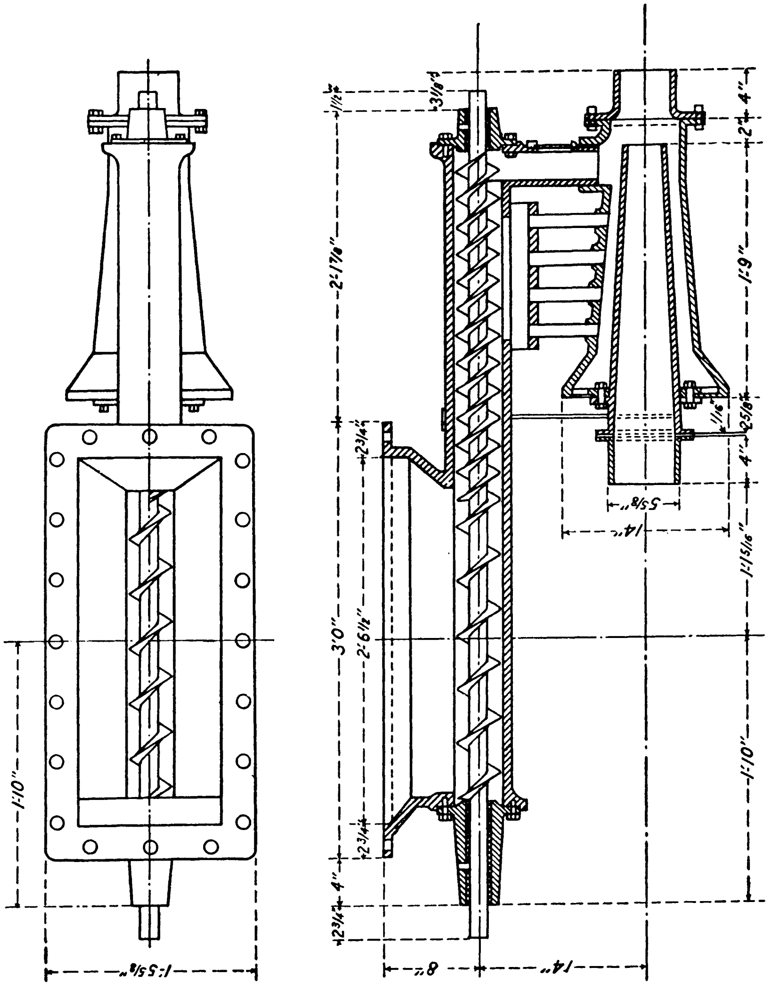


FIGURE 14.—Warford coal feeder and coal and air mixer.

it. The feed screw has a single thread beneath the coal bin and a double thread above the opening in the trough, through which opening the coal falls into the mixer. The air is blown under a pressure of from 14 to 28 inches of water through a conveying pipe in the center of the mixer and leaves this pipe at so high a velocity that it draws air from the atmosphere into the annular space between the air pipe and walls of the mixer. This induced-air draft carries with it the coal falling into this annular chamber, and the mixture of

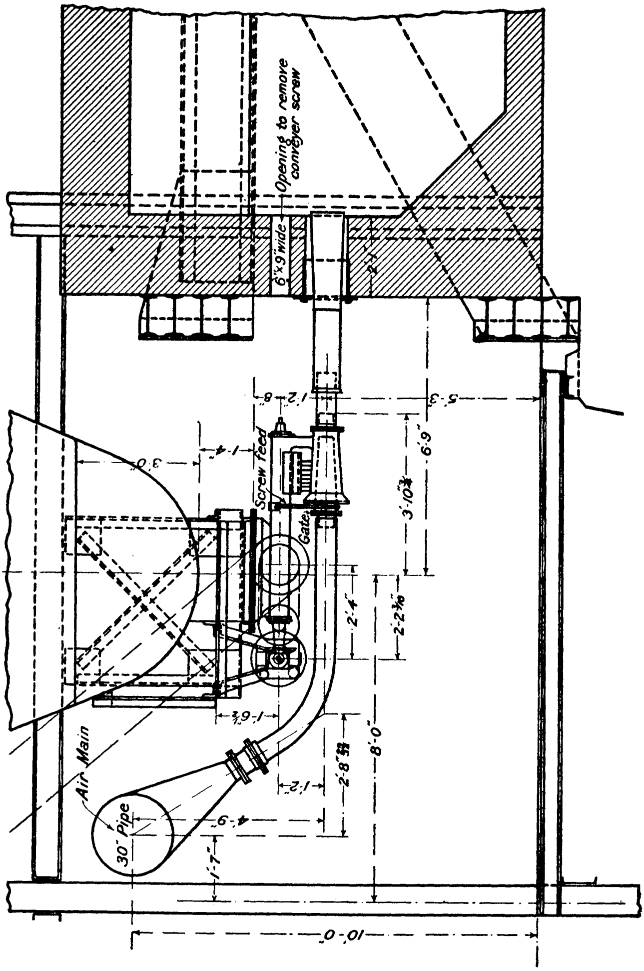


FIGURE 15.—View showing bottom of coal bin, screw feed, air main, and burner for the reverberatory plant at Anaconda.

air from the blower and the induced air and coal pass from the mixer into a blast pipe where more air is drawn in. From the blast pipe the air and coal enter the furnace. Figure 15 shows a general assembly of the feeder and burner on the front of a reverberatory furnace at Anaconda. These furnaces are under suction, and a secondary supply of air passes through annular ports between the blast pipe and the hole through which the blast pipe enters the furnace.

FULLER-LEHIGH FEEDER, MIXER, AND BURNER.

The Fuller-Lehigh Co. installs a pulverized-coal feeder, similar to that used at Anaconda. The feed screw is long and revolves in a cylinder bored to fit it neatly. Its rate of rotation may be varied to suit the required rate of coal feed either by a variable-speed motor or by variable-speed transmission gearing. The flow of coal from the bin to the screw may be cut off by means of slide gates.

The sizes of feeders generally supplied by the Fuller-Lehigh Co. are as follows:

Size.	Capacity at 30 r. p. m.	Capacity at 60 r. p. m.
Inches.	*Pound per hour.*	*Pound per hour.*
3	300	600
4	650	1,300
5	1,300	2,600

A motor of about 1 horsepower is amply able to drive any of the above feed screws. The powdered coal on leaving the feed screw falls through a pipe into a mixer, where it meets a current of low-pressure air. Figure 16 shows a design of coal and air mixer and burner, designed by the Fuller-Lehigh Co. The coal falls in from the top 5-inch opening, meets the air coming from the right-hand opening, and this mixture, after receiving a secondary supply of air, leaves through the left-hand 14-inch opening. Adjustable ports on the outer wall of the mixer are provided, through which the secondary supply of air is drawn.

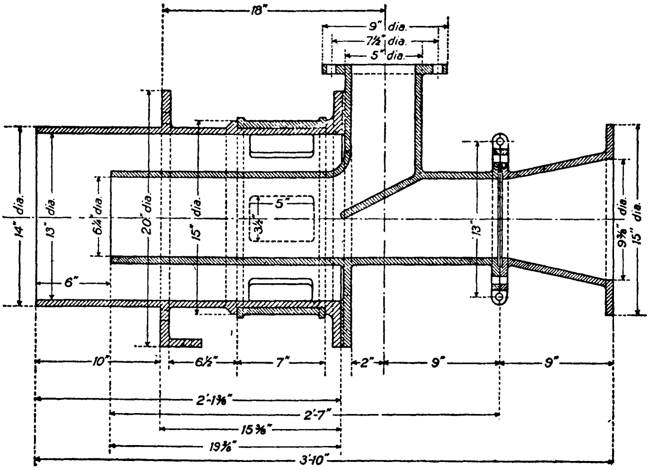


FIGURE 16.—Longitudinal section, mixer and burner. Fuller-Lehigh Co.

AMERICAN INDUSTRIAL ENGINEERING CO. FEEDER, MIXER, AND BURNER.

The American Industrial Engineering Co. installs powdered-coal bins with screw feed. It recommends a screw not less than 3 feet long, and specially designs the casting at the bottom of the bin so that the mean velocity of the coal decreases as it reaches the screw. It also recommends that the screw should revolve completely not less than 20 times per minute, to keep the coal from sticking between the flights. The screw conveyer casting at the end of the screw, remote from the bin, has on top a hole connecting the interior with the atmosphere. This hole provides an outlet for the coal when the feed pipe or burner becomes clogged, and an outlet for any air which might otherwise pass from the air and coal mixer through the coal pipe against the coal current and into the bin. A variable-speed motor turns the screw. The screw is made in lengths up to 25 feet, which permits placing the bin at a reasonable distance from the furnace. For the same reason the coal pipe between the screw conveyer casting and the burner is often made fairly long. Figure 17 shows a general assembly of the American Industrial Engineering Co.'s mixer and burner. The air supply is delivered entirely by a fan through the bottom 10-inch opening, and so auxiliary air is mixed with it on its passage to the furnace. A pressure of about 1 inch of water is sufficient to force the air and the coal into the furnace. In passing through the mixer the air divides into two streams, separated by the wall of a slightly converging pipe inside and concentric with the outer wall of the mixer. The powdered coal

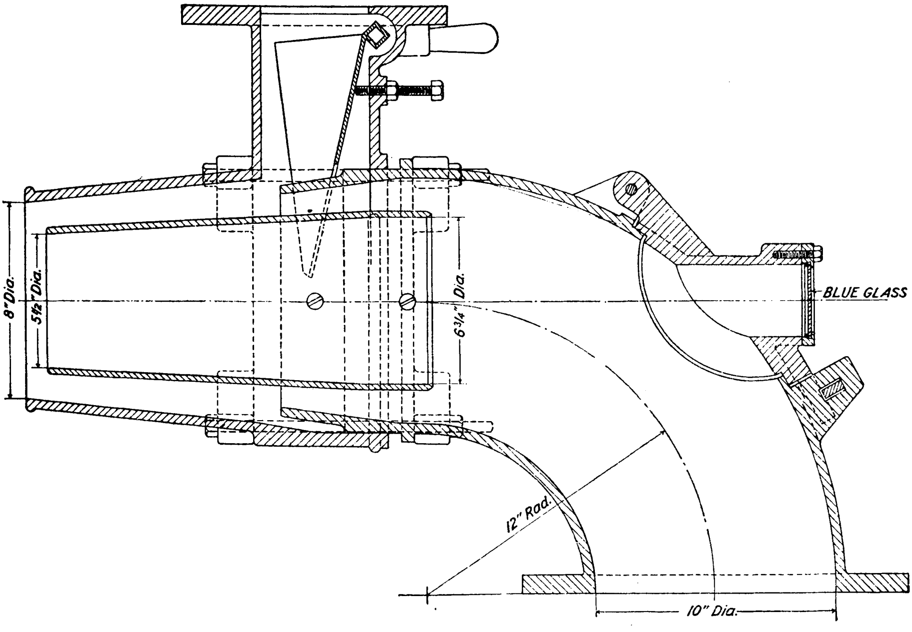


FIGURE 17.—Longitudinal section of powdered-coal burner, type A. American Industrial Engineering Co.

falls through the top opening into the annular space between the outside of the pipe and wall of the burner. A deflector in the vertical coal pipe can be adjusted to change the direction of flow of the coal, and so, to some extent, adjust the proportion of coal and air in the plane perpendicular to its flow. The coal and air mixture leaves the burner surrounding the inner core of air through the left-hand opening.

QUIGLEY FEEDER, MIXER, AND BURNER.

The Quigley Furnace Specialties Co. feeds the coal from the bin through a specially constructed gate by means of a screw rotating at a constant speed. The rate of feed is regulated by means of two swinging shutters or gates, which close round the screw shaft for a short distance where the thread is removed. The coal, after leaving the feeder, enters a screen agitated by a cam and passes to a pipe where it meets a jet of air. This air blast is supplied under about 10 inches of water pressure; but at the point where it meets the coal its pressure is so low as to render it impossible for air to flow back into the bin, where, owing to its lower temperature, it would cool the atmosphere surrounding the coal, condense the steam, and cause the coal to clog. The mixture of coal and primary air, which is about one-eighth of the total air required to burn the coal, passes into the burner through either the side or the back. Here it meets the secondary air supply, under a pressure of about 1 inch of water, and the combustible mixture passes to the furnace. This system of regulating the fuel and air is illustrated in Figure 18.

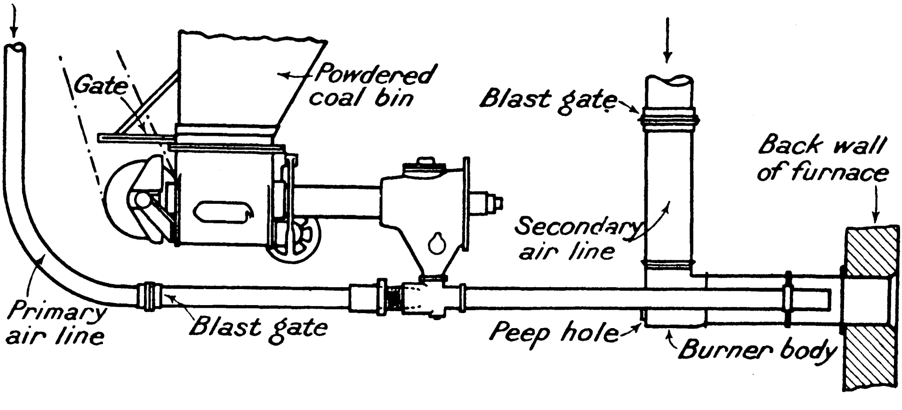


FIGURE 18.—Diagram of apparatus for regulating flow of fuel into burner. Quigley system.

"LOPULCO" FEEDERS.

The Pulverized Fuel Equipment Co. ("Lopulco" equipment manufacturers, now the Combustion Engineering Corporation) has de-

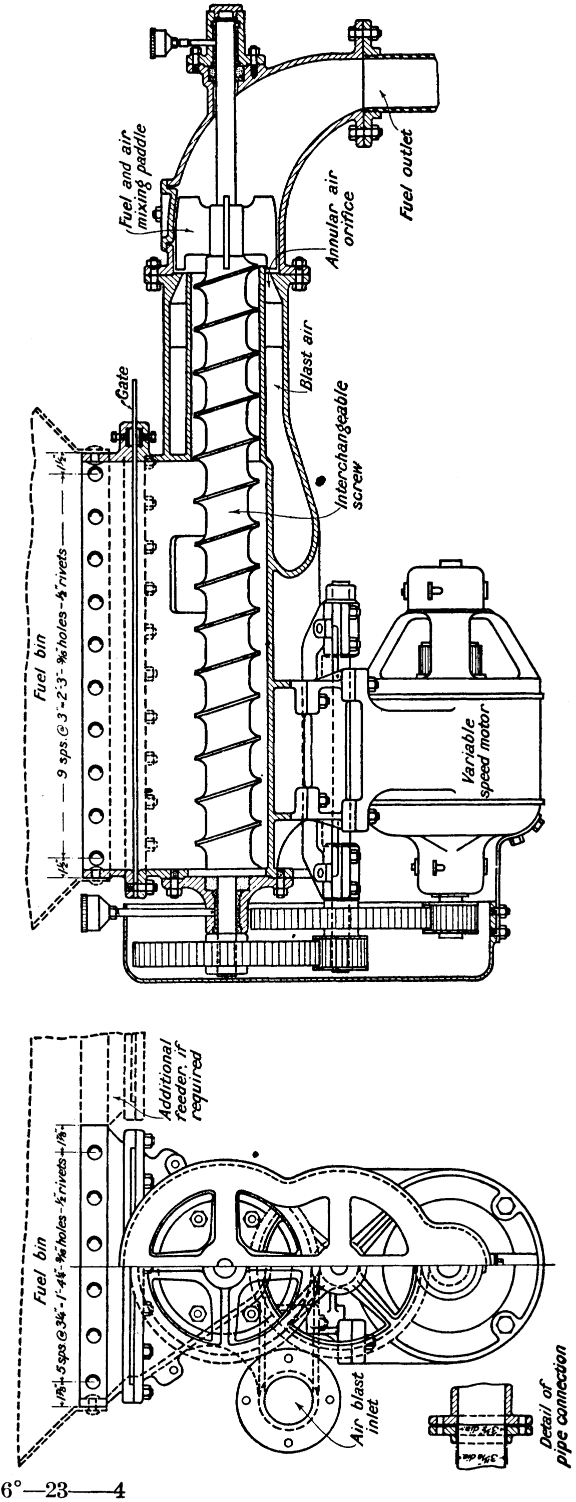


FIGURE 19.—Assembly of type G feeder, Pulverized Fuel Equipment Co.

signed the feeder shown in Figure 19. The screw discharges the powdered coal into a blast of air, discharged under a pressure of about 10 inches of water through an annular orifice. A paddle revolving on the screw shaft mixes the air and coal, and the mixture passes on to the burner. Only about 1 pound of air per pound of coal is mixed with the coal at the feeder. The screw rotates 40 to 110 times per minute, depending on the load, and delivers about three-tenths of a pound of coal per revolution.

"LOPULCO" HORIZONTAL MIXER AND BURNER.

Figure 20 shows a horizontal burner designed by the Pulverized Fuel Equipment Co. for burning coal in a continuous ingot-heating furnace. The coal and air mixture from the feeder enters through the top of the burner, meets a current of low-pressure air from the left-hand opening, and is carried by it into the furnace. On emerging from the burner it meets, from a rectangular orifice beneath it, a further supply of air, moving in a slightly upward direction, which helps the two streams—primary air and coal and secondary air—to mix in the furnace. The relative velocities of the two streams of low-pressure air can be adjusted by opening or closing two dampers placed in the branch circuits.

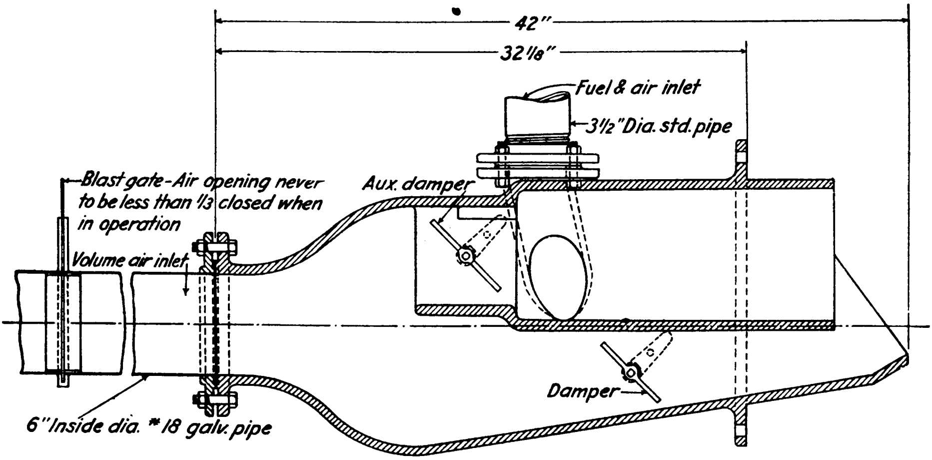
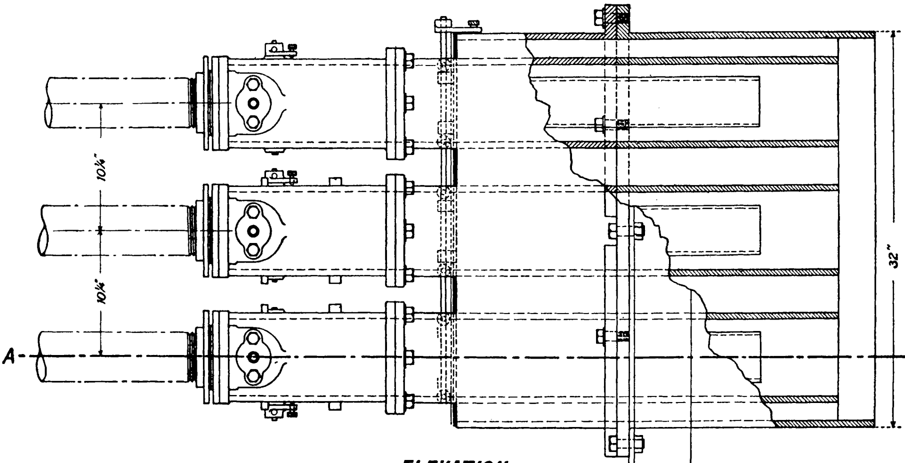


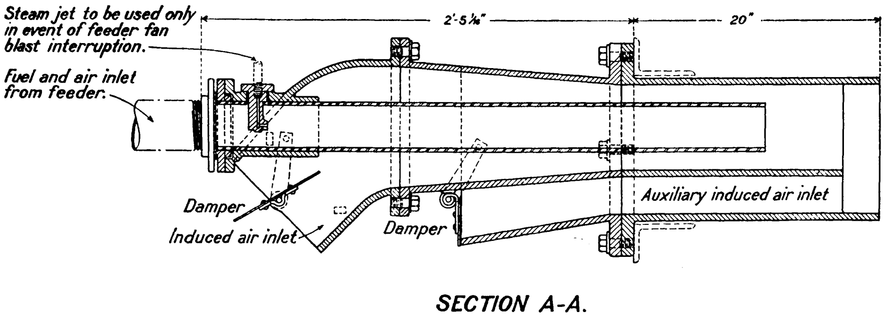
FIGURE 20.—Assembly of horizontal burner, type B, Pulverized Fuel Equipment Co.

"LOPULCO" VERTICAL BURNER.

Figure 21 shows a vertical triplex burner, designed by the Pulverized Fuel Equipment Co., for burning coal in a boiler furnace. The coal and air from the feeder enter the burner through a vertical pipe. A portion of the secondary air is drawn into the burner through four openings, each controlled by a damper. One stream of air entirely surrounds the air-coal mixture and mixes with it before meeting the remaining three streams, which join it on three sides as the whole mixture moves into the boiler furnace. The burner is designed so that the outside streams of air lie between the central core of air and coal and the front and sides of the furnace, and separate the streams of air and coal from adjoining burners. A further supply of secondary air enters the furnace through air ports in the front wall (see Figure 31 and Plate IV, pp. 69 and 70).



ELEVATION.



SECTION A-A.

FIGURE 21.—Vertical triplex burner for boilers, Pulverized Fuel Equipment Co.

HEYL & PATTERSON FEEDER.

Plate III shows a screw feeder developed by Mr. E. C. Covert, of Heyl & Patterson, Pittsburgh, Pa. The principal features lie in the interlocking of two screws, which prevents the coal flowing in a spiral path between the threads past the screw into the furnace.

ELABORATE MIXING DEVICES.

The mixers and burners so far described have no complicated device for mixing the coal and air before these enter the furnace. They rely on the turbulent flow of the currents of coal and air to enable the coal to be burned completely. They have all been used commercially for some time, and for the most part successfully, for many varied purposes.

There are, however, on the market other burners and mixers in which special precautions are taken to insure a very intimate and constant mixture of the coal and air. It may be that for a few very special purposes these burners are to be preferred, but there is no reason to suppose that for ordinary metallurgical and boiler furnaces they will supplant the simpler mixers and burners.

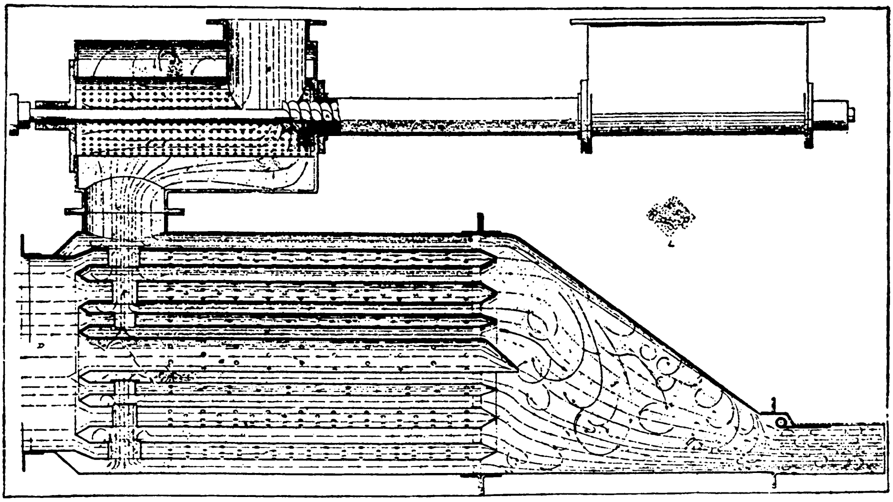


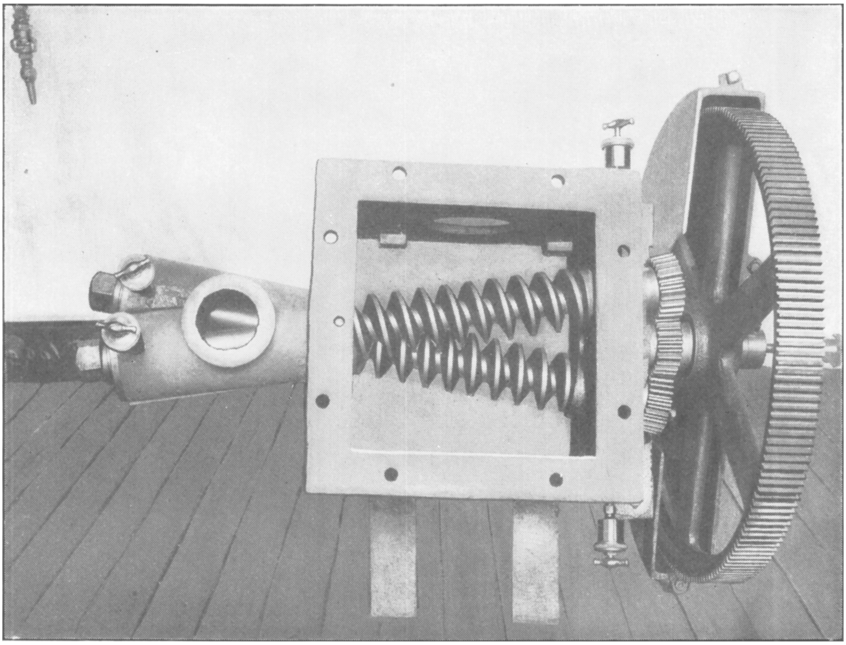
FIGURE 22.—Diagram showing Arrowwood pulverized-coal burner.

POWDERED COAL ENGINEERING AND EQUIPMENT CO.'S MIXER.

The Powdered Coal Engineering and Equipment Co., Chicago, manufactures one of these special devices for mixing and feeding the coal and air. It terms its process the "carburization process;" and to quote from its pamphlet No. 6, the—

> Carbureter contains two chambers, into one of which an auxiliary supply of air is admitted, and from which it is discharged into the second chamber and there mixed with the coal-laden air in such a manner that the intermingling of the coal and air is carried to completeness. Where screw feed is used, the screw and air valves are so synchronized that when it is desirable to change the feed of coal the air is automatically changed at the same time, the coal and air being maintained at the same ratio at all feeds.

The writer visited a plant where this burner was used with screw feed for burning coal in annealing furnaces, and found it to be an improvement on the burner it displaced. But the discarded burner was not one of the modern burners previously described.



COVERT SCREW CONTROLLER.

COMBUSTION ECONOMY CORPORATION'S MIXER.

The Combustion Economy Corporation, Chicago, also supplies a "carbureter in which is placed a stationary fanlike mixer. The outlet end of this carbureter is fan shaped, which causes the flame to spread across the furnace and to ignite more readily."

GROUND COAL ENGINEERING CO.'S MIXER.

Mr. Milton W. Arrowwood of the Ground Coal Engineering Co., Chicago, also has devised an elaborate method of mixing the air and coal before entering the furnace. Figure 22, which appeared in the transactions of the American Foundrymen's Association for 1919, shows this device. The coal is delivered from a bin by a feed screw, which discharges it into a perforated cylinder, where it meets a strong blast of air entering through the top opening. The coal and air pass through the small holes of the cylinder into the lower cylinder C, through a pipe, and into a series of concentric annular chambers with perforated walls. These annular chambers are inclosed in the cylinder. A low-pressure supply of air enters this cylinder from the large opening on the left, flows between the annular chambers, and is mixed with the numerous jets of air and coal flowing through the holes in the annular chambers. The mixture leaves the burner through the rectangular orifice on the right.

The writer saw this system in place in an air melting furnace in the malleable-iron foundry at the works of the General Electric Co., Erie, Pa., but it had not been used at the time of the visit.

FEEDERS OTHER THAN SCREWS.

A rotating screw is almost universally used for feeding powdered coal from bins in modern installations. Other schemes have been tried, notably the Walker system, which has been in use for many years at the plant of the Erie Malleable Iron Co., but which was not seen in use elsewhere.

Screws also are not used in some plants when compressed air is used to give the coal a high velocity.

COMPRESSED-AIR COAL INJECTOR.

Figure 23 shows the compressed-air system of firing and feeding coal to an open-hearth furnace used until recently at the Homestead works of the Carnegie Steel Co. The compressed air enters an injector under a pressure of 90 pounds per square inch, and leaves the inner pipe with so high a velocity that it sucks the coal from the coal bin into the injector, from which it projects it with considerable momentum into the furnace. A high-velocity burner is used only for open-hearth melting and similar processes where it is desired to have the flame impinge on the substance to be heated. In open-hearth work it is essential to provide means for changing the direction of the jet. Thus, after charging the path of the jet is more nearly horizontal than later, when it is directed downward.

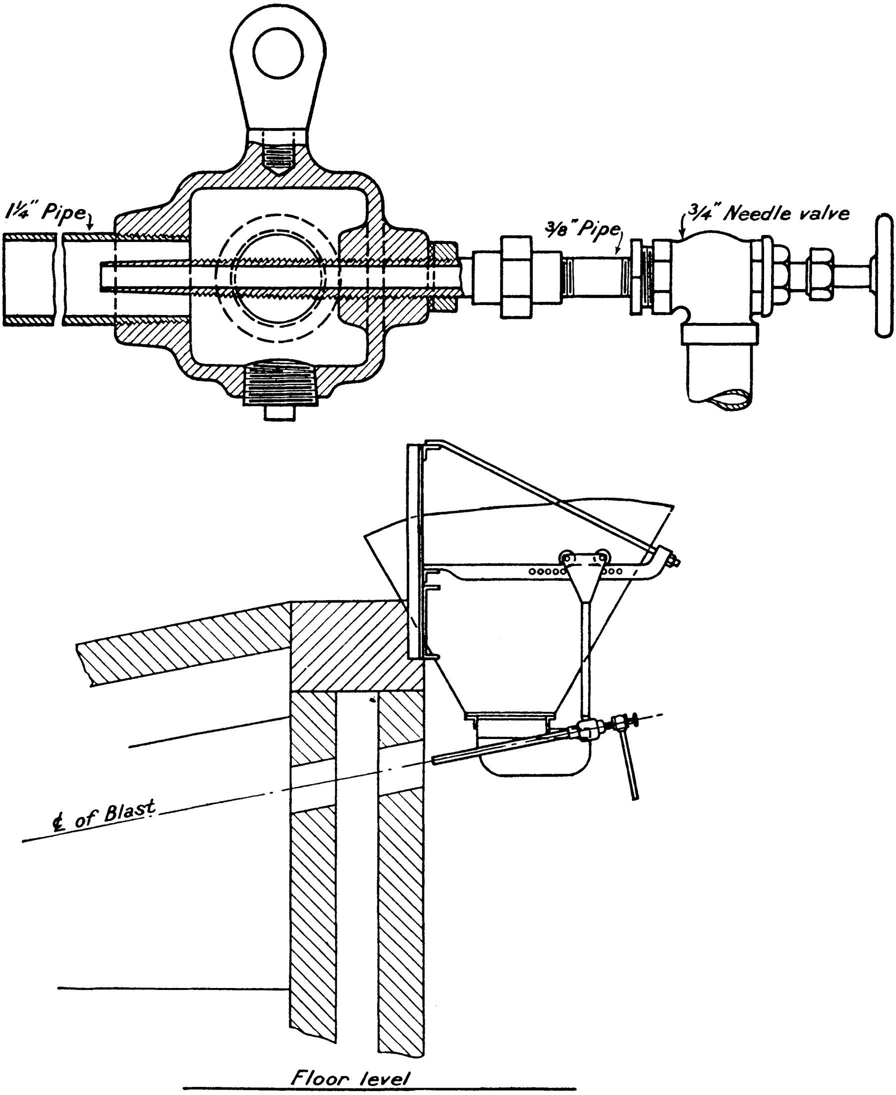


FIGURE 23.—Coal feeder and burner for open-hearth furnace.

COMPRESSED-AIR INJECTOR, COMBINED WITH SCREW FEED.

At the open-hearth plant of the National Malleable Castings Co., Melrose Park, Ill., the powdered coal is fed by means of a screw driven by a variable-speed motor from the bin into a **T**, where it meets a current of compressed air under a pressure of 50 pounds per square inch; the mixture leaves the **T** and passes through a short length of pipe into a larger surrounding pipe, where it joins a stream of air supplied under a pressure of 12 inches of water, and the total mixture passes into the furnace from a nozzle.

CHAPTER V.—USES OF POWDERED COAL.

USE COMPARED WITH GRATES AND STOKERS.

From the foregoing description of the process of preparing and burning powdered coal it may be seen that the process has many qualities to recommend its use. Its principal advantages over hand and stoker firing lie in the comparative ease of conveying coal to furnaces and in the practically complete combustion of the coal, with little excess air, in close contact with the material to be heated, thus avoiding the convection, radiation, and excess-air losses which accompany hand or stoker fired furnaces placed outside reverberatory and many other furnaces. For this reason the most successful field of use has been for those purposes where it has replaced externally fired furnaces. For purposes such as steam raising, where the burning coal can give up heat directly by radiation to the boiler heating surface, there is therefore less opportunity for reducing the fuel consumption by burning powdered coal instead of burning coal on a grate, since the losses which may be reduced by substituting powdered coal firing for hand firing or stoker firing are those only which are due to incomplete combustion and using excess air. These losses, however, are not inconsiderable.

DRAWBACKS TO USE.

COST.

Before powdered-coal firing can compete successfully with grate firing it is obvious that the gain due to the smaller consumption of powdered coal must offset the cost of preparing, conveying, and burning it. These costs will be examined in a later chapter.

DISPOSAL OF THE ASH.

There is a further disadvantage with powdered coal. In grate firing the ash is left on the grates and in the ash pit. But with powdered coal the ash is blown into the furnace, out through the stack, and with some badly designed furnaces out through openings in the furnaces. It may also form a troublesome slag, and fill up the flues so as to impede the draft.

POWDERED-COAL PLANTS DIRTY.

On the whole, powdered-coal plants can not be said to be clean. There are fairly clean powdered-coal plants; but generally, though not universally, a plant using powdered coal is dirtier than a grate-fired plant.[9] At one plant using it, and visited by the writer, the quantity of coal blown out from furnaces was so objectionable in rivet-heating furnaces, with the air-suspension transport system, that it has been replaced by oil firing, in spite of the fact that powdered coal was a cheaper fuel than oil. At another plant where powdered coal delivered by the air-suspension transport system was used for forge furnaces it was found that the increased cost in repairs to presses, cranes, etc., near the furnace, due to firing powdered coal, amounted to 23 cents per ton and the additional cost for repairing furnaces to 15 cents per ton.

HEAT AT ONE PLANT BETTER WITH STOKERS.

Nor has powdered coal always given as satisfactory a heat as stoker firing. One plant visited had abandoned powdered coal for firing forge furnaces because either the gases passed through the furnaces at so high a velocity that it was impossible to obtain a soaking heat or, if they were retarded by closing the damper, ash was blown into the mill.

POWDERED-COAL PLANTS GENERALLY SUCCESSFUL.

It must not be understood from the foregoing that powdered-coal installations have proven unsuccessful. On the contrary, they have generally proved most successful. Of all the plants visited by the writer the only plants where the use of powdered coal was discontinued, besides those mentioned, were as follows: (1) An open-hearth plant using the coal suspended in air method of distribution, where coal was displaced by oil fuel; (2) an open-hearth plant where no means were used to preheat the air; (3) an open-hearth plant where it was replaced with coke-oven gas; (4) a plant where it was replaced by natural gas; and (5) a plant where it was replaced with oil.

At another plant using the air-suspension method of distribution for supplying sheet and pair and annealing furnaces it was about to be replaced by the air transport and bin at furnace system.

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[9] A notable exception to this is at the Oneida Street Station of the Milwaukee Electric Railway & Light Co., where the boiler room using powdered coal is far cleaner than the stoker-fired boiler room beside it.

USE COMPARED WITH GAS AND OIL.

Powdered coal, for the most part, has been used for those purposes which would be served by fuels of high calorific value—gas, oil, or tar—and, generally, where the costs of using natural gas or oil are about the same as for powdered coal the natural gas, oil, or tar is preferred. The reasons for this preference are the absence of dirt and ash, the greater ease with which natural gas, oil, or tar can be conveyed and fed to the burner, and the avoidance of the equivalent of a plant for pulverizing the coal.

The actual flames of burning gas, oil, tar, and powdered coal differ both chemically and physically. For some purposes the rapid radiation of heat from the burning particles of coal makes powdered coal preferable to other fuels, while for other purposes it is less desirable. As the art of burning powdered coal becomes better understood, furnaces and burners will be designed to enable it to take the place of oil, gas, or tar for most purposes. Even to-day there are few purposes for which it has not competed with those fuels successfully, and although in some plants it has been discarded because of inherent defects, in other plants these defects have been overcome and it has been successfully applied for the same purpose.

USE COMPARED WITH PRODUCER GAS.

Powdered coal in many plants has been used for purposes for which producer gas might have been used. Producer gas has much to recommend it. In modern producers it can be manufactured cheaply, and with a fairly constant calorific value from a low-grade coal. It can be fed to the furnace without difficulty, and there is no trouble from the deposit of ash in the furnace, flues, regenerators, or waste-heat boilers. On the other hand, in the process of making producer gas much of the sensible heat of the gas, generated by the incomplete combustion of the coal in the current of air and steam in the producer, is lost. The loss of heat, not less than 10 per cent of the calorific value of the coal, not only reduces the thermal efficiency of the process, but it involves the necessity of returning the heat lost in the producer to the mixture of producer gas and air entering the furnace, if a flame temperature as high as that obtained with powdered coal is desired. To preheat the air and producer gas it is necessary to install heat regenerators or recuperators, whereas air preheaters are unnecessary where powdered coal, high calorific value gas, or oil are burned, except for open-hearth melting or for other furnaces in which a very high temperature is required.

DESIGN OF FURNACES FOR BURNING POWDERED COAL.

Furnaces in which powdered coal is to burn must be large enough, and be correctly shaped, so that the coal may burn completely without impinging on the brickwork, and must be provided with facilities for removing the ash. If the furnace is correctly designed, about 3 B. t. u. per second may be liberated per cubic foot of combustion space. This rate of combustion is sometimes exceeded, but if it is much exceeded the coal will not be burned completely.

In many furnaces the temperature is so high that the ash fuses, and on settling in the furnace collects in a continuous mass. It has become expedient in some furnaces to cool the ash before settling and so prevent it collecting in a continuous mass, though generally this is not done, and the ash collects either on the hearth, whence it is removed when the furnace shuts down, or it is removed as a liquid slag. The ash that does not settle in the furnace goes off with the gases, and care must be taken to see that it may not be deposited in the flues and so impede the draft.

When a furnace previously heated by coal burned on a grate, gas, or oil is to be transformed into a powdered-coal fired furnace, the furnace may or may not have to be modified in design to suit powdered coal. Except for boiler furnaces, very radical alteration of design is unusual. At most, the change consists usually in enlarging the furnace. But no furnace should be fired with powdered coal without the advice of experienced engineers, who will either approve the application of powdered coal to the furnace as it exists or carefully redesign it so that it may be economically operated with powdered coal, using the best means of disposing of the ash.

TRINKS AND BARNHURST ON FURNACE DESIGN.

Prof. W. Trinks,[10] in discussing, in the Blast Furnace and Steel Plant, the design of heating and annealing furnaces, points out that the cost of a furnace is nearly proportional to its volume, and that to determine the rate of combustion per unit volume of combustion space is essential. As flames of burning gas, oil, or powdered coal may be oxidizing or reducing, long or short, the rate of combustion per unit of furnace volume varies. Trinks states that as a rough average:

> With oil or gas fire 3 B. t. u. per second can be liberated in each cubic foot of furnace space. If powdered coal is used, a difference arises between those furnaces in which the coal is burned over and near the material to be heated and those furnaces in which a separate combustion chamber is used for the purpose of depositing the ash before it reaches the heating chamber proper.

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[10] Trinks, W., Heating furnaces and annealing furnaces: Blast Furnace and Steel Plant, February, 1919, p. 98.

(In the former case 3 B. t. u. per second can be developed per cubic foot of furnace.) Under these circumstances only 1½ B. t. u. per second are developed for each cubic foot of furnace and combustion space. These figures give total volume of the empty furnace. If a separate combustion chamber is used, the figures may be doubled. And if the adjustment of the combustion is perfect, they may be trebled, or even quadrupled.

Mr. H. G. Barnhurst,[11] chief engineer, Fuller Engineering Co., Allentown, in the course of a discussion of his paper on the general utilization of pulverized coal before the Cleveland Engineering Society, states that the ratio of furnace volume to the rate of combustion varies, that he thinks it will be necessary to increase the ratio if the ash has a low melting point, that the ratio depends to some extent on the shape of the furnace, and that the general practice is to allow 40 cubic feet in a furnace per pound of combustible burned per minute, though in boilers at Parsons, Kans., running at 125 per cent rating, there were nearly 50 cubic feet of furnace space per pound of combustible burned per minute.

If the combustible has a calorific value of 15,000 B. t. u. per pound, then 40 cubic feet of furnace space per pound burned per minute is equivalent to the liberation of about 6 B. t. u. per cubic foot of space per second, or, if the calorific value of the combustible is only 12,000 B. t. u. per pound, to the liberation of 5 B. t. u. per cubic foot of space per second.

DROP-FORGE FURNACES.

Mr. Charles Longenecker,[12] of the Bonnot Engineering Co., in an article in the American Drop Forger on the use of powdered coal as a forge-shop fuel, points out the necessity in designing drop-forge furnaces of coordinating "the different variables, such as design of furnace, location of burners, and size of opening" if the best efficiency is to be obtained. He also recommends the installation of an exhaust-fan system for exhausting the flue gases from these furnaces.

Unless powdered-coal furnaces are designed with an amply large and correctly shaped combustion space, the burning coal will soon wear away the brickwork. Modern furnaces are designed to reduce this wear, which is also reduced by introducing the coal into the furnace at a low velocity, and causing the flame to spread over a large area.

PURPOSES FOR WHICH POWDERED COAL HAS BEEN USED.

Powdered coal has been successfully applied, and is commonly used, for the following purposes: Open-hearth furnaces; busheling and puddling furnaces; continuous-heating furnaces for blooms and bil-

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[11] Barnhurst, H. G., General utilization of powdered coal: Jour. Cleveland Eng. Soc., vol. 10, 1917, p. 160.

[12] Longenecker, Charles, Using powdered coal as a forge-shop fuel: Am. Drop Forger, vol. 5, 1919, p. 285.

lets; furnaces for heating, reheating, and forging; annealing furnaces for malleable iron and steel castings and plates; sheet and pair and annealing furnaces and tin pots; galvanizing pots; soaking pits; ore roasting and volatilizing; copper-ore roasting and smelting; zinc industry; gold and silver industry; calcining kilns; lime burning; refractory materials; and also in the fertilizer industry. It is used more than any other fuel in the cement industry and has been successfully applied for steam raising. Whenever powdered coal has displaced hand firing the coal consumption has been reduced considerably.

Some of the applications of powdered coal will now be referred to separately.

FORGE FURNACE.

Figure 24 shows a powdered-coal fired furnace, used for heating blanks for drop forging. It is reproduced from an illustration in the Journal of the American Society of Mechanical Engineers from an article by Mr. W. S. Quigley,[13] of New York. It is a rebuilt oil-fired furnace.

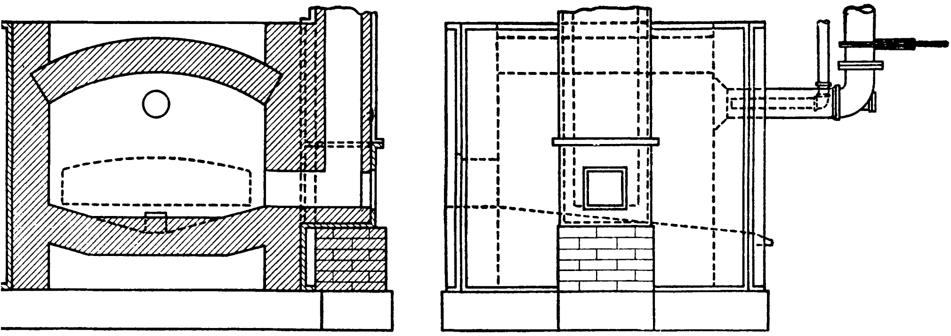

FIGURE 24.—Furnace for heating blanks, converted from oil firing to powdered-coal firing.

PUDDLING.

Figure 25 shows a puddling furnace adapted to powdered-coal firing. It will be observed that the grate bars in the combustion chamber are covered with a bed of ashes onto which much of the ash from the coal drops, and from which it may be raked out through the doors. An arrangement is also provided for preheating the supply of air to the burners. The diagram on the right of this illustration shows the carbon dioxide content of the flue gas when powdered coal was burned and when coal was fired by hand. A test run on this furnace for making special muck bar for stay bolts showed the

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[13] Dalton, William, and Quigley, W. S., An installation for powdered-coal fuel in industrial furnaces: Jour. Am. Soc. Mech. Eng., vol. 36, October, 1914, pp. 109–121.

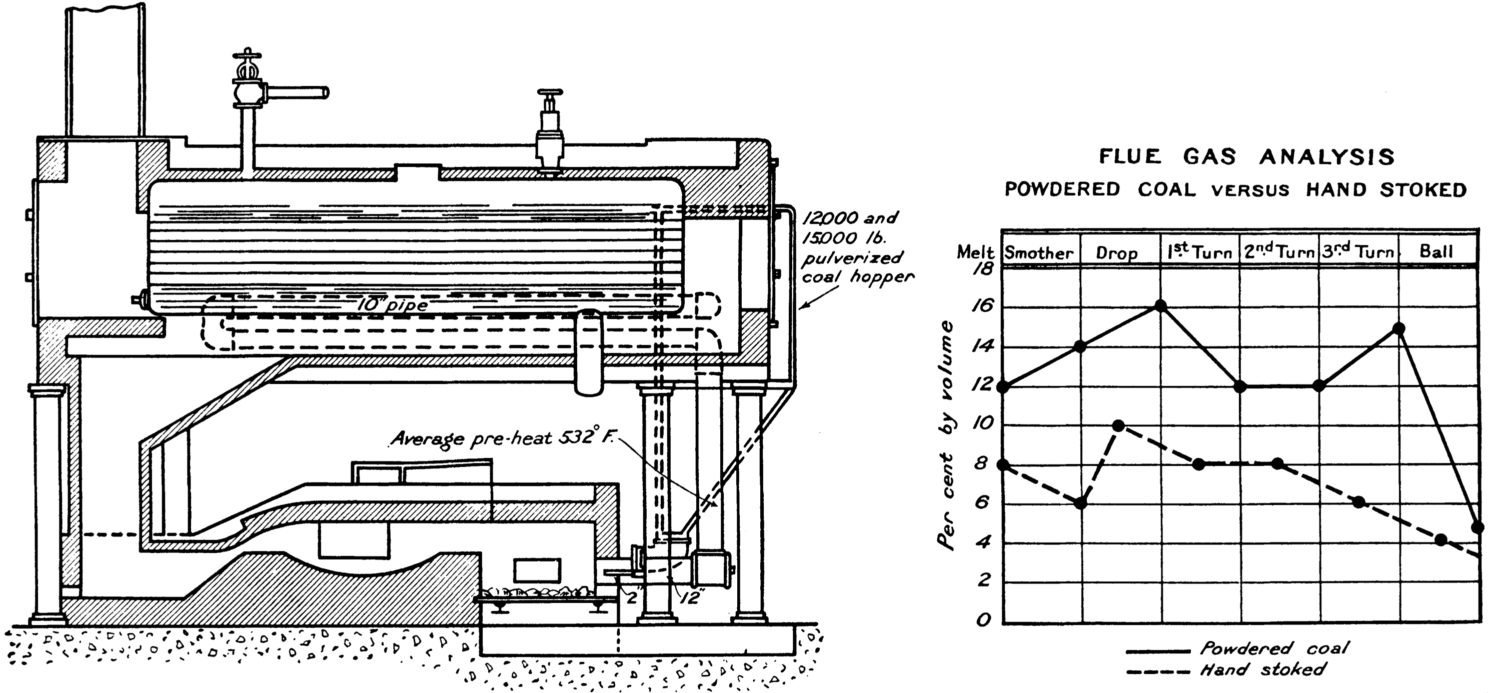

FIGURE 25.—Puddling furnace fired with pulverized coal, and diagram showing carbon dioxide content of flue gas with powdered-coal firing (solid line) and hand firing (broken line).

powdered-coal consumption per gross ton with preheated air to be 1,025 pounds and with cold air to be 1,146 pounds.

Mr. C. J. Gadd[14] states that the saving over hand firing by using powdered coal for puddling is about 30 to 36 per cent.

Mr. W. Simons[15] also says that the saving over hand firing by burning powdered coal for puddling is about 30 to 36 per cent, and that a greater output can be obtained.

ANNEALING FURNACES.

One of the commonest and most successful applications of powdered coal is for annealing malleable castings. For these furnaces very little change in furnace design from hand firing is required, the ash does not appear to be very troublesome through clogging the flues, nor do the repairs to brickwork in the furnace with well-designed burners appear to be high.

AIR FURNACES.

While malleable-iron firms have used powdered coal for many years in malleable-iron annealing furnaces, they have not so readily adopted it for air furnaces for melting the iron. But it appears that the difficulties encountered in applying it to air furnaces are now being overcome.

SHEET AND TIN MILLS.

Powdered coal is also being used in sheet and tin mills, both for the pair furnaces and the annealing furnaces. One sheet-mill firm visited by the writer stated that after changing to powdered coal from hand firing it was using for its whole operation only as much coal as it used originally for the annealing furnace alone.

On the other hand, Mr. G. J. Hagan,[16] in the course of a paper and discussion thereon, in the proceedings of the Engineers' Society of Western Pennsylvania, states that he has equipped 80 per cent of all the sheet and tin mills of the United States with automatic stokers for coal burning, and

> There are, no doubt, a few things in favor of powdered coal rather than the stoker—but very few. One, which we must admit, is that the work can be done on less fuel. I find it takes 300 to 325 pounds of powdered coal per ton of finished product of the tin mill. In stoker practice we do the same work with from 350 to 375 pounds. Comparing the saving between the amounts of coal required with powdered fuel and with stokers and adding your cost of pulverizing (and I have

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[14] Gadd, C. J., Designed heating furnaces from a practical standpoint: Jour. Franklin Inst., vol. 182, September, 1916, p. 343.

[15] Simons, W., Report of experimental use of powdered fuel for puddling furnaces: Jour. Iron and Steel Inst., vol. 100, 1916, p. 76.

[16] Hagan, G. J., Powdered coal in metallurgy: Proc. Eng. Soc. West. Pennsylvania, vol. 35, 1918–1919, pp. 31–47.

never yet found a cost of 40 cents in pulverizing coal, and I know of a plant where the cost is $1.10), you will find the saving in dollars and cents in favor of the stoker.

In spite of this, in an article in the Iron Age[17] describing the powdered-coal equipment of the Newport Rolling Mill Co., Newport, Ky., installed by the Quigley Furnace Specialties Co. of New York, there appears the following statement:

> Pulverized-coal equipment is now superseding all former firing methods as rapidly as the necessary changes can be made, new equipment installed, and the furnaces rebuilt.
>
> There are 15 sheet mills now in operation rolling sheets from 16 gage to 34 gage. The furnace equipment of three mills consists of 10 combination sheet and pair furnaces, three continuous pair furnaces with adjacent sheet furnaces, and two slab furnaces for heavier sheets, all of these operating on powdered coal.
>
> There are five additional sheet mills under construction, together with necessary powdered-coal fired furnaces, which, it is expected, will be in operation this fall. The first furnace using powdered coal was fired in November, 1918, and since that time the others have been added as fast as the furnace could be remodeled for the powdered-coal equipment.
>
> Present plans call for a total of 20 mills served by 23 furnaces. The original plans called for eight double-box, double-chamber, pulverized-coal fired annealing furnaces, to take the place of an equal number of hand and stoker fired furnaces. This number has been reduced to six as a result of the performance of the two which have been operating with powdered coal, the output of the sheets treated having greatly exceeded expectations. Two have been in operation for nearly one year. Two more are about completed, and two are under construction.
>
> Based on investigation and compilation of data on output of hand fired, stoker fired, and powdered-coal fired annealing furnaces in this plant, it is stated that the six furnaces of the type adopted using powdered coal will handle a tonnage which would have required eight stoker-fired furnaces of the same size.

OPEN-HEARTH FURNACES.

Powdered coal has now been used as a fuel for making basic steel in open-hearth furnaces for several years. But it has not proved a successful fuel for making acid steel in the open hearth, probably because of too high a sulphur content in the coal.

Powdered coal for open-hearth work should be very finely pulverized (85 per cent through 200 mesh) and contain very little sulphur and ash. It is carried into the furnace in a stream of primary air, which comes either entirely from a jet of compressed air or both from a jet of compressed air and a jet of low-pressure air. One of these burners has been described and illustrated (Fig. 23, p. 44) in Chapter IV.

The secondary air comes into the furnace from the heat regenerators, and is about six times the volume of the primary air.

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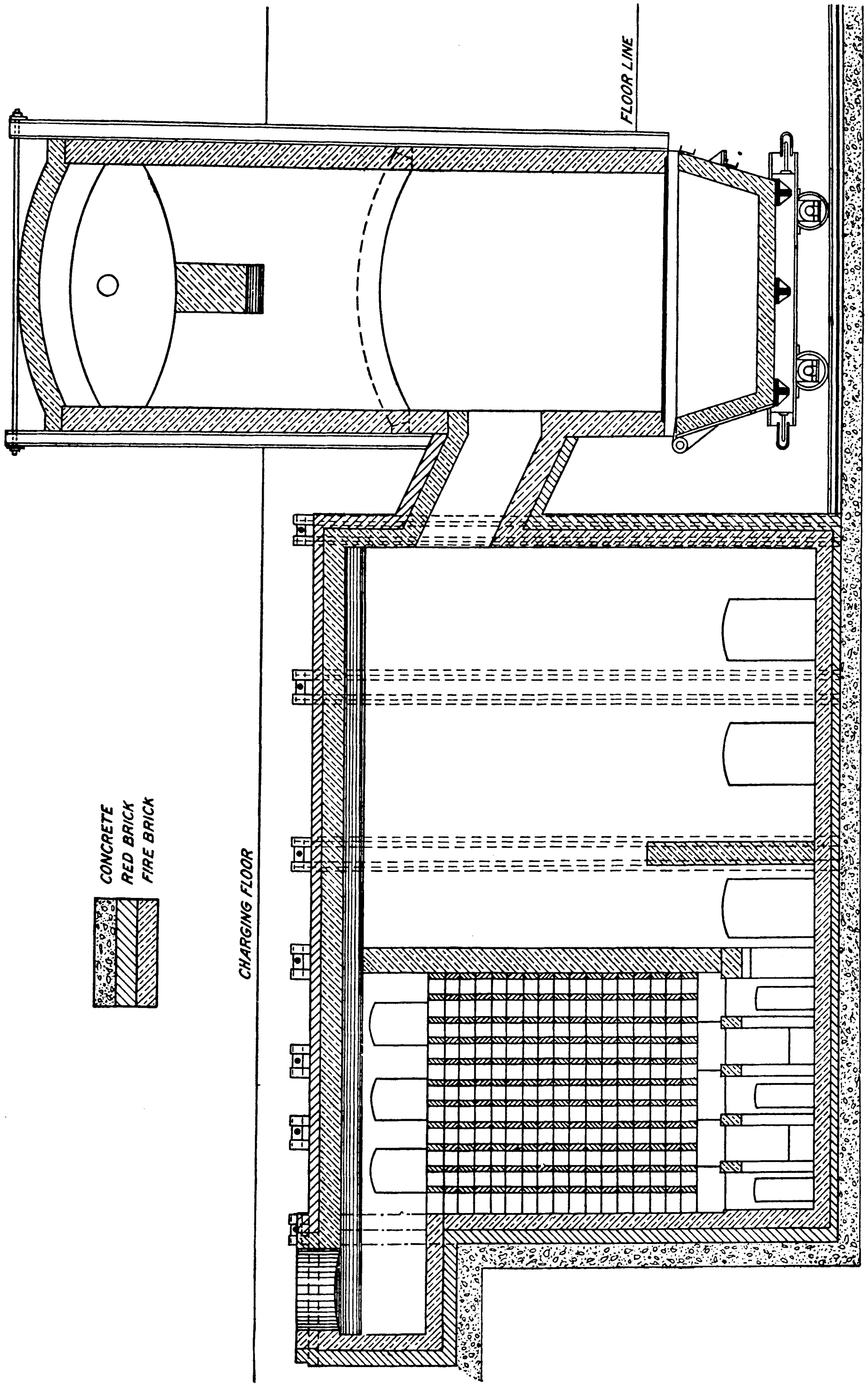
[17] Iron Age, Burning pulverized coal in a sheet mill: Vol. 104, 1919, pp. 1167–1172.

Where powdered coal is used for open-hearth work, the cost of repairing the furnace and checkerwork has been found to be higher than with other fuels. But these costs are gradually being reduced as furnaces and checkerwork are being redesigned in the light of previous experience. Another difficulty encountered in powdered-coal fired open-hearth practice lies in the disposal of the ash. At one plant visited by the writer it was estimated that 10 per cent of the ash passed up the stack, 25 per cent was caught in the regenerators, and the remainder was deposited in the slag pockets and bath. The deposit of ash in the checkers has proved a serious drawback to the use of powdered coal in open-hearth work. It necessitates frequent cleaning and scraping of the checkers, obviously a greater drawback when furnaces are operated continuously than when they are operated intermittently. It has been reduced somewhat by grinding the coal more finely and by enlarging the openings in the checkerwork. But if the checker openings are enlarged, the gases give up less heat, and so the efficiency of the process is reduced. Mr. W. H. Fitch, manager of the metallurgical department of the Fuller Engineering Co., presented to the writer a design of open hearth wherein it is hoped the trouble due to the deposit of ash in the checkers may be considerably reduced. A view of this furnace is shown in Figure 26. This view shows the slag chamber, at the base of which is a car in which the heavy oxides are precipitated and a dust chamber between the slag chamber and regenerative chamber. The dust chamber is intended to collect dust and permit gases free from dust to rise through the checkerwork of the regenerative chamber. At the time of writing this report, this design of furnace has not been used; if successful it would obviate the expenditure of time and labor in cleaning the checkers, and make possible the use of sufficient checkerwork to store up efficiently heat from the waste gases. There is a disadvantage in this design of furnace in that additional space is required for the dust chamber and the hot gases pass up through the checkerwork, thus being more likely to cause an uneven distribution of temperature in the checkerwork than if they passed downward as in the ordinary design.

The relative efficiency of powdered coal and other fuels and the cost of repairs for open-hearth practice are difficult to obtain. But at one plant visited it was found that a furnace gave only 120 heats with powdered coal, as against 300 heats with natural gas. At another plant visited, where powdered coal had replaced producer gas, it was found that 500 pounds of powdered coal gave the heat equivalent of 600 pounds of coal charged into gas producers.


FLOOR LINE
CHARGING FLOOR
CONCRETE
RED BRICK
FIRE BRICK

Mr. N. C. Harrison,[18] general superintendent, Atlantic Steel Co., Atlanta, in a paper published in the Journal of the American Society of Mechanical Engineers (August, 1919), makes the following comments on the use of coal for open-hearth furnaces:

> All open-hearth furnaces using pulverized coal as a fuel are of the reversing type. There has been only one exception in this country to this, as far as the writer knows, and that exception was at the plant of the American Iron & Steel Manufacturing Co., Lebanon, Pa., where they fired their open-hearth furnaces from one end only. At the other end they installed waste-heat boilers and economizers. As an open-hearth proposition this turned out to be a failure, but as a waste-heat boiler proposition it was a wonderful success. During 1918 they remodeled these furnaces and fired them from both ends.
>
> In the open-hearth furnaces the pulverized coal is delivered into storage bins located at each end of the furnace. On the bottom of these bins are screw feeders, driven by variable-speed motors, for supplying the amount of coal desired. This carries the coal by gravity into the burner pipe. These burners are usually a combination of compressed air at from 60 to 80 pounds pressure and fan air at about 8 ounces pressure. In some cases compressed air alone is used as the medium for conveying this coal into the furnace. The hearth of a pulverized-coal open-hearth furnace is practically the same as the hearth of any other open-hearth furnace, but the uptakes, slag pockets, and checker chambers are entirely different. The uptakes are made as small as possible, so as to hold the gases in the furnace as long as possible without blowing, and the slag pockets are made large, so that the gases will have a slow velocity going through them, thereby depositing a large percentage of the heavy particles that are in the outgoing gases. On account of this heavy deposit, removable slag pockets or very deep stationary pockets should be used, so as to collect this accumulation over the run of the furnace. Where removable slag pockets are used, they are taken out and cleaned and replaced about every two weeks.
>
> Only one checker chamber is needed on each end of the furnace. If the checker chamber is large enough, these chambers should be built up with large tiles and laid in such a manner as to form vertical flues having openings of at least 5 inches by 9 inches or, better, 9 inches to 11 inches. In some cases no checkers at all are used, but the chambers are filled with baffle walls with openings from the outside, so that the accumulation between these baffle walls can be raked out. All passages from slag pockets to stack must be as straight as possible, and wherever any bends must be made some agitating device should be installed at these points. The reversing valves are usually of the mushroom and damper-slide type.
>
> The best coal for use in pulverized form in open-hearth practice is bituminous coal as high in volatile matter as possible and preferably low in ash. It should never contain below 32 per cent of volatile nor more than 8 per cent of ash. For open-hearth furnace use it is necessary that the coal be as finely ground as possible, and it should be so fine that about 97 per cent will pass through the 100-mesh sieve, perferably 90 to 93 per cent, and not less than 85 per cent through the 200-mesh sieve.
>
> This very fine pulverization is necessary for quick combustion and for the removal of sulphur in the coal; and in order to obtain this complete combustion before the flame strikes the bath, some 6 or 8 feet are necessary from the end of the burners to the bath.

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[18] Harrison, N. C., Pulverized coal as fuel: Jour. Am. Soc. Mech. Eng., vol. 41, August, 1919, pp. 355–376.

Open-hearth furnaces using powdered fuel operate on a very low fuel combustion, equal to the best producer-gas practice and much better than the average of the older plants in this country; at the writer's plant (the Atlantic Steel Co., Atlanta, Ga.) about 50 per cent less.

In the writer's plant the pulverized-coal open-hearth furnace has been shut down more often than the producer-gas furnace of the same size. This has been due to checkers and slag pockets filling up with cinders and slag after about 80 heats. These troubles, however, are being gradually overcome by decreasing the size of the uptakes and enlarging the slag pockets, thereby holding the gases in the furnace longer and passing them slowly through the large slag pockets, so that the heavy particles can settle, and now only the fine particles are going to the checkers, which particles are being blown off daily by compressed air. By these means it is expected to get a much longer life out of the checkers, and consequently longer runs out of the furnace, since the filling up of the checkers has always been the deciding factor in the length of run of the furnace.

Sulphur does not give any trouble as long as there is a good draft, and the furnace is working hot, as this plant is now using over 1 per cent sulphur in its coal and getting good results, although when checkers get clogged up and the furnace begins to blow, due to lack of draft, there is trouble with the bath taking up sulphur. This takes place during the last week's run of the furnace, just before it goes down for repairs.

The pulverized-coal open-hearth furnace is under complete control of the first helper as to the amount of coal being used at all times, air blast, and temperature.

The flame, using the same coal as on gas producers, is hotter, which allows the use of a greater percentage of scrap per ton of steel, thus reducing the consumption of high-priced pig iron.

The finished steel is quieter in the molds, due to not being overoxidized, as the coal coming directly in contact with the bath has a greater reducing action. All gas-house trouble is eliminated (cleaning fires, burning out flues, etc.), although the pulverizing plant must be given attention as to dryness and fineness of coal.

Up to date, the refractory costs have been very much greater on the furnace using pulverized coal than on the gas-producer furnaces, and were almost twice as great a year or so ago, although the writer believes that on account of the steadily increasing development of the use of this fuel these refractory costs will be steadily decreased.

The following table shows a comparison of fuel costs for all fuels now used on open-hearth furnaces, and it will be seen that natural gas is not only the ideal fuel but is the cheapest.

Fuel costs for open-hearth furnaces.

Kind of fuel.	Remarks.	Amount per ton of steel.	Rate cost of fuel.[1]	Cost of fuel and labor.[1]	Cost per ton of steel.[1]
Natural gas		6,000 cubic feet	$0.04 per M		$0.24
Do		do	.12 per M		.72
Producer gas	Hot metal	510 pounds coal	3.40	$3.93	1.00
Do.[2]	Cold metal	739 pounds coal	3.40	3.93	1.46
Fuel oil		40 gallons	.02		.80
Tar[3]		do	.025		1.00
Pulverized coal		500 pounds coal	3.40	3.90	.975
Electric power		500 kw. hours	.0075		3.75

[1] Above includes handling cost.

[2] Atlantic Steel Co., Atlanta, Ga.

[3] Tar is a waste product at some plants, and has to be burned.

BLAST-FURNACE SMELTING.

Powdered coal has been used in blast-furnace smelting of copper-nickel ores at the works of the International Nickel Co. at Copper Cliff, Ontario, and for smelting copper ores at the plant of the Tennessee Copper Co. Its use was discontinued at Copper Cliff owing to the difficulty of burning the coal completely, and to leakage of coal dust from the tuyères while they were being punched. But it is expected that, with the construction of the tuyères and furnace modified, powdered coal may be used successfully in the blast-furnace smelting of copper-nickel ores. (See Engineering and Mining Journal, April 3, 1920, p. 803.)

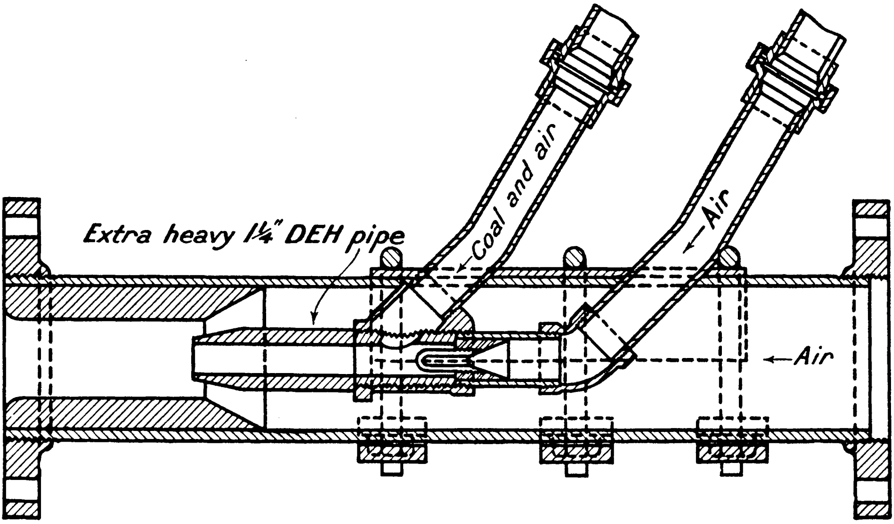

FIGURE 27.—Section of Tennessee Copper Co. pulverized-coal ejector.

Figure 27 shows a view of a pulverized-coal ejector used on the copper blast furnace of the Tennessee Copper Co., at Copperhill, Tenn.

REVERBERATORY COPPER SMELTING.

Largely due to pioneer work at Copper Cliff in Canada, powdered coal has been used very successfully for smelting copper ores.

Mr. L. V. Bender,[19] in a paper describing the coal-dust fired reverberatory furnaces at the Washoe Reduction Works, Anaconda, before the American Institute of Mining Engineers, says that since installing powdered-coal firing in place of hand firing the tonnage has increased. The efficiency is much higher, due to burning the coal inside the furnace instead of burning it outside in a fire box with hand firing and to more even temperatures. The excess air is only 25 per cent with powdered coal and was 100 per cent with hand firing.

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[19] Bender, L. V., Coal-dust-fired reverberatories at Washoe Reduction Works: Trans. Am. Inst. Min. Eng., vol. 51, 1915, pp. 743–751.

The following tables and information are also taken from Mr. Bender's paper:

Coal used at Anaconda.

Kind of coal.	Moisture.	Volatile matter.	Ash.	B. t. u. a pound dry coal.
	Per cent.	*Per cent.*	*Per cent.*	
Lochray	8.0	29.3	20.9	10,350
Bear Creek	9.0	35.5	12.7	11,500
Diamondville	5.6	41.4	8.1	12,960

The coal is dried to 1 per cent or less moisture and pulverized, so that 93 to 97 per cent will pass through 100 mesh and 79 to 82 through 200 mesh.

Comparison of work of No. 7 and No. 8 reverberatory furnaces, September, 1914.

Furnace.	Fuel.	Tons smelted per furnace day.	Total tons smelted.	Tons coal.	Tons smelted per ton coal.	
					Excluding drier coal.	Including drier coal.
No. 7	Diamondville, grate fired	259	7,260	1,871	3.88	....
No. 8	Diamondville, dust fired	475	14,272	1,985	7.19	7.08

The ash from the powdered coal burned in these furnaces gives very little trouble. The flue between the furnace and waste-heat boiler is cleaned once a day by two men in four to six hours. The ash deposited from different coals varies. From one coal (22 per cent ash) it was light, fluffy, and easier to remove than that from another coal (9 per cent ash) which tended to sinter. About one-half of the ash of the coal floats on top of or is absorbed by the slag and does not noticeably interfere with the work of the furnace. Very little ash goes into the boiler settings, and the boiler tubes are cleaned no more frequently than with grate-fired furnaces.

Samples of gas taken at about the center of the furnace had the following composition:

Sample.	1	2	3
Carbon dioxide	16.0	[1] 13.0	15.0
Oxygen	2.0	3.5	3.5
Carbon monoxide	0.0	0.0	0.0

[1] The sum of the carbon dioxide and oxygen content here is so low as to lead to questioning the accuracy of the gas analyses.

The temperature 40 feet from the back end of the furnace varied from 2,250° F. to 2,353° F., and in the flue from 1,595° F. to 1,700° F. In the same volume of the transactions of the American Institute of Mining Engineers, Mr. D. H. Browne[20] describes an earlier installation of coal-fired reverberatory furnaces at the Canadian Copper Co. smelter at Copper Cliff, Ont. The powdered-coal system at Copper Cliff is similar to that at Anaconda, where the system was designed largely in the light of experience already gained at Copper Cliff.

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[20] Browne, D. H., Coal-dust-fired reverberatory furnaces of the Canadian Copper Co.: Trans. Am. Inst. Min. Eng., vol. 51, 1915, pp. 752–763.

CHAPTER VI.—POWDERED COAL FOR STEAM RAISING.

GENERAL PRINCIPLES TO BE OBSERVED IN DESIGN.

That a boiler may operate economically when fired with powdered coal it is necessary that the coal be burned completely with little excess air. This involves feeding coal, sufficiently dry and pulverized, and air to the furnace as required in the correct proportions, and providing a furnace large enough and of the correct shape, so that the coal may be readily ignited, may not impinge on the brickwork, and may follow a path sufficiently long to permit almost complete combustion before reaching the tubes.

TROUBLES WITH ASH AND SLAG.

The temperature in the flame is so high that the ash fuses. In settling on the hearth of the furnace the ash will, unless cooled and kept below the fusing point, fuse into a continuous mass, which on cooling is difficult to remove. This slag may be removed as a liquid, though with some difficulty, or the ash may be cooled as it settles and kept cool after settling, so that the small particles of ash do not stick together on or after settling, and are therefore easily removed as small, separate particles.

The ash may be cooled by permitting it to fall through water-cooled coils connected with the boiler. This is an efficient method of preventing the ash from fusing together on settling, and the coils protect the ash on settling from the heat rays of the furnace. But these coils lower the temperature of the flame and therefore the velocity of combustion, which may permit some coal to leave the furnace unburned.

Attempts are also made to pass the air for combustion over the furnace walls and so cool them, but this scheme has so far failed to maintain the ash at a temperature below its fusing point when the coal is burned with very little excess air.

Not more than about one-third of the ash settles in the furnace; the remainder settles during passage through the boiler or passes off with the gases. Care must be taken to see that the ash may not settle on any part of the heating surface, and that it may settle in parts whence it can be easily removed.

TYPES OF BOILERS TO WHICH IT IS ADAPTABLE.

Powdered coal is better adapted for firing stationary water-tube boilers than other boilers. With these boilers furnaces of sufficient size and of the correct shape may be constructed, and the gases pass through no tubes wherein ash may settle to obstruct the draft and shield the heating surface. It has been found difficult to burn powdered coal in locomotive and cylindrical marine boilers because the combustion space is too small to permit the coal to be burned completely.

Here follow descriptions of various boilers which have been fired with powdered coal:

BETTINGTON BOILER.

One of the earliest successful powdered-coal fired boilers was the Bettington boiler. This boiler differs from other installations in that the pulverizer, blower, and boiler are all designed as a unit for steam raising with powdered coal, and no dryer is required. The combined pulverizer and blower are similar in construction to the Aero pulverizer and blower already described. The mixture of coal and air passes into the combustion chamber of the boiler through a vertical water-cooled burner. It burns in the center of the combustion chamber, the hot products of combustion rise in the central flame, then fall on the outside of the flame, and leave the combustion chamber near the bottom. The combustion chamber is cylindrical, with its axis vertical; on its top is the steam drum exposed to the flame, and its sides are inclosed with fire brick, on the outside of which are the vertical water tubes of the boiler.

The Bettington boiler was designed to be used with low-grade fuels, to operate with high efficiency, and to give no trouble with a high-ash clinkering coal. The Canadian National Railways installed a Bettington boiler for supplying steam to its workshops at Moncton, New Brunswick, the intention being to burn a low-grade coal. But its steam generation with this coal proved impracticable, because the ash fused and formed a ring on the wall of the combustion chamber around the burner. This deposit restricted the area through which the products of combustion passed, and occasionally pieces of slag fell into the burner, whence it was difficult to remove them. After encountering many difficulties from the slag formation, cracking of the water-cooled burner, and failure of the combustion chamber lining, a somewhat better grade of fuel was used. A sample of the coal now used was forwarded to the fuel-testing division and gave the following proximate analysis:

Analysis of coal burned in a Bettington boiler.

	Per cent.
Moisture	1.1
Ash	20.3
Volatile matter	26.7
Fixed carbon	51.9

The mechanical analysis of the pulverized coal was as follows:

Screen test of pulverized coal.

Per cent by weight passing through 8-mesh screen	98.2
Per cent by weight passing through 14-mesh screen	94.8
Per cent by weight passing through 28-mesh screen	87.2
Per cent by weight passing through 48-mesh screen	72.9
Per cent by weight passing through 100-mesh screen	40.4
Per cent by weight passing through 150-mesh screen	34.0
Per cent by weight passing through 200-mesh screen	13.5

The proximate analysis shows this coal contains a high percentage of ash, and the mechanical analysis shows that the coal is not well pulverized, since only about 40 per cent of it passes through the 100-mesh screen, whereas in ordinary pulverizing plants about 95 per cent passes through. This boiler is still generating steam, and at the time of the writer's visit full steam pressure was generated from cold water 20 minutes after starting up the boiler. Nevertheless, the Bettington boiler has not proved entirely satisfactory at this plant.

FRANKLIN BOILER.

Figure 28 shows a 300-horsepower Franklin boiler equipped in 1913 for burning powdered coal. This design of furnace proved unsatisfactory and was changed to the design shown in Plate IV. There are three burners. The coal is introduced into the main supply of air, which is under a pressure of about three-tenths inch of water, by means of a jet of compressed air under a pressure of about 20 pounds per square inch. This plant was visited by the writer, who was told that it had been running since 1915 with practically no maintenance costs. Mr. W. G. Freer, who is in charge of the boiler room, attributes the success of this boiler not only to the construction of the furnace, design of burner, and rearrangement of the baffle walls, but to the proper control of the flame. That is to say, it is essential to have neither too hot a flame through too little dilution of air nor too cool a flame with excess air. With too much air the velocity of combustion decreases, some of the coal burns in the bottom of the furnace, causing the ash to slag, and it passes to the tubes causing a honeycomb formation of ash. Mr. Freer's experience has been practically identical with that in other plants. At this boiler plant practically all the ash is blown up the stack, and very little removed from the furnace. The tiles beneath the first row of tubes which form the roof of the furnace were proportioned as shown in Figure 29 only after various trials. At first these tiles were entirely removed; this gave too low a temperature. With the present arrangement the furnace temperature is maintained and very little ash deposited on the baffles. In spite of the success of this boiler with powdered coal and nearly horizontal baffles, at subsequent water-tube boiler installations using powdered coal vertical baffles have been substituted for horizontal baffles. Mr. Charles L. Heisler,[21] of

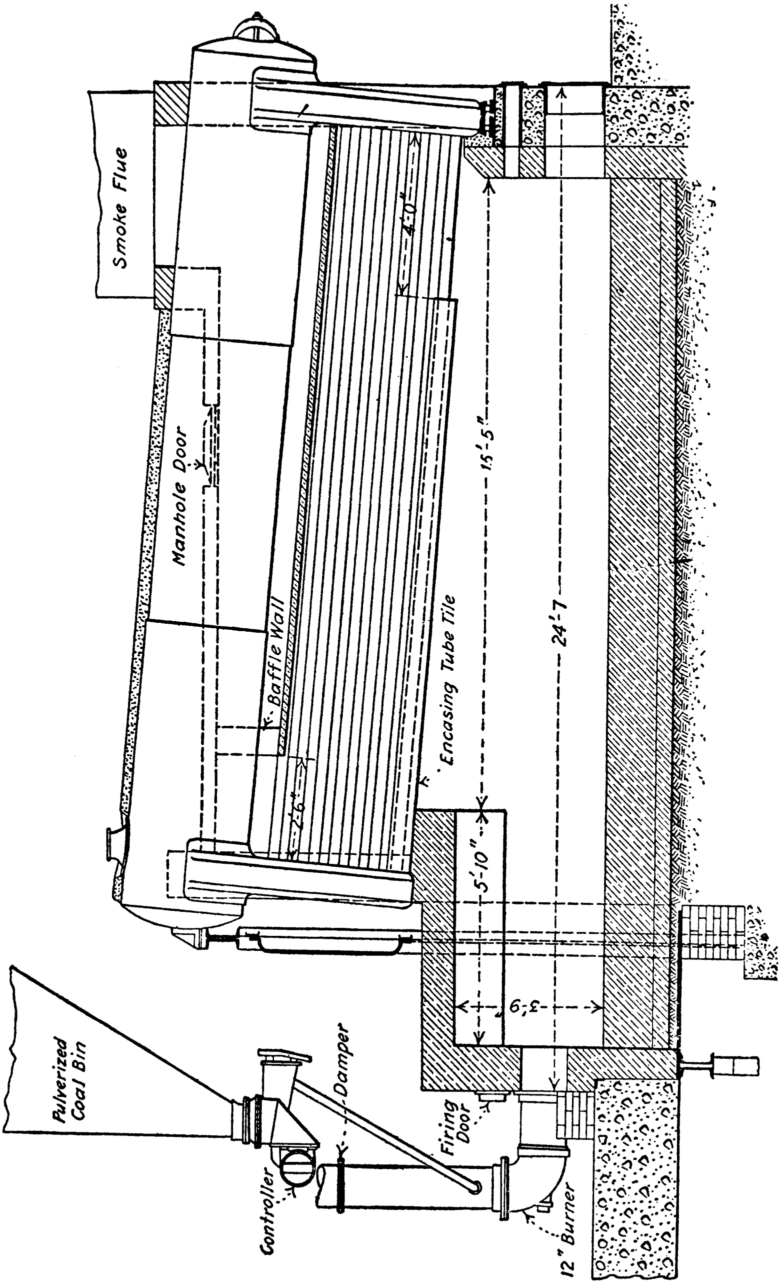

FIGURE 28.—300-horsepower Franklin boiler, American Locomotive Co. as originally arranged for powdered-coal firing.

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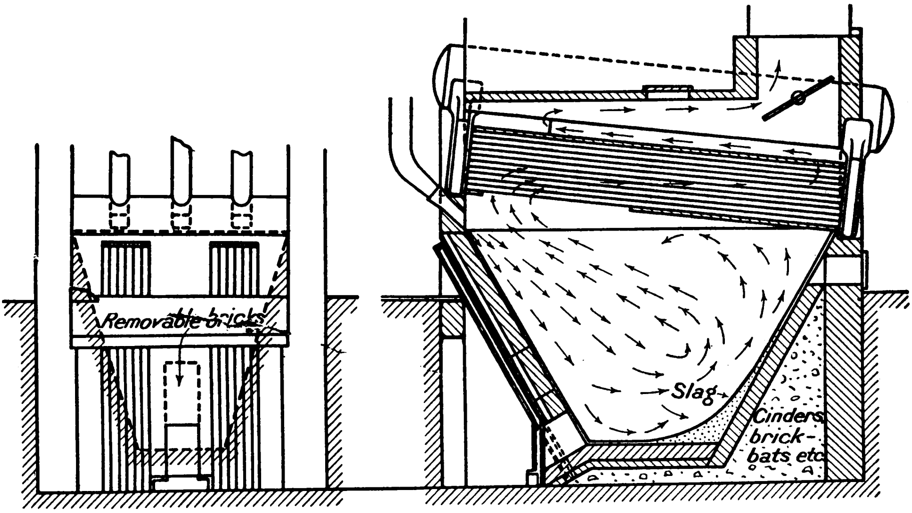
[21] Heisler, C. L., The use of powdered coal as fuel: Am. Soc. Mech. Eng., vol. 38, 1916, p. 999.

Schenectady, in an interesting letter to the Journal of the American Society of Mechanical Engineers states that the CO_2 content of the flue gas rarely falls below 16 per cent and that the—

> Several evaporative tests made by W. G. Freer, member American Society of Mechanical Engineers, show that this extremely simple furnace (illustrated in Fig. 29) gave a materially higher evaporative efficiency than could be obtained from a duplicate Franklin boiler fired by mechanical stokers and supplied with feed water at the same temperature, and that it responded much more promptly to a sudden increased demand for steam than the adjoining stoker-fired boilers. An ordinary fire-room helper was readily taught to give the furnace all the attention ever required.



This drawing illustrates the temporary construction of the furnace as originally made early in March 1915 and which is in continual daily service without having been changed or altered.

FIGURE 29.—Furnace which replaced that shown in Figure 28. The two sets of vertical pipes support the front wall of the furnace.

Previous to the installation of this furnace, between November, 1914, and March, 1915, several constructive revisions were made in a powdered-fuel furnace experimentally installed under the same boiler. Unfortunately, the brick arches and vertical walls completely failed to withstand the high-temperature flame, and there were excessive accumulations of hard slag at the bottom of the furnace and deposits of unburned products around the tubes and in the gas passes.

Several years ago the writer concluded that the only way to prevent the destruction of vertical walls and arches in powdered-coal furnaces was not to have them, and to substitute incandescent ignition surfaces formed by simple outwardly inclined walls which would be automatically maintained by a coating of protecting slag. After the failure of the vertical walls and arches referred to, permission was granted by J. R. Magarvey, manager of the Schenectady works of the American Locomotive Co., to install the furnace shown in Figure 29, which suggested itself, and is shown as originally installed. This furnace now has been in continual service for 18 months without a single repair expense on the hopper-shaped furnace walls. These walls are coated with slag of a thickness of about 1 inch to 3 inches, and are seemingly in as good condition as at the time they were built. Only a small section of the old vertical wall which remained from the former furnaces was replaced at a cost of about five hours mason's labor; otherwise, there were no repairs, with the exception of small fire-clay patches under the powdered-coal inlet tuyeres, which required about 30 minutes' work.

BOILER INSTALLATIONS BY THE BONNOT ENGINEERING CO.

The Bonnot Engineering Co. has installed a powdered-coal fired installation for raising steam in water-tube boilers of the Babcock & Wilcox type, at the works of Messrs. Armstrong Whitworth, Longueuil, Province of Quebec. The coal is delivered in suspension in air, on the Holbeck system, and the furnace is somewhat similar in shape to that shown in Figure 29. The furnace does not lie entirely beneath the boiler, but is extended in front of it and has a flat fire-brick roof near the front. It is shown as originally installed in Figure 30. This design did not prove successful and has been changed. The coal is now introduced through the roof of the furnace, and the front walls were made vertical. It has been found difficult either to get the full rated steaming capacity out of this boiler or to maintain a high CO_2 content in the flue gas or to obtain a thermal efficiency high enough to warrant the cost of preparing and delivering the coal to the furnace. At the time of the writer's visit the flame was not burning regularly, because of irregular feeding of the coal. At this plant, after much experimenting in furnace design, Mr. W. N. Watson has succeeded in removing the ash without difficulty as a liquid slag.

WICKES BOILER WITH PULVERIZED-FUEL EQUIPMENT.

One of the most successful dust-fired boilers seen by the writer was that shown in Figure 31. The boiler is a 333-horsepower Wickes boiler and was equipped for powdered firing by the Locomotive Pulverized Fuel Equipment Co. The burner delivers the coal vertically downward, the flame is U shaped, and the coal pursues a path long enough to permit burning completely. The furnace is very deep (about 18 feet), to avoid heating its bottom and fusing the ash there. In addition to the supply of air, which is blown and drawn in with the coal at the burner, an auxiliary supply of air is drawn in through auxiliary inlets on the front and sides of the furnace. With this boiler it has been found possible to obtain practically any percentage of CO_2 in the flue gas; but to avoid too high a temperature it has been found best to obtain about 12 per cent CO_2. The boiler flues are blown twice a day; there is no great deposit of ash to be blown out, and what accumulates is easily removed. At the time of the writer's visit the furnace had not been cleaned out for four days, and

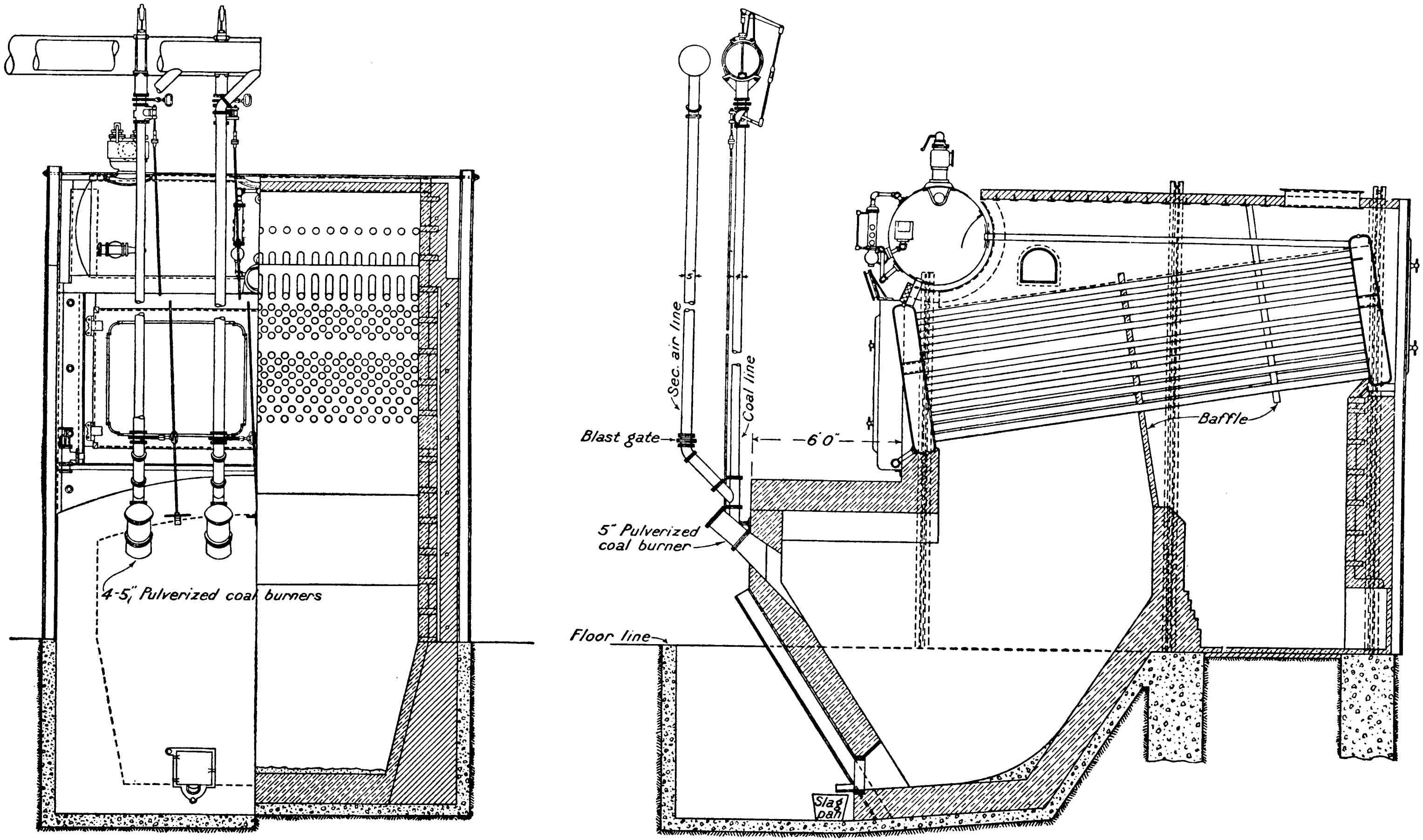


FIGURE 30.—Boiler setting for powdered-coal firing. Holbeck distribution system, Bonnot company.

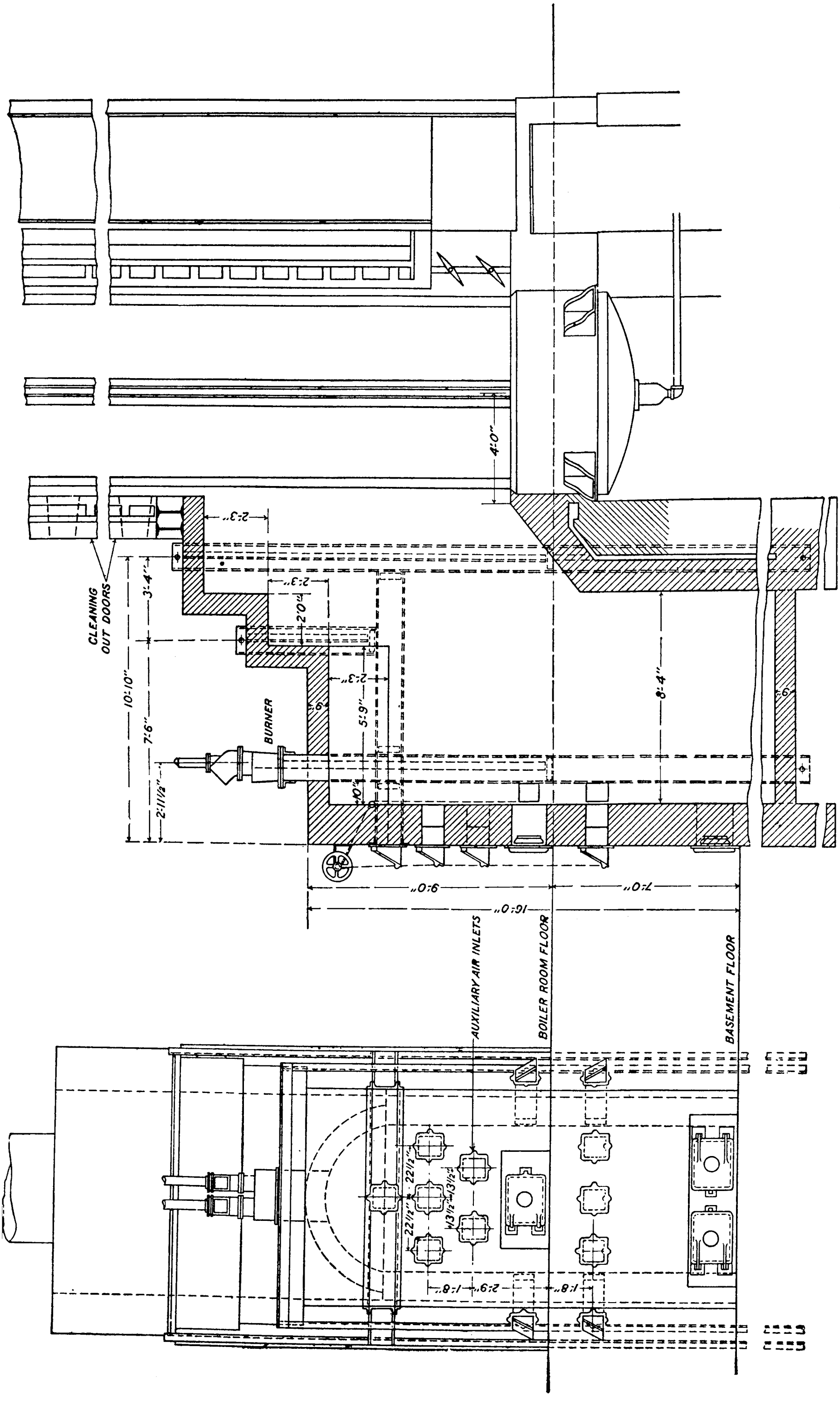


FIGURE 31.—Arrangement of combustion chamber for firing a Wickes boiler with powdered coal. Pulverized Fuel Equipment Co.

on its bottom were lumps of fused clinker. This clinker is removed once a week, and the removal takes about half a day. When the boiler was first installed the ash fused into a solid mass and was extremely difficult to remove, but this difficulty was overcome by lowering the floor of the furnace, which gives the molten particles of ash in the flame time to cool below a temperature at which they would coalesce on reaching the floor of the furnace.

It is interesting to note that at this plant the coal is not dried. It contains from 2 to 3 per cent of moisture and about 12 per cent of ash.

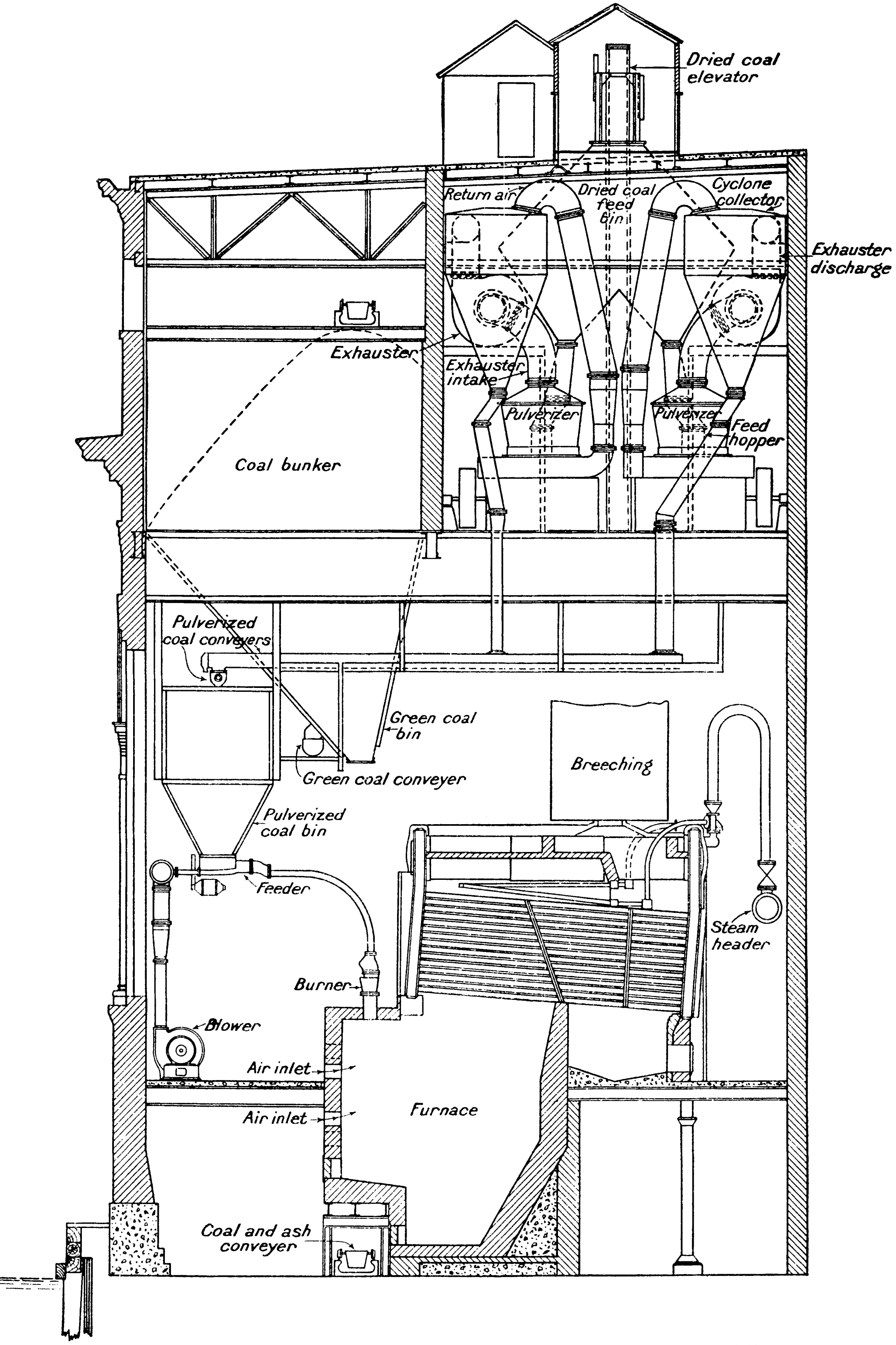
PULVERIZED FUEL EQUIPMENT CO.'S INSTALLATION WITH EDGEMOOR BOILERS.

At the Oneida Street power station of the Milwaukee Electric Railway & Light Co. a battery of five boilers has been equipped by the Pulverized Fuel Equipment Co. for firing with powdered coal. The boilers are Edgemoor water-tube boilers with vertical baffles; the furnaces and air ports are similar to those shown in Figure 31. As originally designed, the furnace was too small and the air supply insufficient, so that the temperature in the furnace became very high, and the ash fused and collected between the tubes, on the furnace walls, and in the ash pit. But since the combustion chamber was enlarged and auxiliary air openings added there has been little trouble, when the flame was properly controlled. If the flame in its path through the combustion chamber approaches too closely the ash pit, the ash quickly slags and becomes difficult to remove. With a flame properly adjusted, there appears to be little trouble with ash at this plant, since most of it goes up the stack and does not seem to cause any inconvenience to near-by citizens. Bituminous screenings are burned at the Oneida Street station, and from 12 to 15 per cent CO_2 obtained in the flue gases.

A cross section through the Oneida Street boiler plant is shown in Plate IV, which is reproduced from a paper presented before the technical league of the Employees' Mutual Benefit Association, Milwaukee, February 19, 1920.

The working of the Oneida Street boiler plant with pulverized coal has been described in a paper on the "Use of pulverized coal under central-station boilers," by Mr. John Anderson, chief engineer of power plants at Milwaukee. The following information has been abstracted from this valuable paper.

Stress is laid upon the necessity of the operation of the plant being changed by the operators to suit a change in the quality of the coal. The driers must be regulated to suit the varying moisture content and size of the coal, since if they are not properly regulated the coal may be so moist as to plug the feeders. At this station the



CROSS SECTION THROUGH ONEIDA STREET BOILER PLANT, MILWAUKEE.

coal is delivered from the feed screws to the furnace by a blast of air, and should the air supply be cut off the coal would not be removed from the feeders, and the coal feed would be plugged. To avoid this, arrangements are made to automatically cut off the power to the feeder motors should the air cease to flow to the mixing chambers and burners.

Mr. Anderson points out that 16 to 17 per cent of CO_2 in the flue gas is easily obtained, but can not be maintained in actual operation without destroying the brickwork of the furnace. The flame temperature should not exceed 3,000° F., and the brickwork temperature should not exceed 2,400 to 2,500° F. Higher temperatures than these fuse the ash particles and form a molten slag, which destroys the brickwork with which it comes in contact.

He refers also to the adaptability of the pulverized-fuel furnace to the use of widely varying grades of coal without decreasing the boiler efficiency. The boiler capacity is in no way affected when an inferior coal is burned. The following quotation from Mr. Anderson's paper contains some very valuable information on the working of the Oneida Street powdered-coal boiler plant:

> Operation of a pulverized-fuel fired boiler equipped with proper instruments can be varied to take big fluctuations in load over very brief period of time. A heavy overload can be quickly taken on or dropped off by adjustment of the coal and air feeds, and without any waste of fuel, as always occurs under like conditions in stoker practice. No losses occur due to clinkering of coal or cleaning of fires, this condition of operation being entirely eliminated. Irregularities caused by change in quality and variation in size of coal, such as the fireman can not successfully cope with on stokers, are also eliminated. Furnace conditions necessary to most economical combustion are more perfectly obtained, and hence a horizontal combined efficiency curve is possible of approximate attainment.
>
> Due to its easily regulated coal and air supply and its perfectly controlled rate of combustion, the pulverized-fuel furnace practically eliminates losses of combustible in ash. Ordinarily this loss is relatively large and varies according to the nature of the coal, type of stoker, and the boiler load carried. In pulverized-fuel practice the loss is very small and these variations do not occur.
>
> The ease with which the fuel feed and draft is controlled, the ability to take on and drop off heavy overloads in brief time, the thorough combustion of the coal, and the uniformly high efficiency obtained under normal operation constitute the chief advantages of pulverized fuel over other methods of coal burning.
>
> An additional economy is effected during banked boiler hours. Banking conditions, when operating with pulverized fuel, are somewhat different from those obtained in stoker practice. By stopping the fuel supply and closing up all dampers and auxiliary air inlets, a boiler fitted for use of pulverized fuel can be held up to pressure for several hours. The furnace brickwork, having been heated to incandescence during operation, gives off a radiant heat which is almost all absorbed by the boiler rather than escaping up the stack intermixed with an excess of cooling air. Only radiation losses occur, as against radiation plus stack and grate losses in the case of the stoker.

Commenting for a moment on the maintenance features of such a plant as has been described, it is the writer's belief, based on two years' operation experience, that the furnace brickwork in a pulverized-fuel furnace will stand up equally as well as a stoker installation, with a very great advantage in favor of the former, due to the elimination of all ironwork in the furnace or anywhere near the high temperate zones of the boiler furnace. Regarding the maintenance of the pulverizing plant equipment it has not been found that any great amount of maintenance is likely to be necessary, as all the equipment is of the slow-moving type, and many opportunities are afforded of applying the same concentration of effort that has been typical of the stationary engineer's work in improving equipment when defects or fast-wearing parts are uncovered. The pulverized-machinery manufacturers have done a great deal along this line, but there are still matters that can be improved upon by the engineer looking for the least troublesome, as well as the most economical, plan from a maintenance standpoint.

Powdered-fuel installations are not feasible in every location. There is one limitation, and that is the size of boiler plant to be served. A plant of less than 2,500 developed boiler horsepower on a 24-hour operating basis should not consider using powdered fuel. The amount of coal pulverized per day, the cost of installation, and the labor for operating the preparation plant, when properly studied, will bring before those interested the reasons therefor.

In general, we have found the powdered-fuel method applied to our furnaces a distinctly advantageous one. Our firemen prefer to operate such equipment rather than the stokers when it becomes a matter of choice. It has proved more economical, as evidenced by the monthly coal bill. It seems to make the formation of scale in the boiler less than in stoker-fired boilers. There is absolutely no trouble from smoke, consequently no reduction in ability of the boiler to absorb heat due to soot on the tubes.

The use of high-sulphur coal, which is so destructive to boiler tubes, breechings, smokestack, and all other steel equipment found in a boiler plant, is much more satisfactory, as the low moisture content of the coal as fired reduces the opportunity for attack from sulphuric acid.

Although frequently cautioned against explosions, we have had no evidence that such caution is necessary. The reason for our freedom from such unpleasant occurrences is due almost entirely to a proper care in preventing coal from being dried too much and pulverized to a fineness beyond what is necessary. Matters of a kind similar to the foregoing are in the hands of the operating engineers, and do not benefit by the highbrow application of theories. The engineer who is careful of his everyday equipment and keeps his plant free from accidents of every nature—from fly-wheel explosions to burned-out motors—can operate a pulverized-fuel plant successfully without other assistance than his own experience.

TESTS.

COAL.

The following is an extract of the tests carried out on the Oneida Street station boilers and reported in the paper before the technical league:

With the exception of the first day, when 100 per cent Youghiogheny was used, the coal for the test was a mixture 50 per cent each Eastern Kentucky and Youghiogheny screenings, running approximately 25 per cent nut, 45 per cent pea, and 30 per cent slack. This coal is the same as is used in daily operation. The coal as supplied to the drier after passing through disintegrator was approximately 50 per cent slack and 50 per cent small pea and nut, not any of the pieces being larger than one-half inch.

During the progress of the test the coal was regularly sampled at five points along the line of fuel travel. Samples taken at the coal scale were for moisture, proximate and ultimate analyses, while those taken at the drier inlet and outlet and burner outlets were for moisture determinations only. Those at pulverizer outlet and burner outlets were for moisture determinations only. All samples were taken and made up according to the A. S. M. E. standards.

All determinations and analyses were made at the laboratories of the T. M. E. R. & L. Co. according to approved practices of the Bureau of Mines. An Emerson bomb was used for obtaining calorific values of the coal.

STARTING, CHECKING, AND STOPPING.

In pulverized-fuel test practice standard methods can not be followed. The level of pulverized fuel in the storage bins is the determining factor in starting, checking, and stopping.

Previous to the starting signal for the final test the green-coal system was run clear of fuel and the pulverized-fuel system filled to capacity. The conditions of the respective systems were identical for each check (after the burning of 40½ tons of coal) and at the close of the test. The amount of coal to be burned between checks was determined by the capacity of the green-coal storage bunkers. Three bunkers of 40½ tons capacity each were available during the test, all of which were filled once in 24 hours.

OPERATING CONDITIONS.

Pulverizing room.—Operation in the pulverizing room was changed somewhat during the test in order to fulfill conditions required in making the periodic checks of boiler operation. It was essential that the levels of the fuel in the pulverized bins should be controllable at certain hours of the day (at the time of check) and therefore operation of pulverizer equipment was extended over 24 hours, although, without these considerations, sufficient coal could have been pulverized during the 18-hour run. As a result, irregular operation of the equipment—frequent starts and short runs—increased power consumption and decreased hourly capacities.

No interruptions due to failure of equipment occurred during the test. The pulverized-fuel conveyer choked up on two occasions when the storage bins were allowed to overfill at a check hour.

Uniform and satisfactory removal of moisture was affected by the drier without any unusual regulation.

The firing of the furnace was varied, as it is ordinarily, depending upon the moisture content of the green coal.

The pulverizers operated uninterruptedly and provided fuel of the desired fineness with little variation.

Pulverized-fuel storage bins.—During the first 24 hours of the test it appeared that moisture, with its attendant difficulties, was collecting in the storage bins. Cold-air drafts through windows along the side of the bins caused this condition by rapidly condensing the vapor in the entrained air. When the windows were tightly closed it was eliminated.

Boiler room.—Choking and plugging of the screw feeders and feeder pipes were the chief causes of interruption in the fireroom. It was on the second day that the tendency of the feeder lines to choke was most noticeable, and this must be attributed to the moisture conditions encountered the night previous. In one instance, however, one of the lines to a burner stopped feeding when a piece of tarred paper lodged in it above the burner. No doubt this had been dropped into the pulverized fuel system accidentally. Operation of the furnace on which this occurred had been noticeably affected during the 24 hours previous to the removal of the pipe and the discovery of the source of trouble. A total of four feeder hours were lost during the test.

A high percentage of CO_2 was easily obtainable, but could not be maintained for longer than an hour at a time, due to excessive slagging on the hearth. This slagging on the hearth and furnace bottoms may be attributed to flame characteristics resulting from certain draft conditions and can only be avoided by air regulation. On the newer type of Lopulco furnaces, as are in use at the Oneida Street plant, the method of air regulation is such that while admitting air for slag prevention, a large volume not needed for combustion enters, bypasses the flame zone, and is carried with the products of combustion in the form of excess air. The high percentage of excess air, together with a correspondingly low percentage of CO_2, as indicated by the flue-gas analysis, was not determined by combustion considerations, but rather by furnace limitations.

No slagging occurred on the boiler tubes.

Flues were blown once every eight hours.

Slag was withdrawn from the furnaces twice in 24 hours.

Back-chamber ash was removed once every two days.

Due to the use of a single stack for the entire boiler plant, which includes six underfeed-stoker boilers, no smoke observations were made. Smoke from the pulverized-coal furnaces, however, has proved on all occasions when pulverized fuel alone is used to be a negligible quantity and appears in the form of a light yellow haze, which disappears within 25 yards of the stack. The ash particles are so fine that no estimate can be made of the distance they were carried before being dropped from the air. No noticeable deposit has accumulated on or about the plant, although continuous operation has been carried on for more than a year.

T. M. E. R. & L. Co. test of five 468-horsepower boilers—Nos. 1 to 5, inclusive.

Oneida Street Power Plant, November 11–15, 1919.

Dimensions:	
1. Number and kind of boilers—Five Edgmoor water-tube boilers.	
2. Kind of furnaces—Pulverized-fuel burning furnaces.	
3. Volume of combustion space, per boiler cubic feet	1,678
4. Water-heating surface, per boiler square feet	4,680
5. Superheating surface, per boiler (approximate) do	594
a. Type of superheater—Foster.	
6. Total heating surface, per boiler do	5,274
a. Ratio of water-heating surface to volume of combustion space	1 to 0.359
b. Ratio of total heating surface to volume of combustion space	1 to 0.318
Date, duration, etc.:	
7. Date—November 11–15, 1919.	
8. Duration hours	99
a. Boiler-hours	495
9. Kind and size of coal—Mixture of 50 per cent Youghiogheny screenings and 50 per cent eastern Kentucky screenings.	
10. Steam pressure by gage, per square inch pounds	167.8
a. Barometric pressure inches of mercury	29.49
11. Steam pressure, absolute, per square inch pounds	182.3

Date, duration, etc.—Continued.	
12. Temperature of steam leaving superheaters ° F	441.9
a. Normal temperature saturated steam at above pressure, ° F	374.2
13. Temperature of feed water entering boiler ° F	156.3
14. Temperature of escaping gases do	496.6
a. Temperature of flame above hearth do	2,767
b. Temperature of furnace bottoms do	2,180
15. Draft under damper inches of water	0.173
16. Draft in furnaces do	0.031
17 Air pressure at blower do	6.36
a. Pressure of air mixing with coal at screw feeder do	6.00
b. Pressure of air and coal mixture above burner outlet, inches of water	1.00
18. State of weather—	
a. Temperature outside ° F	28
b. Relative humidity per cent	72
c. Room temperature ° F	75.7
Quality of steam:	
19. Number of degrees of superheat	67.7
Total quantities:	
20. Total weight of coal, as received pounds	958,074
21. Percentage of moisture	7.23
22. Total weight of coal, as fired pounds	894,800
23. Percentage of moisture	0.67
24. Total weight of dry coal pounds	888,805
25. Slag, ash, and refuse (dry, laboratory basis) per cent	11.90
A. Withdrawn from furnace bottom, total pounds	9,770
a. Withdrawn from furnace bottom, per boiler, pounds per hour	19.8
B. Withdrawn from tubes, flues, and combustion chamber, total pounds	9,862
b. Withdrawn from tubes, flues, and combustion chamber, per boiler pounds per hour	20.0
C. Blown away with gases (difference between laboratory and actual weight) pounds	87,549
c. Blown away with gases, per boiler, pounds per hour	176.8
D. Percentage of total lost with gases	82.8
E. Percentage of combustible in slag and ash recovered (combined analysis) per cent	6.9
26. Total combustible burned pounds	781,622
27. Total weight of water fed to boiler do	8,249,536
28. Factor of evaporation	1.1473
29. Total equivalent evaporation from and at 212° F pounds	9,464,693
Hourly quantities and rates:	
30. Dry coal per hour pounds	8,978
a. Dry coal per hour, per boiler do	1,796
31. Water evaporated per hour, actual do	83,328
a. Water evaporated per hour, per boiler, actual do	16,666
32. Equivalent evaporation per hour from and at 212° F do	95,603
a. Equivalent evaporation per hour, per boiler, from and at 212° F pounds	19,121
33. Equivalent evaporation per hour from and at 212° F. per square foot of water heating surface pounds	4.09
Capacity:	
34. Evaporation per hour, from and at 212° F., per boiler do	19,121
a. Boiler horsepower developed	554
35. Rated capacity per hour, from and at 212° F., per boiler pounds	16,146
a. Rated boiler horsepower	468
36. Percentage of rated capacity developed	118.4
37. Water fed per pound of coal, as received pounds	8.611
38. Water fed per pound of coal, as fired do	9.219
39. Water evaporated per pound of coal, dry do	9,282
40. Water evaporated per pound of combustible do	10.554

Capacity—Continued.	
41. Equivalent evaporation from and at 212° F. per pound of coal, as received ... pounds	9.879
42. Equivalent evaporation from and at 212° F., per pound of coal, as fired ... pounds	10.577
43. Equivalent evaporation from and at 212° F., per pound of coal dry ... pounds	10.649
44. Equivalent evaporation from and at 212° F., per pound of combustible ... pounds	12.109
Gross efficiencies:	
45. Calorific value of 1 pound of dry coal by calorimeter ... B. t. u.	12,810
46. Gross efficiency of boiler and furnace ... per cent	80.67
47. Efficiency of furnace ... do	99.79
Smoke data:	
48. See notes.	
Analyses of flue gases:	
49. Carbon dioxide ... do	12.26
50. Oxygen ... do	6.82
51. Carbon monoxide ... do	0.00

Analyses of coal:	As received.	As fired.	Dry.
52. Proximate—			
a. Moisture	7.23	0.67	--------
b. Volatile	32.13	34.40	34.63
c. Fixed carbon	49.60	53.11	53.47
d. Ash	11.04	11.82	11.90
	100.00	100.00	100.00

e. Sulphur, separately determined, referred to dry coal	1.62
53. Ultimate analyses—	
a. Carbon	73.57
b. Hydrogen	4.35
c. Oxygen	7.22
d. Nitrogen	1.34
e. Sulphur	1.62
f. Ash	11.90
	100.00

54. Analyses of—	Slag.	Ash retained.	Ash lost.
a. Moisture	0.00	13.00	
b. Combustible	0.59	13.00	Unknown.
c. Earthy matter	99.41	86.24	---------

Heat balance:	B. t. u.	Per cent.
a. Heat absorbed by the boiler	10,334	80.67
b. Loss due to evaporation of moisture in coal	8	0.06
c. Loss due to heat carried away by steam formed by the burning of hydrogen	486	3.79
d. Loss due to heat carried away in dry flue gases	1,527	11.93
e. Loss due to carbon monoxide	0	0.00
f. Loss due to combustible in ash	23	0.18
g. Loss due to heating moisture in air	39	0.30
h. Loss due to combustible carried away with flue gases, unconsumed hydrogen, hydrocarbons, radiation, and unaccounted for	393	3.07
i. Total calorific value of 1 pound of dry coal	12,810	--------
j. Total per cent		100.00

ANALYSES OF LOSSES AS SHOWN BY HEAT BALANCE.

LOSSES DUE TO EVAPORATION OF MOISTURE IN COAL.

These losses when expressed in a heat balance are dependent upon the quantity of moisture in the coal as fired, and ordinarily are independent of installation. Since in this case the coal was dried to 0.67 of 1 per cent of moisture, only a small loss, 0.06 of 1 per cent, due to the presence of moisture, occurred in combustion. The actual loss resulting from this factor is set forth in the table showing net boiler efficiency. It exceeds the minimum theoretical loss, dependent upon quantity of moisture that is always assumed in a heat balance, and which in this case would be (if coal had not been dried) equal to 0.6 per cent. The efficiency of the drier referred to on this basis is only 40 per cent.

LOSSES DUE TO HYDROGEN IN COAL.

These losses are independent of the installation.

LOSSES DUE TO HEAT CARRIED AWAY IN THE DRY FLUE GASES.

In view of the fact that the boilers were operated at the most economical rating, these losses were higher than expected. To account for them, it must be considered that up to the time of the test three of the five boilers had been operated about 300 hours since receiving a partial wash, and that each of the five had been in service 600 hours since the last full cleaning. This condition, together with the fact that 90 per cent of the feed water was untreated, reduced the heat absorption of the boilers appreciably. One of the boilers examined subsequent to the test showed deposits sufficient to affect efficiency.

Further losses under this heading may be attributed to an excess of air, not needed for proper combustion, but essential to the control of furnace temperatures and the prevention of excessive slagging on the hearth and furnace bottom, as is explained under "Boiler-room operating conditions."

LOSSES DUE TO CARBON MONOXIDE.

These were not measurable, since few gas analyses showed CO present and then only in traces.

LOSSES DUE TO COMBUSTIBLE IN ASH.

This loss is very small and denotes the completeness of combustion. Since only 17.2 per cent of the total ash (laboratory basis) was recovered, and half of that—the slag—contained no combustible, it might be assumed that, with the 82.8 per cent of ash that escaped with the flue gases, a large amount of combustible was carried away. On the other hand, it is more likely that, since the unaccounted for losses are less than in the average boiler test, most of the unburned combustible lodged in the combustion chamber and was without doubt the heavier particles.

LOSSES DUE TO COMBUSTIBLE CARRIED AWAY WITH FLUE GASES, UNCONSUMED HYDROGEN AND HYDROCARBONS, TO RADIATION, AND UNACCOUNTED FOR.

These losses are not great comparatively and are not wholly preventable. Radiation was reduced to a minimum by properly covering and lagging boilers.

Analysis of coal received during test.

No.	Proximate analysis.				B. t. u. per pound dry coal.	B. t. u. per pound as received.	Ultimate analysis of dry coal.					
	Moisture.	Dry coal.					C	H	O	N	S	Ash.
		Fixed carbon.	Volatile matter.	Ash.								
1	8.3	55.71	33.47	10.82	13,003	11,924	76.88	3.04	5.73	1.36	1.38	11.61
2	4.2	55.89	32.10	12.01	12,974	12,389						
3	4.9	55.72	33.28	12.00	12,988	12,352						
4	6.6	56.14	33.46	10.40	13,539	12,876	72.42	4.73	7.35	1.45	1.63	12.42
5	4.9	54.63	31.74	13.63	12,729	11,889						
6	9.7	51.37	35.41	13.22	12,515	11,301						
7	10.0	52.11	35.50	12.39	12,551	11,296	72.16	4.53	8.07	1.21	1.72	12.31
8	8.8	52.74	34.74	12.52	12,589	11,481						
9	9.1	52.43	35.54	12.03	12,573	11,429						
10	7.3	53.02	35.93	11.05	12,983	12,035	72.85	5.10	7.71	1.35	1.74	11.25
11	5.9	51.49	37.17	11.34	12,601	11,858						
12	7.0	51.44	37.21	11.35	12,673	11,786						
Average.	7.23	53.47	34.63	11.90	12,810	11,884	73.57	4.35	7.22	1.34	1.62	11.90

Test of fuel-pulverizing equipment.

ONEIDA STREET POWER PLANT, DECEMBER 11–15, 1919.

General conditions—average temperatures, etc.:		
1. Temperatures of air entering drier furnace	°F	93.8
2. Temperature of gases leaving drier	°F	181.8
3. Humidity of outside air	per cent	72.0
4. Draft through drier	inches of water	0.77
5. Vacuum in pulverizers, inches of water, No. 1, 5.0; No. 2, 5.16; average		5.08
Coal temperatures, moistures and fineness:		
6. Temperature of coal entering drier	°F	88.2
7. Temperature of coal leaving drier	°F	237.9
8. Temperature of coal leaving pulverizers	°F	169.7
9. Moisture of coal entering drier	per cent	5.59
10. Moisture of coal leaving drier	do	1.61
11. Moisture of coal leaving pulverizers	do	1.03
12. Fineness of pulverized coal, 200-mesh	do	81.30
13. Fineness of pulverized coal, 90-mesh	do	97.40
14. Fineness of pulverized coal, 80-mesh	do	99.30
15. Fineness of pulverized coal, 60-mesh	do	100.00

TOTAL AND HOURLY QUANTITIES.

Crusher:		
16. Total coal crushed, as received at crusher	tons	479.0
17. Coal crushed per hour, as received	do	17.5
Drier:		
18. Total coal dried, as received	do	471.2
19. Total coal dried, per hour of drier operation, as received	do	6.7
Pulverizer:		
20. Total coal pulverized, coal from drier	do	447.4
21. Capacity of pulverizer per hour	do	5.0
22. Coal pulverized per hour, dry, total	do	7.90
23. Coal pulverized per hour, dry, per mill	do	3.95
24. Coal pulverized per hour, per mill, as received at plant	do	4.23
Consumption for lubricants:		
25. Total grease consumed by elevators and conveyers	pounds	6.0
26. Grease per ton of coal, as received	do	.012
27. Total grease consumed by pulverizers	do	13.0
28. Grease consumed per pulverizer per hour of operation	do	.112
29. Grease consumed per pulverizer per ton of coal pulverized,	pounds	.028

Consumption for lubricants—Continued.	
30. Grease consumed on all equipment per ton of coal, as received, pounds	0.040
31. Total oil consumed on all equipment quarts	17.0
32. Oil consumed per ton of coal as received do	.036
Electric energy and coal consumption:	
33. Total energy consumed by crusher and green coal elevator, kilowatt hour	220.0
34. Energy per ton of coal, as received do	.47
35. Total energy consumed by drier do	735
36. Energy per ton of coal, as received, consumed by drier do	1.53
37. Total energy consumed by pulverizers (fan and drive motor), kilowatt hour	8,010
38. Motor input per hour—	
Mill No. 1 horsepower	93.8
Mill No. 2 do	90.2
39. Energy consumed by pulverizer per ton of coal, as received, kilowatt hour	16.72
40. Energy consumed by pulverizer per ton of coal, as pulverized, kilowatt hour	17.90
41. Total energy consumed by pulverized coal conveyers, feeder blowers, and feeders kilowatt hour	1,789
42. Total energy consumed by pulverized coal conveyers, feeder blowers, and feeders per ton of coal, as received kw. hr	3.73
43. Total energy consumed by pulverized coal conveyers, feeder blowers, and feeders per ton of coal, as fired kilowatt hour	4.00
44. Total energy consumed by all equipment on preparation and firing of pulverized fuel kilowatt hour	10,754
45. Energy per ton of coal, as received, grand total do	22.45
46. Coal equivalent for this energy at 1.5 pounds coal per kilowatt hour pounds	33.68
47. Total coal used in drier furnace do	12,291
48. Coal per ton of fuel dried (based on coal as received) do	25.66
49. Total coal and equivalent consumed in preparation and firing of 1 ton of pulverized fuel pounds	59.34
Cost of preparation—operation and maintenance:	
50. Cost of labor per ton of coal—operation	$0.143
51. Cost of fuel for drying, plus fuel for electric energy—coal at $4 per ton	$0.119
52. Cost of lubricants per ton of coal—grease at 9 cents per pound	$0.007
53. Cost of labor per ton of coal—maintenance	$0.036
54. Cost of material—maintenance	$0.020
55. Total cost per ton of coal	$0.325

Moisture in coal at various points along line of fuel travel—Fineness of coal at pulverizer outlets.

No.	Moisture in coal.					Fineness at pulverizer outlets.			
	As received at plant.	At drier inlet.	At drier outlet.	At pulverizer outlet.	At burners.	200 mesh.	100 mesh.	80 mesh.	60 mesh.
1	8.3	4.9	0.8	0.5	0.5	82.8	98.9	99.8	100
2	4.2	4.2	1.2	0.6	1.0	84.0	97.5	99.9	100
3	4.9	4.2	0.9	0.5	0.6	82.5	98.1	99.6	100
4	6.6	6.3	1.2	0.5	0.4	80.5	98.0	99.5	100
5	4.9	4.0	1.1	0.4	0.4	79.6	96.0	98.8	100
6	9.7	8.1	1.2	0.8	0.5	80.0	98.0	99.2	100
7	10.0	8.2	3.2	2.3	1.4	80.0	96.0	99.1	100
8	8.8	6.6	2.5	1.6	0.9	83.2	97.6	99.2	100
9	9.1	6.1	2.0	1.5	0.6	79.3	96.3	99.1	100
10	7.3	4.0	1.3	1.2	0.6	81.2	97.4	99.1	100
11	5.9	4.0	1.0	1.0	0.4	80.1	97.4	99.1	100
12	7.0	6.5	2.9	1.5	0.7	82.0	97.5	99.4	100
Average	7.23	5.59	1.61	1.03	0.67	81.3	97.4	99.3	100

NOTE.—Item 50 is based on the labor required to pulverize coal sufficient for five boilers through a 24-hour run per day.

Summary sheet.

Electric Energy and Fuel Consumption Per Ton of Coal Pulverized.

1.	Energy consumed by conveyers, crushers, elevators, driers, blowers, and feeders	kilowatt hours	5.73
2.	Energy consumed by pulverizer	do	16.72
3.	Total energy	do	22.45
4.	Coal equivalent, at 1.5 pounds per kilowatt	pounds	33.68
5.	Coal consumed in drier furnace per ton of fuel dried	do	25.66
6.	Total coal and equivalent	do	59.34
7.	Gross efficiency, less deductions for total coal and equivalent, item 6		78.36

Cost of Fuel Preparation, Firing, and Ash Disposal.

8.	Labor, coal preparation		$0.143
9.	Labor, firing		$0.112
10.	Labor, ash removal		$0.025
11.	Drier fuel, coal, at $4 per ton		$0.051
12.	Electric energy, coal per kilowatt hour, at 1.5 pounds		$0.068
13.	Maintenance, manufacturer's estimate: Labor, at 3.6 cents; material, at 2 cents; lubricants, at 0.7 cent		$0.063
14.	Total cost of fuel preparation, firing, ash disposal, and maintenance		$0.462
15.	Price of coal as purchased	per ton	$4.000
16.	Total cost		$4.462

Efficiency.

17.	Actual gross efficiency	per cent	80.67
18.	Net efficiency, after all incidental costs have been accounted for	do	72.32

CONCLUSIONS.

The conclusions can be best drawn from a comparison between the pulverized-fuel-burning equipment and mechanical stokers.

Comparison of costs and net efficiencies.

Electric Energy and Fuel Consumption Per Ton of Coal Burned.

		Pulverized-fuel system.	Modern stoker.
Energy consumed by conveyers, crusher, elevators, driers, fans and feeders	kw. h.	5.73	[1] 10.94
Energy consumed by pulverizer	do	16.72	....
Total energy	do	22.45	10.94
Coal equivalent at 1.5 pounds per kw. h	pound	33.68	16.41
Coal consumed in drier furnace	do	25.66	....
Total coal and equivalent	do	59.34	16.41

Cost of Fuel Preparation, Firing, and Ash Disposal.

Labor—coal preparation		$0.143	$0.000
Labor—firing		.112	.140
Labor—ash removal (in plant)		.025	.064
Drier fuel—coal at $4 per ton		.051	.000
Electric energy—coal per kw. h. at 1.5 pound		.068	.033
Maintenance: Labor, at $0.36; material, at $0.020, manufacturer's estimate; lubricants, at $0.007		.063	[2] .007
Total cost of fuel preparation, firing, ash disposal, and maintenance		.462	.334
Price of coal as purchased	per ton	4.000	4.000
Total cost	do	4.462	4.334
Cost of coal in powdered-fuel system over modern stoker	do	.128	....

Efficiency.

Actual gross efficiency	per cent	80.67	76.80
Net efficiency after all incidental costs have been accounted for	do	72.32	70.88
Difference in favor of pulverized-fuel system	do	1.44	....

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[1] Stokers and blowers,.

[2] Labor at $0.046; material at $0.049; lubricants at $0.002.

An extract from the remarks of Mr. Paul W. Thompson, technical engineer of power plants, Detroit Edison Co., which appeared in the same paper, follows:

The boiler-room operation was indeed much simpler than is obtained with a stoker installation. The rate of steaming of the boiler is controlled by varying the speed of the feeder motor and adjusting the damper to take care of the different quantity of flue gas. It is unnecessary to look into the furnace at any frequent interval, as is the case when firing with stokers and where holes in the fire or heavy spots must be corrected. In fact, when once the feeder speed is set to give a certain rate of steaming of the boiler there seems to be no reason why this rating could not be maintained continuously as far as the furnace is concerned without it being necessary to make any changes whatever. Variations in the kind and quality of fuel burned seemed to have no effect on the operation, except that when feeding at a constant quantity the rating of the boiler varied with the heating value of the coal. At one time during the test Youghiogheny was used, which coal had a higher heating value, higher volatile content, less ash, and less sulphur than the mixture of Youghiogheny and Kentucky coal which was used throughout the remainder of the test.

Losses which are inherent in stoker practice, such as breakdowns in the stoker itself, breaking up clinkers, loosening clinkers, continually watching the fire to maintain correct and uniform thickness, watching the gas passes of the boiler to note any large sparks which indicate a carrying away of combustible, dumping, and the many other operations that are necessary in stoker operation, are eliminated. In other words, efficient combustion is obtained at all times without continual supervision by an experienced operator, and from the standpoint of reliability of operation the odds are in favor of the pulverized fuel. This is an item for serious consideration in plants designed with 4.5-kw. capacity or more per installed boiler horsepower, where the losing of a boiler due to stoker trouble at the time of maximum load on the station might seriously overload the remaining boilers or make it necessary to drop a portion of the load on the plant.

The handling of the ash resulting from combustion of the pulverized fuel is a very simple matter due to the very small quantity which is deposited in the furnace. It is in the form of a very fine impalpable powder, which during the test was removed twice each 24 hours. On several occasions during the first and second days of the test slagging occurred in a furnace due to not admitting a sufficient quantity of air. The direct cause of this was the overanxiousness on the part of the men conducting the test to obtain a higher per cent of CO_2 in the flue gas, and the reduction in the excess air permitted the furnace temperature to rise to a point where slagging occurred. The removing of this slag from the bottom or floor of the furnace presented more difficulty than is usually experienced in removing the refuse from the ash hopper of a stoker-fired boiler. This slag had to be broken up and pulled out before it fused to the brick lining of the furnace. It appeared to the writer that this formation of slag could have been almost entirely eliminated by a more frequent inspection of the floor of the furnace and the admitting of more air through the openings in the front of the furnace if it was found that slag was beginning to form. Even at times of removing this slag it was possible to maintain the rating on the boiler by increasing the coal feed, which, however, resulted in a decreased efficiency during this time amounting to about 45 mniutes in 24 hours for each boiler. A large portion of the ash resulting from combustion is carried on through the passes of the boiler and out of the stack. Owing to the fineness of this ash it apparently carried a considerable distance even in a moderate wind before being precipitated. Throughout the test there was a moderate wind blowing, probably between 4 and 8 miles per hour, and the writer was unable to find any noticeable deposit of ash from blowing the boiler tubes, which was done three times a day, requiring about 20 minutes per boiler for each blow. No noticeable precipitation of ash could be found in the streets. At no time during the test was there any tendency for slag to form on the tubes of the boiler.

Strictly speaking, there is no such thing as a banked boiler when using pulverized fuel, as all that is necessary when it is desired to cut out a boiler is to shut off the coal feed and close all the dampers and auxiliary air inlets to the furnace. In this way the Milwaukee Electric Railway & Light Co. has found by test that it is possible to hold the boiler up to pressure for about 10 hours by the radiant heat stored up in the furnace and boiler setting, which is gradually absorbed by the boiler. The loss which occurs, and which can be compared to the banking loss in a stoker-fired boiler, is the heat which is radiated from the boiler and setting, and equivalent in amount to that required to heat up the boiler and setting again to the temperature attained when steaming. In a plant where the ratio of boiler hours to boiler steaming hours averages 43 per cent or greater, which corresponds to an average daily plant load factor of 67 per cent, the saving resulting from the use of pulverized fuel is worth considering. Assuming 1.2 pounds coal consumed per b. hp. banking hour in a plant equipped with underfeed stokers, this loss amounts to about 1.5 per cent, which in a pulverized-fuel burning plant should easily be reduced to one-half this figure, resulting in a net saving of 0.7 per cent on this one item alone.

The conveying and preparation of pulverized fuel presents a somewhat more complex problem, although the present equipment in the Oneida Street station is operating satisfactorily and during the test operated without any serious interruptions. Moisture in the pulverized fuel caused by sweating on the inside of the pulverized-fuel bins resulted in some feeder troubles, but this was only a temporary condition and was overcome by closing the windows just above the bins, stopping the cold air from blowing directly on them. One of the feeder pipes between the bin and the furnace became practically plugged up, due to a paper-composition gasket becoming lodged in the pipe just above the burner. The boiler on which this occurred was operated for at least 24 hours at the desired rating by increasing the feeder speed on the other burner until the trouble was located and removed. During this period the efficiency of combustion was undoubtedly below the average, as the coal which did come through the plugged feeder was not fed in with the correct quantity of air, due to the obstruction in the feeder pipe. No trouble was experienced with the drier or pulverizing mills at any time during the test.

The writer does not believe that under test conditions over a period of constant boiler rating the efficiency obtained with the use of pulverized fuel will exceed that which has been obtained from the best stoker practice under similar operating conditions. However, under normal operation it is believed that the elimination of the many variable conditions entering into stoker operation will result in higher efficiency for the pulverized-fuel installation. Over-all efficiencies of boiler, furnace, and grate as high as 82 or 83 per cent have been obtained on test with stoker-fired boilers, but normal operation day in and day out seldom exceed 76 per cent in the very best practice where highly skilled help is employed in supervising the boiler-room operation. The gross over-all efficiency of boiler and furnace of 79.6 per cent as obtained from the results of this test would unquestionably have been higher had the boiler been cleaned prior to the test. As a matter of fact, each boiler had been in operation prior to the test approximately 600 hours since being entirely cleaned, including the first four rows.

Inasmuch as the boiler-feed water consists of approximately 90 per cent untreated water, the scale formation in the tubes would tend to give a lower efficiency than would have been obtained with clean boilers. At the time of writing this report it has not been possible to open up the boilers and ascertain the exact amount of scale on the tubes. This, however, will be done within a few days, and a statement made regarding it in the final report of the test.

Certainly the results obtained in the pulverized-fuel burning plant as a whole, where the equipment was installed and made to fit into an old plant originally equipped with Jones stokers, are encouraging enough to warrant serious consideration of the use of this kind of fuel in stations to be built in the future. There are many improvements which can be made in the design of a new plant, especially in the design of furnace, location of drying and coal-pulverizing equipment, method of coal handling, drying, and pulverizing, method of ash handling, slag prevention, possibility of using waste gases for the drying of fuel, all of which will have an effect on the efficiency which may ultimately be obtained. The application of pulverized fuel to central generating stations has been in use to a very limited extent for several years, but there still remains much experimental work to be done before we can hope to exhaust all the possibilities for increased efficiency and bring it to as high a state of development as is the stoker at the present time.

NEW POWDERED-COAL BOILER PLANT AT MILWAUKEE.

The Milwaukee Electric Railway & Light Co. is constructing a new power station at Lakeside. At this plant there will be eight 1,300-horsepower boilers all fired with powdered coal. The Pulverized Fuel Equipment Co. will equip six of these boilers with three vertical duplex burners per boiler. The Fuller Engineering Co. will equip the remaining two boilers with four horizontal burners per boiler. The pulverized coal at this plant will be transported by the Fuller Kinyon pump.

BOILER FOR BURNING POWDERED ANTHRACITE.

Figure 32 illustrates a boiler furnace designed by M. A. Hanna & Co., of Cleveland, Ohio, for burning anthracite slush or silt, which has been wasted hitherto. Blue prints of this boiler and particulars of tests and experiments with powdered anthracite were obtained through the kindness of Mr. R. S. Walker, consulting engineer to M. A. Hanna & Co. The boiler is installed in the power plant of the Lytle Coal Co.

M. A. Hanna & Co. had many difficulties to overcome. By diligent research on a boiler at Lykens they evolved a successful method of burning powdered anthracite. Originally they used a horizontal burner and injected the coal beneath an arch. With this arrangement the coal burned successfully, but the ash fused, solidified, and was removed only after drilling and blasting. Later, the coal was spread into a stream, forced against a water-cooled deflector, and ignited by the radiated heat from the flame itself instead of igniting from the hot brickwork. The experiments showed, too, the necessity of lengthening the path of the flame as the rate of combustion increases, so that the coal may burn completely before reaching the tubes.

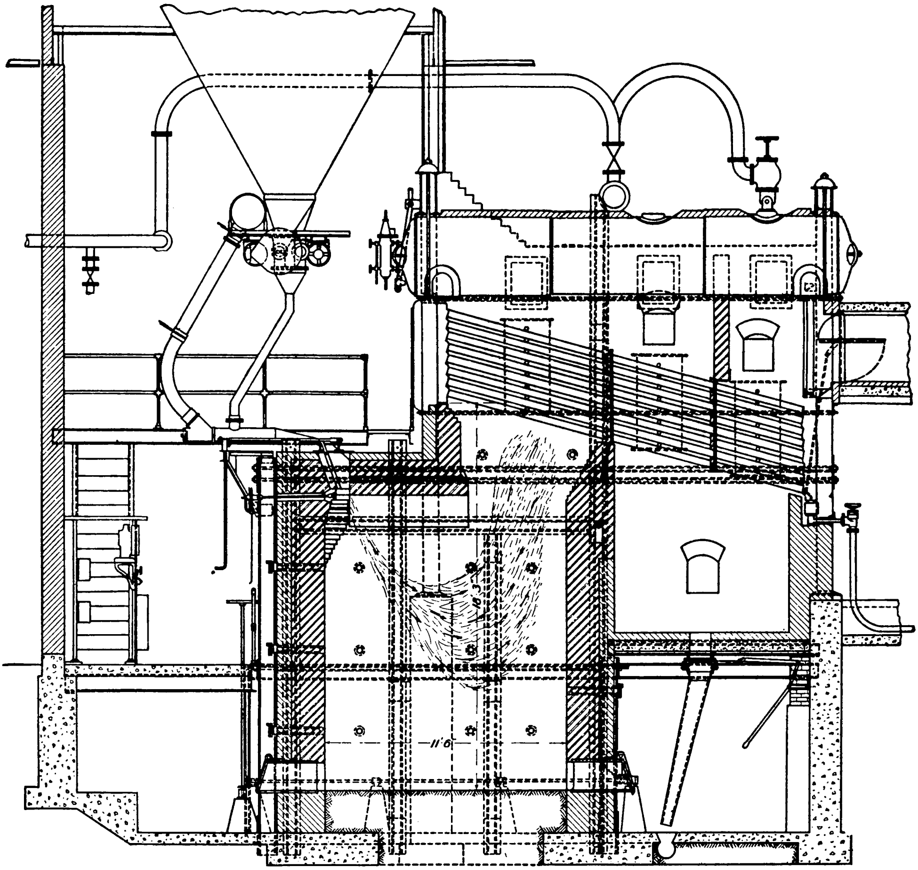

FIGURE 32.—Pulverized-anthracite fired boiler for the Lytle Coal Co.

Later the water-cooled deflector was abandoned and the design of furnace deflector plate and feeder evolved, as shown in Figure 32. The pulverized coal is removed from the hopper by two variable-speed screws and flows horizontally in two streams which converge; it falls through a 5-inch pipe into an 8-inch pipe, where it meets a blast of air from the air main. This mixture of coal and air passes along the mixer pipe and through the burner nozzle into the furnace, The burner nozzle is shaped to give a flattened fan-shaped current of air and coal. On its tip is a plate which may be adjusted, by a rod, screw, and wheel, to change the direction of the entering stream of air and coal. By means of two levers, operating two butterfly valves, air may be permitted to flow into the furnace as required on the inner and outer side of the coal and primary air jet. An additional air supply is drawn in at the bottom and rear of the combustion chamber. Peepholes in the walls of the combustion chamber are provided to enable the fireman to observe the position, steadiness, and color of the flame. At the Lykens boiler plant most of the ash passes up the stack, but appears to be so widely dispersed as not to be even detected.

The following table is extracted from the results of trials carried out by M. A. Hanna & Co. at the pulverized-fuel plant at Lykens. The first three tests were carried out in April, 1919, and the last in August, 1919. The boiler is a Babcock & Wilcox three-pass boiler with 2,357 square feet of heating surface. The fuel used in the trial marked "A" was Dover, Ohio, coke breeze; that in the trial marked "B" was Nanticoke slush; that in the trial marked "C" was Lykens seam dirt.

Results of tests at the Lykens boiler plant.

Trial.	A	B	C
Duration of trial.....hours..	6.2	5.92	4.28
Steam pressure, per square inch.....pounds..	117	111	112
Draft in flue behind boiler.....inch water..	0.329	0.327	0.388
Draft in furnace at bottom.....do....	0.196	0.186	0.172
Draft in furnace at top.....do....	0.054	0.044	0.048
Draft in boiler at top of first pass.....do....	0.049	0.033	0.036
Draft in boiler at bottom of second pass.....do....	0.111	0.100	0.104
Draft in boiler at top of third pass.....do....	0.116	0.110	0.124
Blast at rise on pipe.....do....	1.71	1.99	2.02
Flue-gas temperature.....degrees Fahrenheit..	562	574	617
Fuel, proximate analysis.			
Moisture.....per cent..	0.99	0.98	0.60
Volatile matter.....do....	9.89	7.17	8.09
Fixed carbon.....do....	73.76	64.71	80.11
Ash.....do....	15.36	27.14	11.20
Calorific value, per pound dry coal.....tB. u..	12,190	10,008	13,407
Fuel size.			
Through 100-mesh.....per cent..	98.3	88.5	97.9
Through 200-mesh.....do....	92.6	80.8	89.5
Density of fuel, per cubic foot.....pounds..	57.5	54.4	58.5
Proximate analysis of refuse from top of first pass.			
Volatile matter.....per cent..	2.04	1.70	2.40
Fixed carbon.....do....	12.48	20.90	9.12
Ash.....do....	85.48	77.40	88.48
Equivalent evaporation from and at 212° per square foot heating surface, per hour.....pounds..	4.44	3.83	4.34
Equivalent evaporation per pound of dry fuel.....do....	9.49	7.20	11.02
Carbon dioxide, by volume, at top of first pass.....per cent..	11.96	13.1	10.8
Combined efficiency of furnace and boiler.....do....	75.5	69.8	79.7

The carbon dioxide content of the flue gas in these trials was not as high as is anticipated commonly with powdered-coal fired boilers, but was as high as that obtained in practice; and Mr. Walker, in a letter to the writer, says that since the last of these tests was run the excess air has been reduced by directing the flame against the back wall by means of the deflector, which prevents the air entering through the air inlet at the back of the furnace from passing up the back wall unused. Since the flame has been directed toward the back wall the flue gas has been found to contain 16 per cent of carbon dioxide continuously. In addition to 6,300-horsepower boilers at the Lytle power plant, M. A. Hanna & Co. are installing four 500-horsepower Edgemoor boilers for the Short Mountain colliery at Lykens, Pa., and for the Pennsylvania colliery at Shamokin.

INSTALLATION AT PARSONS, KANS.

Figure 33 illustrates a powdered-coal fired boiler equipment designed by the Fuller Engineering Co. This company has designed several pulverized-fuel boiler plants.

It prefers the horizontal burner, as shown previously in Figure 16 (p. 36). One of its earliest boiler installations was at the shops of the Missouri, Kansas & Texas Railway Co. at Parsons, Kans.

The boilers are O'Brien water-tube boilers. After replacing the horizontal baffles, on which ash accumulated, with vertical baffles and enlarging and remodeling the furnaces, there has been little trouble in operating these boilers successfully.

Owing to the decrease in the price of oil and the increase in the price of coal and of labor, these boilers are now using oil fuel. Several interesting trials were made with various powdered fuels at Parsons, and extracts from the results are shown below. It was found unnecessary at this plant to dry Texas lignite to a moisture content of less than 6 per cent, and lignite containing 17 per cent moisture has been burned. But the moisture content of lignite is so high that either a large drier must be used or the expedient adopted of passing the lignite twice through the drier. At Parsons the lignite was passed through the drier twice.

Extracts from results of tests on boilers at the Missouri, Kansas & Texas Railway Co. shops at Parsons, Kans., follow:

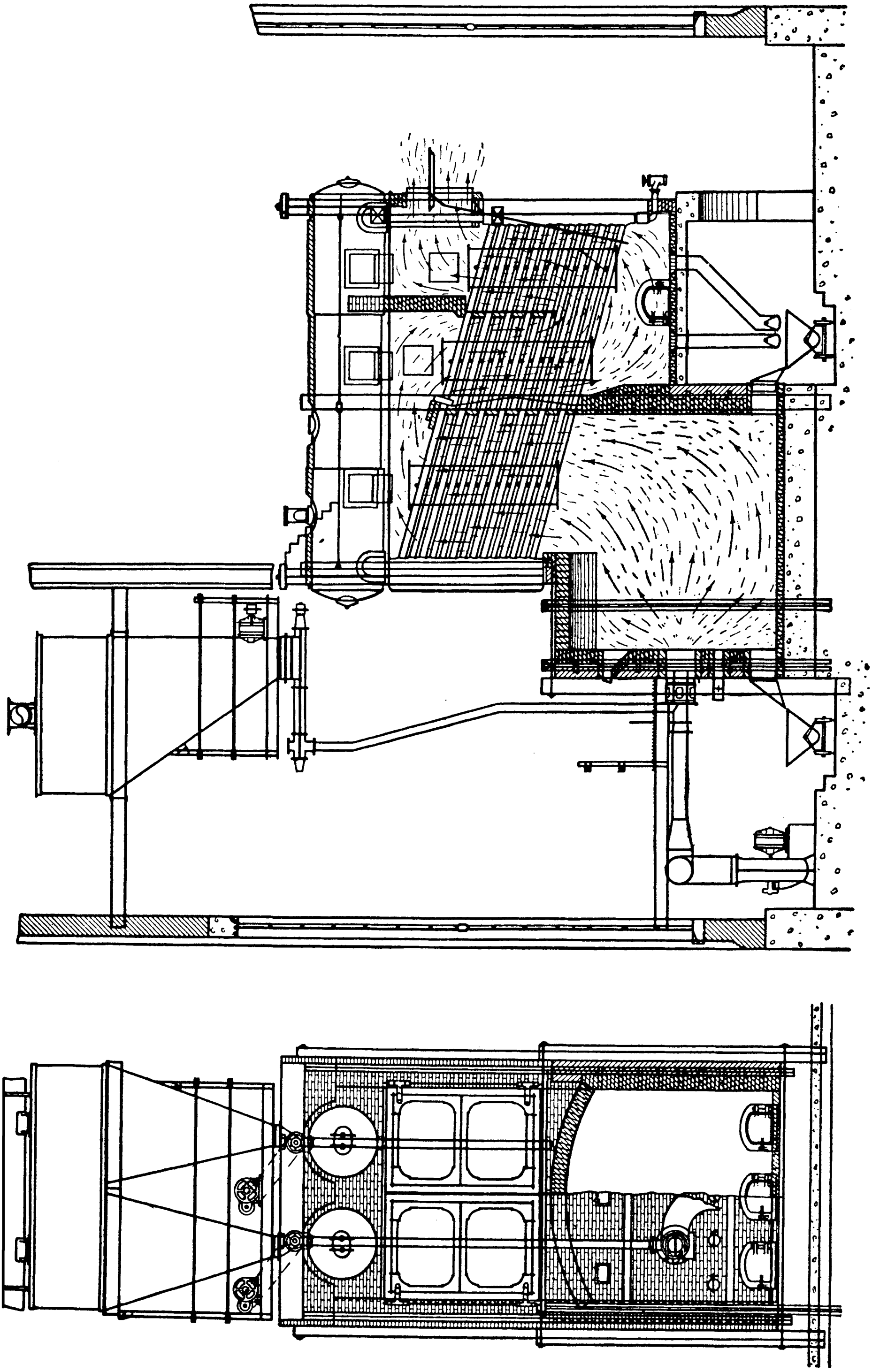

FIGURE 33.—500-horsepower Babcock & Wilcox boiler, arranged for pulverized-coal firing. Fuller Engineering Co.

Tests on boilers in railroad shops, Parsons, Kans.

No. of test.	Kind of coal.	Rated boiler horse-power.	Duration of test-hours.		Steam pressure by gage, pounds.	Flue-gas analysis.				Proximate analysis of dry coal.			B. t. u. per pound dry coal.
			Hours.	Minutes.		CO_2 per cent.	O per cent.	CO per cent.	N per cent.	Volume per cent.	Fixed carbon.	Ash.	
1	Cherokee mineral slack	191	1	0	126	12	8	0	80	28	49	22	11,580
2	Texas lignite	191	2	4	127.4	10	10	5	79.5	42.5	32	9.5	11,250
3	McAllister	191	2	12	127	10	9.5	0	80.5	34.3	50.1	15.1	12,630
4	Texas lignite	191	1	30	118.1	10	[1] 11	0	79	47.1	35.4	10.5	11,250
5	.....do	191	1	13	130.6	12.5	[1] 8.5	0	79	47.1	35.4	10.5	11,250
6	Cherokee mineral slack	382	1	24	126	10	[1] 11	0	79	28.4	48.7	21.9	11,380
7	.....do	191	2	0	123	13.5	[1] 7.5	0	79	28.4	47.7	21.9	11,580
8	.....do	191	6	58	126.5	10.7	9.3	0	80	28.4	48.7	21.9	11,580
9	Texas lignite	191	4	30	137.5	14.75	5	0	81.16	61.52	24.72	13.76	10,675
10	Cherokee mineral slack	191	4	0	136	14.8	3.5	0	81.9	32.41	49.57	18.02	12,185
11	"Semianthracite"	191	3	30	135.5	15.8	3.5	0	81.6	22.29	59.94	17.77	12,625

[1] The sum of the carbon dioxide and oxygen contents in these trials is 21, which is too high unless the sole combustible constituent is pure carbon. The flue gas must have been analyzed incorrectly. J. B.

INSTALLATION AT VANCOUVER, FULLER ENGINEERING CO.

The Fuller Engineering Co. has equipped the boiler plant of the British Columbia sugar refinery at Vancouver, B. C., with an installation for powdered-coal firing. Three types of boiler are equipped for powdered-coal firing—the Badenhausen water-tube boiler, the Babcock & Wilcox water-tube boiler, and the horizontal return tubular fire-tube boiler.

Each boiler has one horizontal burner and a separate bin, feeder, and fan, except that two out of the three horizontal return tubular boilers have one fan between them.

An unwashed slack coal from Nanaimo is burned. It contains about 30 per cent ash and has a calorific value of 9,000 to 10,000 B. t. u. per pound.

Practically all the ash in the coal appears to pass up the stack, settle in the yard and on the refinery buildings, and is so much of a nuisance that the British Columbia Sugar Refinery Co. intends installing a centrifugal separator to remove the ash from the flue gases. The company has already tried removing the dust by precipitating it electrically; it was successful, but abandoned this electrical scheme because of the expense.

This plant has been in full operation since June, 1919, and no serious trouble has been encountered. Very little slag forms, and the ash which settles in the ash pit gathers in a honeycomb formation which is easily removed.

The tubes of the water-tube boilers are blown only once in 24 hours. But considerable difficulty is experienced in removing the ash from the interior of the tubes in the horizontal return tubular fire-tube boilers. When these tubes are blown from the back, the ash is blown out through the front of the boiler, and when blown from the front it is difficult to blow out the ash entirely, since the draft tends to carry the ash toward the front.

Two ports are provided in the front of the Badenhausen boilers, through which extra air may be drawn to supplement the air entering with the coal. No special supplementary air openings are provided in the other boilers, though air may be admitted through the old fire doors and ash-pit doors. The coal is dried in a drier by the combustion of powdered coal. Three Fuller 42-inch pulverizer mills pulverize the coal so that about 70 per cent of it will pass through a 200-mesh sieve.

The British Columbia Sugar Refinery Co. finds powdered coal highly suitable for an extremely irregular demand for steam, as it is possible to start up and shut down boiler units in a short time. The boilers are equipped so that oil may be substituted for coal in a short time when necessary. The British Columbia Sugar Refinery Co. supplied the writer with copies of two trials carried out on the Badenhausen boiler. During the first trial, which lasted six hours, the boiler evaporated water at the rate of about 20,000 pounds per hour, or one and a quarter times the normal steaming rate, and the flue-gas temperature was about 500° F.

Mr. D. Guthrie, the engineer, comments upon this test as follows:

> The boiler steamed steadily right through the test, being pushed as much as was deemed advisable. On shutting down, conditions in the furnace (re ashes and slag) were only slightly worse than usual. The CO_2, except when cleaning fires, remained about 13 per cent. Being without a determination of the calorific value of the coal, the efficiency can not be definitely ascertained, but it is probably high.

Ten days later another test of four hours' duration was run on a Badenhausen boiler at a higher rate of steaming. Unfortunately, no flue-gas analyses are given.

Summary of test of Badenhausen boiler.

Coal used, Nanaimo bituminous slack, Vancouver Island.

Weight of coal as fired (1.61 per cent moisture)	pounds	13, 870. 86
Weight of water fed to boiler	do	104, 357. 5
Temperature of water entering boiler	°F	185. 5
Temperature of water entering economizer	°F	93
Gage steam pressure per square inch	pounds	76. 6
Weight coal fired per hour	do	3, 467
Weight water per hour from and at 212°	do	27, 706
Water evaporated per pound of coal from and at 212°	do	7. 9
Rated horsepower of boiler		504
Horsepower developed		803. 09
Percentage of rated capacity		159. 3
Calorific value of coal	B. t. u.	10, 050
Combined boiler and furnace efficiency based on coal as fired, per cent		76. 27

INSTALLATIONS IN SEATTLE.

Largely through the pioneer work of Mr. W. J. Santmeyer, advisory engineer to the Puget Sound Traction, Light & Power Co., of Seattle; of the Pacific Coast Coal Co.; and of Mr. Ralph Galt, now manager of the Seattle office of the Fuller Engineering Co., many boilers are using powdered coal in Seattle.

The largest of the boiler plants is that of the Puget Sound Traction, Light & Power Co.'s steam-heating plant. Much of the information about this plant is taken from the Stone and Webster Journal for August, 1919. This plant contains 10 Babcock & Wilcox boilers, with an aggregate boiler horsepower of 4,100. They originally burned fuel oil, but now burn culm obtained from a dump consisting of washings from the Benton lignite mine. The lignite has a calorific value of about 9,000 B. t. u. per pound, 18 per cent of moisture, and 16 per cent of ash. The culm as received has a calorific value of about 7,300 B. t. u. per pound, 25 per cent of moisture, 28 per cent volatile matter, 26 per cent fixed carbon, and ·20 per cent ash. Occasionally for light loads sludge containing 25 to 35 per cent of ash is used.

The coal is dried in two driers and pulverized in four pulverizers. The pulverized coal is delivered to the bins by a 12-inch screw conveyer, which conveys it to four 12-inch conveyers, running at right angles to the main conveyer and between the main conveyer and the two bins above the boilers. Ten bins, each capable of holding about 15 tons of powdered coal, are placed over the boilers. The powdered coal is removed as required from the bottom of the bin by a variable-speed screw, which discharges it into a vertical pipe, where it meets a current of low-pressure air. This mixture of coal and air passes down to the burner. This burner is known as the Santmeyer burner. Two of these burners are shown in position in Figure 34, taken from a blue print given to the writer by Mr. W. J. Santmeyer. From Figure 34 it will be seen that the primary fuel and air supply meets an additional supply of low-pressure air at the elbow. A small supply of high-pressure air also enters the elbow to help control the flame.

These boilers have burned powdered coal during one heating season, but at the time of the writer's visit they were burning oil, and the powdered-coal equipment was being changed.

At this boiler plant it is intended to fuse the ash and remove it as slag, rather than blow the ash up the stack. The slag pit and slag conveyer are shown in Figure 34.

SMALL BOILERS FIRED WITH POWDERED COAL.

Several boiler installations in Seattle burn powdered coal bought and delivered in powdered form. In the company of Mr. Santmeyer the writer saw one of these powdered-coal fired boilers steaming at the high school. Figure 35 shows this system as developed in Seattle by Messrs. Santmeyer and Galt, and applied to a horizontal return tubular boiler in Stockton, Calif., for Mr. R. N. Buell.

At the Stockton plant (see Fig. 35) oil has now displaced powdered coal, though apparently there was no difficulty in using the powdered coal. The plant was operated as follows: The powdered coal is fed from the bin by a screw to a vertical 3-inch pipe, the top of which is open. The coal falls down this pipe to the **T**, where a jet of air sucks in the coal and a supply of air from the open top of the vertical pipe. The air jet is produced by a positive blower. The speed of the coal-feed screw is changed by moving a friction pulley, driven by the motor, across a disk keyed to the screw shaft.

The mixture of air and coal passes to the furnace through a 3-inch pipe, which on reaching the furnace projects into a larger

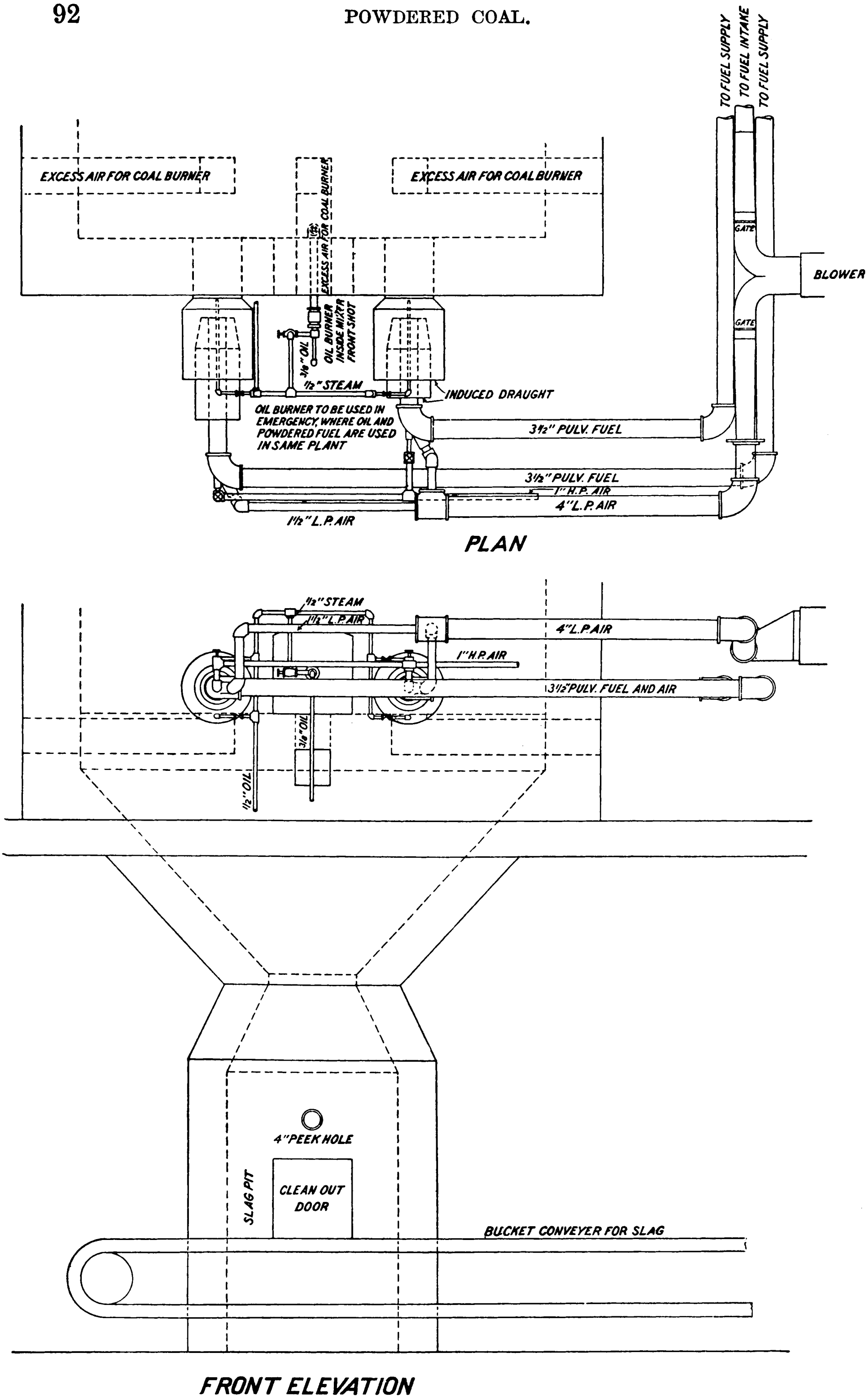

FIGURE 34.—General arrangement of burners and other apparatus for pulverized-coal firing, designed by W. J. Santmeyer.

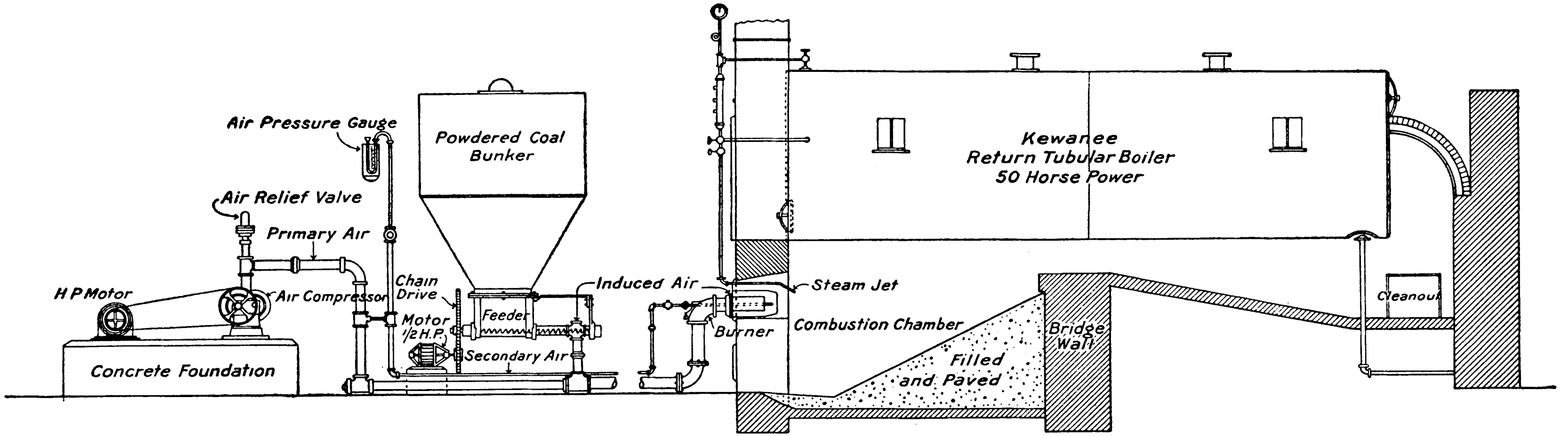

Figure 35.—System for burning powdered coal beneath small boilers used by Mr. R. N. Buell at Stockton, Calif. This system has been developed in Seattle by Messrs. Santmeyer and Gault, where the coal is delivered already pulverized.

pipe. An additional air current is drawn into the furnace between these pipes, and, further, a small volume of higher-pressure air enters as shown through a small ¾-inch pipe, which passes through the elbow and inner pipe into the furnace. It is used to adjust the position of the flame of burning coal in the furnace. These small systems have proved a good means of substituting low-grade coal for oil in Seattle. Apparently, there is some difficulty with this type of installation in feeding the coal for low rates of steaming. At one plant at Seattle the engineer, at the time of the writer's visit, gave this reason for using oil when little steam was required.

ERIE CITY IRON WORKS BOILER FIRED WITH POWDERED COAL.

Figure 36 shows a scheme for firing powdered coal to a boiler, devised by Mr. Frederick Seymour and Mr. F. C. Plume. The coal is pulverized in an Aero pulverizer, which delivers it with the air for combustion directly to the furnace. The boiler was built by the Erie City Iron Works about 15 years ago, but a special furnace as shown was designed and added in 1919. This furnace was so designed that it can be added to this or similar boilers without disturbing the original setting.

The coal and air are blown into a chamber lined with ordinary refractory material, on the outside of which are tubes to prevent the refractory material attaining too high a temperature. At the bottom of this combustion chamber is a narrow longitudinal opening, through which molten ash may pass and fall to the ash pit. The molten ash in falling from the slot to the ash pit chills sufficiently to permit it to collect in a pile of friable material that may be easily removed. There is no massing of the slag, and since the ash pit is presented to the direct radiation of the flame only through the narrow slot at the bottom of the combustion chamber, the ash is not remelted by radiation from the flame. At the time of the writer's visit the United States Bureau of Mines was using this installation for research into the combustion of powdered coal. High percentages of CO_2 (15 to 16 per cent) were obtained, which dropped to 9 per cent when the coal was not fed rapidly enough for the air supply. This defect in the coal-feeding mechanism has since been remedied. No trouble, at the time of the writer's visit, had been experienced with the slag.

More recently Mr. F. C. Plume forwarded to the writer the results of a trial on this boiler carried out by W. C. Heckeroth, of the Erie City Iron Works. Extracts from this test are appended.

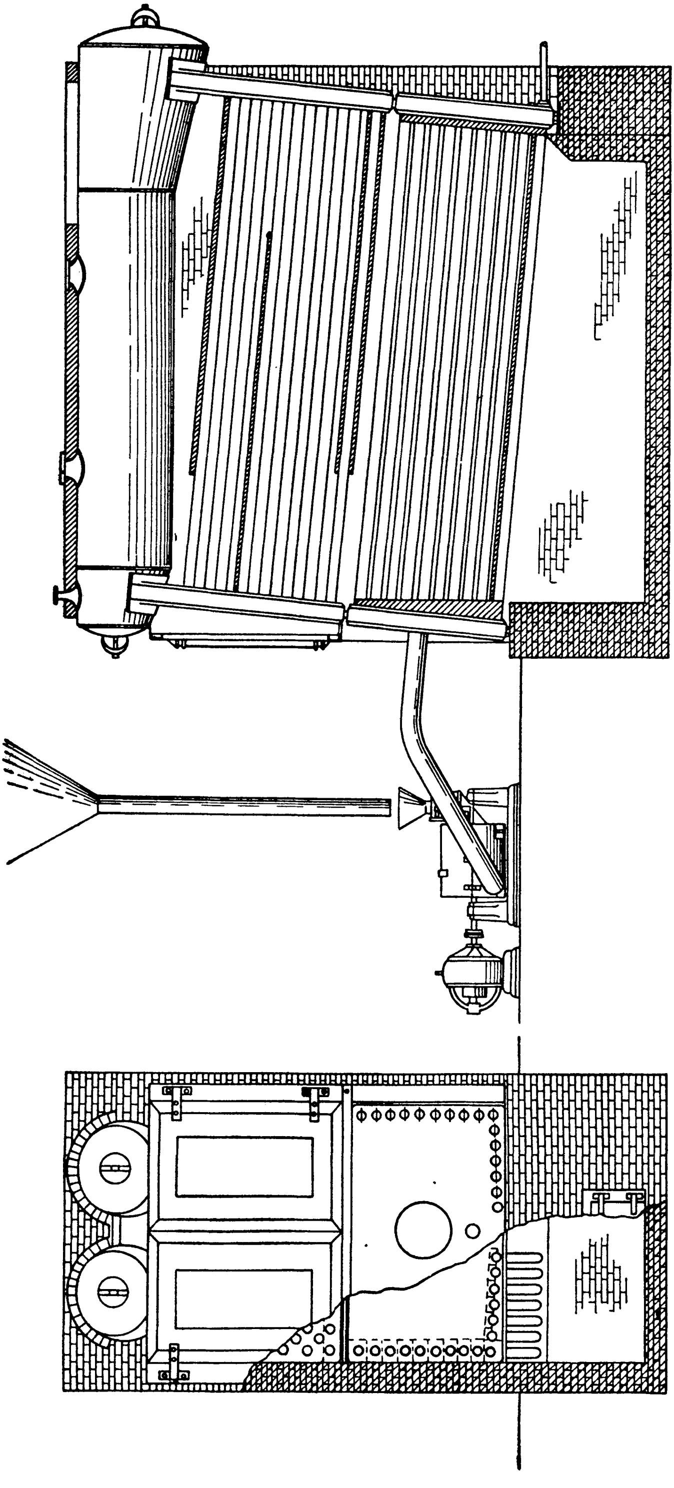

FIGURE 36.—System for pulverizing coal with Aero pulverizer and delivering directly to a water-tube boiler with specially designed furnace.

Summary of test of Erie City horizontal water-tube boiler, with special water-jacketed furnace designed for use with pulverized coal.

General conditions:		
Water heating surface	square feet	4,022
Date of test, December 23, 1919.		
Duration of trial, 8 hours.		
Fuel, bituminous, slack, pulverized.		
Steam pressure, gage	pounds square inch	146
Flue-gas temperature	°F	508
Draft at damper	inches of water	0.44
Draft at furnace	do	0.03
Coal analysis, as received:		
Moisture	per cent	6.44
Ash	do	10.75
B. t. u. per pound of dry coal		13,134
Moisture in coal after being pulverized	per cent	1.78
Screen test of coal:		
Per cent through 200 mesh		42
Per cent through 100 mesh		66
Horsepower-hour used by pulverizer blower per ton of wet coal		41
Flue-gas analysis:		
Carbon dioxide	per cent	16.4
Oxygen	do	2.1
Carbon monoxide	do	0.1
Water rate:		
Equivalent evaporation per hour, from and at 212°F	pounds	22,546
Equivalent evaporation per hour, from and at 212° F. per square foot of heating surface	pounds	5.6
Economic results:		
Equivalent evaporation from and at 212° F. per pound of dry coal	pounds	10.08
Efficiency of boiler and furnace	per cent	74.4

An outstanding feature of this test lies in the good efficiency of the boiler when firing coal pulverized only to a moderate degree of fineness—about 66 per cent through 100 mesh and about 42 per cent through 200 mesh. This comparatively coarse pulverization was deliberately chosen after various experiments had shown that with this setting there is no advantage in extremely fine pulverization.

Another interesting result is the reduction in the moisture content of the coal in passing through the pulverizer where about 5 per cent of the moisture was removed. From other experiments carried out with this experimental plant it appears that there would be no need to install a drier for coals containing 10 per cent or less moisture.

LOCOMOTIVE AND MARINE BOILERS.

No investigation was made of the use of pulverized coal for raising steam on locomotives, though a small switching locomotive in the yard of the Fuller-Lehigh Co. was seen at the time of the writer's visit to Allentown, Pa. It had been using powdered coal since January, 1918. Locomotives have used pulverized coal in the United States, but when the United States entered the war its use was abandoned.

Mr. Muhlfeld[22] in a discussion on pulverized fuel before the American Society of Mechanical Engineers gives many interesting facts about its use on locomotives, and says that the Central Railway of Brazil locomotives are using powdered coal for operating fast passenger, mixed passenger and freight, and freight service with excellent results. The Great Central Railway of England is now equipping a locomotive for burning powdered coal. Powdered coal has also been tried as a fuel for marine boilers on the U. S. S. *Gem*, but so far has not been used commercially for marine boilers.

POWDERED COAL VERSUS STOKERS.

The application of powdered coal for firing stationary boilers has proved entirely practical and should not be left out of consideration, either in the preliminary investigation of means of firing new plants or in any subsequent remodeling of stoker-fired boilers. Its chief advantages are the possibility of obtaining a high carbon dioxide content in the flue gas with very little or no combustible gas, flexibility, and the almost complete combustion of coal. But to obtain excellent flue-gas analyses a furnace much larger than that ordinarily used with stokers must be constructed, and the practice in many plants of disposing of much of the ash by blowing it out with the flue gases is apt to become objectionable. Nor does the high carbon-dioxide content with no unburned combustible gas pertain entirely to powdered coal. Equally good results have been reported with stokers, as notably the trials, abstracted below, made by Prof. Carl Thomas,[23] of Johns Hopkins University, on a Stirling boiler fired with an underfeed stoker.

Summary of results of tests of a Stirling boiler.

Duration of trial........hours..	25	24	24	12
Heating surface........square feet..	10,134	10,134	10,134	10,134
Water evaporated from and at 212° F. per square foot of heating surface........pounds..	5.41	3.68	5.17	6.83
Coal fired per hour........do....	5,603	3,433	5,279	7,238
Flue-gas temperature........°F..	600	510	597	731
Gas analysis, carbon dioxide........per cent..	15.15	16.16	16.58	15.05
Oxygen........do....	3.30	2.28	1.66	3.21
Carbon monoxide........do....	.05	.03	.26	.51
Moisture in coal........do....	3.65	2.94	4.00	3.16
Ash in coal........do....	11.61	11.65	11.87	12.47
B. t. u. per pound dry coal........	13,452	13,369	13,386	13,247
Carbon in ash and refuse........per cent..	22.70	17.28	20.47	33.44
Heat balance, dry bass.				
Heat absorbed by boiler........per cent..	73.22	81.08	74.93	72.30
Heat loss due to hot flue gas........do....	11.14	9.04	10.38	14.05
Heat loss due to combustible in ash........do....	3.35	2.31	2.86	5.31
Heat loss due to moisture in coal........do....	.35	.28	.39	.32
Heat loss due to burning hydrogen........do....	4.43	4.12	4.25	4.60
Heat loss due to carbon monoxide........do....	.18	.10	.86	1.81
Heat unaccounted for........do....	7.33	3.07	6.33	1.61
Horsepower, stoker motor........	....	7.13	8.51	10.91
Horsepower, fan motor........	....	25.09	28.34	41.04
Total horsepower, fan and stoker........	....	33.22	36.85	51.95
Total horsepower per 2,000 pounds coal fired per hour........	....	19	14	14

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[22] Muhlfeld, J. E., Tests on East 53rd Street station: Jour. Am. Soc. Mech. Eng., vol. 41, September, 1919, pp. 999–1046.

[23] Ballard, F. W., The Cleveland municipal electric light plant: Proc. Am. Soc. Mech. Eng., vol. 36, 1914, p. 672.

There is little room for improving these results by substituting pulverized coal for this stoker at this plant, if these results are maintained in practice. The loss due to unburned carbon monoxide is almost negligible, and the gain in efficiency due to burning completely the combustible in the ash would be about 3, 2, 2, and 4 per cent, respectively.

The horsepower used to operate the fan and stoker is about one-half to two-thirds of that required to pulverize and dry the coal.

But these results can not be said to represent the average stoker practice, nor, on the other hand, do all powdered-coal fired boilers show an exceptionally high efficiency and low percentage of excess air. However, there is every possibility, should powdered-coal firing for boilers become more common, that the average excess air with powdered coal will be sensibly less than the excess air with the average stoker plant.

The relative maintenance costs of powdered-coal and stoker plants are extremely variable. Mr. John Anderson, of Milwaukee, has estimated the cost of maintenance of the drying and pulverizing plant at the Oneida Street station at 3 cents per ton of fuel fired, as against 5 cents per ton for stokers.

PLANTS UNDER CONSTRUCTION.

Several powdered-coal boiler plants are being constructed, one notable one is that of the Ford Motor Co. blast-furnace plant, where the Pulverized Fuel Equipment Co. are installing their system of furnace construction, burners, and feeders, and another by the Quigley Furnace Corporation in the boiler plant of the Philadelphia Rapid Transit Co.

REMARKS ON FORD MOTOR CO.'S PLANT.

The following remarks on the Ford plant by Mr. W. F. Verner,[24] mechanical engineer, Ford Motor Co., Detroit, Mich., during a discussion on powdered-coal fired boilers before the American Society of Mechanical Engineers, are interesting.

W. F. Verner gave estimates that had been prepared covering the comparative costs of operating six 2,400-horsepower boilers at the Ford Motor Co.'s blast-furnace plant with pulverized fuel and with stoker fuel. The estimated cost for the pulverizer equipment and buildings was $691,000 and for a corresponding stoker plant $475,000. The cost of pulverizing per ton, including fixed charges, power, maintenance, lubricants, etc., and labor (at $8 per day) was 76 cents; for transmission from pulverizing building to boiler room, 25 cents; and for boiler room $1.13; or a total of $2.14. For a corresponding stoker plant the figures were, for transmission from

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[24] Jour. Am. Soc. Mech. Eng., vol. 41, August, 1919, p. 661.

breaker building, 24 cents; boiler room, $1.66; total, $1.90. For a plant with twelve 2,400-horsepower boilers the total for the pulverized-coal installation was $1.63 and for the stoker equipment $1.49. These figures, in connection with the higher estimated efficiency of the pulverized-fuel plant, indicated for it a saving of 4 per cent over the stoker plant.

One important point in favor of pulverized-fuel plants was that the stand-by losses were reduced to a minimum as compared with stoker installations, where the fires had to be banked over the shutdown periods. An additional reason for installing the former was that blast-furnace gas would be available for use under the boilers and in quantity sufficient to carry the light loads.

SUMMARY: POWDERED COAL FOR BOILERS.

A modern, well-designed, multiple-unit, powdered-coal fired boiler plant is operated more easily than a modern stoker plant, for the following reasons:

1. There is but little coal in the furnace at any time, which makes it possible to increase or decrease the rate of combustion very quickly by changing the rate of supply of coal and air.
2. Practically any coal may be burned completely with a small excess of air and without making any but the simplest changes in feeding the coal and air.
3. No mechanism is exposed to the high furnace temperature, and the cost of installation, maintenance, and operation of the boiler-firing machinery will be less than in a stoker plant.
4. Very little labor is required to operate the boilers. One man can operate five large boilers, and he has none of the arduous work involved in caring for the fire bed of a stoker.
5. The ash, if the furnace be properly designed, gives less trouble and costs less to remove than the ash in stoker plants.
6. The powdered-coal fired furnace is quickly and simply adapted for burning gaseous or liquid fuels should they be available at a cheap price.
7. In everyday running the efficiency will be higher than with stoker-fired boilers, through the smaller loss because of unburnt fuel and the smaller loss in using less air to burn the coal.

The above advantages are offset by the first cost, maintenance, and operation of the preparation-plant machinery for a powdered-coal plant. The operating expense of the distribution system will vary with the system used and plan of the plant, but with good design they need not exceed the costs of distributing the coal in a stoker plant, and may be less.

It is seldom advisable to consider installing a multiple-unit plant for firing boilers where less than 80 tons of coal a day are to be used.

CHAPTER VII.—COSTS OF PREPARING AND DELIVERING POWDERED COAL TO THE FURNACE.

The actual total costs, including everything, of preparing and delivering and firing powdered coal vary between about 50 cents and $3 a ton. Three dollars a ton is extremely high, but, nevertheless, was attained at a comparatively modern plant, while 50 cents a ton is well below the average cost in a modern, well-designed plant, this cost being about 80 to 90 cents a ton.

CAPITAL COSTS.

The capital cost of a plant varies considerably with the design of the plant. Some estimates of capital costs made by two well-known engineering firms follow. It will be observed that the capital cost per daily output decreases with the size of the plant.

ESTIMATES OF FULLER ENGINEERING CO.

The Fuller Engineering Co. in May, 1919, prepared the following table of the size of plant buildings required for the various daily capacities shown in the table. This estimate will always require revision for any particular plant; for instance, the floor space might be materially reduced by placing the drier on a floor above the pulverizers:

Output and size of pulverizer.

Daily output.	Pulverizer.		Drier.		Floor space preparation plant.
	Number.	Size.	Number.	Size.	
Tons.		*Inches.*		*Ft. In. Ft.*	*Ft. Ft.*
30-40	1	33	1	3 0 by 42	23 by 64
75-80	1	42	1	3 6 by 42	23 by 64
150-160	2	42	1	4 6 by 42	24 by 96
230-240	3	42	1	5 0 by 42	34 by 90
310-320	4	42	1	6 0 by 42	34 by 124
390-400	5	42	1	6 0 by 42	34 by 132
470-480	3	57	2	4 6 by 42	36 by 120
600-640	4	57	2	5 6 by 42	36 by 128
750-800	5	57	2	6 0 by 42	40 by 140
900-960	6	57	2	6 6 by 42	40 by 150
1,060-1,120	7	57	2	6 6 by 42	40 by 160

In May, 1919, the Fuller company's estimate of the cost of various sizes of pulverizing plants and buildings was as follows:

Capacity and cost of pulverizer.

Capacity, tons per day.	Total cost.	Building only.	Capacity, tons per day.	Total cost.	Building only.
100	$50,985	$10,700	600	$124,630	$17,500
200	67,980	12,500	700	139,359	18,500
300	81,376	14,750	800	154,480	19,500
400	96,305	15,300	900	167,684	20,500
500	109,901	16,000	1,000	182,413	21,750

At the time of the writer's visit (August 5, 1919) to the Fuller Engineering Co. he was given the following estimate of the costs of pulverized-coal plants and buildings:

Daily capacity.	Total cost.	Fuller mills.		Daily capacity.	Total cost.	Fuller mills.	
		Number required.	Size.			Number required.	Size.
Net tons.			*Inches.*	*Net tons.*			*Inches.*
20	$33,716	1	33	320	$94,173	4	42
30	33,716	1	33	400	103,000	5	42
40	33,716	1	33	480	106,000	3	57
80	40,000	1	42	640	117,000	4	57
120	52,000	3	33	800	157,000	5	57
160	55,000	2	42	960	180,000	6	57
240	72,280	3	42	1,120	195,000	7	57

ESTIMATE OF AMERICAN INDUSTRIAL ENGINEERING CO.

In September, 1919, the American Industrial Engineering Co., through Mr. Bergman, gave the writer the following estimated costs of pulverizing plants:

Capacity per day, machinery running 7 hours out of each 8-hour shift.			Mills.		Total cost.
1 shift.	2 shifts.	3 shifts.	Number.	Size.	
Tons.	*Tons.*	*Tons.*		Single-unit plant.	
17	34	51	1	3-roller	$30,000
26	52	78	1	4-roller	35,000
32	64	96	1	5-roller	40,000
				Double-unit plant.	
34	68	102	2	3-roller	55,000
52	104	156	2	4-roller	60,000
64	128	192	2	5-roller	65,000

Plants include all machinery from car hopper to cyclone collector, motor for direct current. Foundation and erection work under favorable conditions.

These costs include the pulverizing plant only, and it is obvious that the investment costs of the pulverizing plant decrease both with the size of the installation and the hours of full use.

The cost of the equipment for conveying the coal from the pulverizing plant to the furnaces depends upon the system of conveying, the number of furnaces, the distance between the furnaces and the pulverizing house, and may easily amount to more than the cost of the pulverizing equipment. It may be necessary, too, to provide for the crushing of the coal.

TOTAL COSTS.

ESTIMATE OF SCHEFFLER AND BARNHURST.

Messrs. F. A. Scheffler and H. G. Barnhurst[25] (both with the Fuller Engineering Co.), give the following on the cost of pulverizing coal for power plants:

> The cost of pulverizing the coal is of prime importance, as low costs are essential for success and are achieved when the quantity used per day of 24 hours exceeds 100 tons. The cost of pulverizing is made up of a number of items, as follows: Power, repairs and maintenance, coal for drying, labor, interest, depreciation, insurance, and taxes.
>
> *Power.*—The power required in an up-to-date pulverized-coal plant is from 12 to 13 kilowatt hours per net ton of coal crushed, dried, and pulverized. The additional power required for transferring the coal to the point of use and feeding it to the boilers will vary considerably, depending upon the distance transported, the size and number of the boilers, and the condition under which they operate. The power required for this latter purpose varies between 4 and 6 kilowatt hours per net ton, so that the total power for the entire process from the track and storage delivered to the boilers is 17 or 18 kilowatt hours per net ton. In the following paragraphs the cost of power has been assumed at ¾ cent per kilowatt hour.
>
> *Repairs.*—The item of repairs, including material, labor, and general upkeep of the plant, or maintenance, for the entire pulverizing plant and burning equipment will vary from 7 to 10 cents per net ton of coal handled. The figures depend upon local conditions and the size and general arrangement of the entire installation.
>
> *Drier fuel.*—The item of coal for drying depends directly upon the percentage of moisture and upon the price of coal. Ordinarily only from 1 to 1¼ per cent of the total amount of coal used is required for drying. Assuming coal to have an average of 7 per cent moisture as received and the cost to be $2.50 per net ton, the cost per net ton of drying the coal will be 3 cents. At $5 per net ton the cost of the drier coal will be 6 cents.
>
> *Labor.*—This item is the greatest variable in connection with the pulverizing of coal, due to the increased output that can be obtained in larger plants per man employed. It is also subject to local rates of wages. For example, assuming labor at 40 cents per hour, a plant of 100 tons daily capacity, properly designed and equipped, will require approximately 34 labor hours to prepare

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[25] Scheffler, F. A., and Barnhurst, H. G., Pulverized coal for stationary boilers: Proc. Am. Soc. Mech. Eng., vol. 41, 1919, pp. 377–391.

the fuel and deliver it to the conveyers, whereas in a plant having a daily capacity of 1,000 tons approximately 115 labor hours are required. Therefore the labor cost would be 14 cents per net ton in a 100-ton plant, only 4 cents per net ton in a 1,000-ton plant, and as low as 2½ cents per net ton in a plant of 5,000 tons daily capacity.

Interest.—The interest is based on 6 per cent of the entire investment, and the cost of the pulverized-coal plant and burning equipment will, of course, vary considerably with the conditions under which the plant is installed. Roughly speaking, however, the actual investment will vary from $12.80 per kilowatt output in a 5,000-kilowatt plant down to $4.80 per kilowatt in a 50,000-kilowatt plant, and $4.12 in a 100,000-kilowatt plant (assuming a turbo-generator water rate of 16 pounds and continuous boiler and furnace efficiency of 75 per cent).

All these figures in relation to cost are based on the present high prices. The investment required for a 5,000-kilowatt plant, using 100 tons of pulverized coal daily, is approximately $64,000, and for a 50,000-kilowatt plant, using 1,000 tons of pulverized coal daily, approximately $240,000, so that, on a basis of 6 per cent, and allowing for 365 days continuous operation, the interest item will vary from 10½ cents per net ton in a 100-ton plant down to 3.9 cents per ton in a 1,000-ton plant.

Depreciation.—Depreciation in a coal-pulverizing plant is usually calculated as follows: The life of the building is considered as 40 years, of the coal driers as 15 years, and of the balance of the equipment as 20 years. With a 100-ton pulverized-coal plant and burning equipment the depreciation item will be approximately 12 cents per net ton, and in a plant of 1,000 tons daily capacity it will be approximately 4 cents per net ton.

Taxes and insurance.—Taxes and insurance are based on 2 per cent of the entire investment, and for a 100-ton plant this item is approximately 3½ cents per ton and for a 1,000-ton plant 1.3 cents per ton. Summarizing, the foregoing results show that the total cost of pulverizing and delivering coal to boilers is approximately as given in the following table:

Cost of delivering pulverized fuel to boilers.

	100-ton plant, per net ton.	1,000-ton plant, per net ton.
Power at ¾ cents per kilowatt hour and 17 kilowatt hour per net ton	$0.1275	$0.1275
Labor at 40 cents per hour	.14	.04
Drier coal at $5 per net ton delivered	.06	.06
Repairs	.07	.07
Total actual cost of pulverizing	.3975	.2975
Interest at 6 per cent	.105	.039
Depreciation	.12	.04
Taxes and insurance	.035	.013
Total cost	.6575	.3895

ESTIMATE OF AMERICAN INDUSTRIAL ENGINEERING CO.

Mr. L. H. Bergman, of the American Industrial Engineering Co., prepared in September, 1919, the following estimates of costs for a pulverized-fuel plant for preparing coal for domestic purposes. He assumes an output of 250 tons of powdered coal in 24 hours, and allows for two driers, capacity 10 tons per hour, and three Raymond pulverizers, capacity 5 tons per hour. He recommends the operation of the driers so that the outgoing coal will have a temperature not greater than 125° F., and advises the storage of the dried coal for three hours before it enters the pulverizer. This means two storage bins of 15 tons capacity each for the dried coal. The three Raymond mills would deliver the powdered coal into a screw conveyer at the rate of 15 tons per hour and thence to four storage bins of 50 tons capacity.

His estimated costs are as follows: It will be noticed that the operating costs are 50 cents a ton and the total costs 61.2 cents a ton.

Cost of pulverizing plant.

Building	$8,000
Foundation	3,000
Machinery: Crusher, elevators, magnetic separator, raw-coal storage bin, feeders for driers, two 10-ton driers, dry-coal elevator, dry-coal bins, three Raymond pulverizers, etc	50,000
Motors: One 25-horsepower motor for crusher, one 7½-horsepower motor for raw-coal elevator, two 25-horsepower motors for driers, one 7½-horsepower motor for dry-coal elevator, three 100-horsepower motors for pulverizers, one 15-horsepower motor for conveyers	10,000
Erection of machinery	8,000
Electric light and wiring	1,000
Four 50-ton concrete bins	12,000
Powdered-coal conveyer 125 feet long	2,000
Total	85,000

To insure continuous operation, machinery will be so arranged that either drier will feed into either dry-coal storage bin supplying either one of the three pulverizers. All elevators and bins will be ventilated and motors electrically interlocked to insure proper sequence in operation.

Pulverizing cost per 24 hours, output 250 tons.

	Total.	Per ton.
		Cents.
1 foreman per shift at $6	$12	4.8
2 operators in pulverizing plant per shift at $5	20	8.0
1 operator on conveyor per shift at $4	18	3.2
1 oiler and repair man per shift at $5	10	4.0
20 per cent overhead on labor	10	4.0
Drying cost 16 pounds per ton at $4	8	3.2
Power, 18 kilowatt hours per ton at 1 cent	45	18.0
Stores and purchased material at 4.8 cents per ton	12	4.8
Interest and depreciation at 10 per cent on $85,000 per year of 300 days	28	11.2
	152	61.2

Cost per ton, $153÷250=$0.61.

OPERATING COSTS.

ATLANTIC STEEL CO. PLANT.

Mr. N. C. Harrison gives the following actual operating costs per net ton at the Atlantic Steel Co.'s plant, Atlanta, Ga.:[26]

	Cost per ton.
Daily output 80 tons per day:	
Labor	$0.22
Repairs	.19
Power	.134
Drier coal	.0218
Total cost	.5658
Daily output 90 tons per day:	
Labor	.195
Repairs	.19
Power	.134
Drier coal	.0218
Total cost	.5408
Daily output 100 tons per day:	
Labor	.176
Repairs	.19
Power	.134
Drier coal	.0218
Total	.5218

Total coal pulverized Jan. and Feb., 1919 tons		5,275
Power: 17.9 kilowatt hour per ton coal pulverized at ¾ c per ton		.134
Labor:		
1 man 16 hours at $0.40	$6.40	
2 men 16 hours at $0.35	11.20	
		17.60
Daily cost		17.60

(—$0.22 for 80 tons output, $0.195 for 90 tons, $0.176 for 100 tons.)

Drier coal: Cost of drier fuel 2.18 cents per ton, based on 2.62 per cent moisture. Coal at $5 per ton, 6 pounds evaporated per pound of coal burned or 8.7 pounds per ton of coal pulverized.

Repairs: Total repairs for January and February	1,412.16
Credit	409.69
Charged	1,002.47

(—$0.19 per ton pulverized.)

LARGE MANUFACTURING PLANT.

The lowest figures for operating and repairs at a manufacturing plant that were obtained by the writer were those of a large up-to-

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[26] Harrison, N. C., Pulverized coal as a fuel: Trans. Am. Soc. Mech. Eng., vol. 41, 1919, p. 363.

date plant using Raymond mills and screw conveyers, where they were about 65 cents per ton, and included all operating costs between the raw coal delivered to the crushers and the furnace feeders. The operating costs alone were about 50 cents per ton and the repair costs about 15 cents a ton. These costs had been carefully kept over a period of six months, labor was dear, and power cheap. At the same plant over another six months the operating costs, exclusive of repair costs, were about 65 cents and the repair costs about 17 cents per ton. The total labor costs for operating and repairs were about 40 cents a ton and the total power costs were about 16 cents a ton.

STEEL PLANT.

At a steel plant where pulverized coal is being used for forging and puddling furnaces, at a normal rate of about 4,000 to 5,000 tons per month, the following costs and particulars were obtained:

The plant uses five pulverizers, two in one building and three in the other, and the coal is conveyed to the furnaces by screw conveyers. The total power used for crushing, pulverizing, drying, and conveying the coal to the furnace was as follows, the power cost being taken as 1.4 cents per kilowatt hour.

Operating costs at a steel plant.

Month.	Tons of coal.	Kilowatt-hours.	Kilowatt-hours per ton.	Power cost.
1918.				*Cents.*
January	4,300	70,700	16.4	23
February	3,750	72,700	19.4	27
March	5,200	86,400	16.6	23
April	5,200	88,900	17.1	24
May	4,800	84,500	17.6	25
September	4,600	81,700	17.8	25
October	4,650	97,300	20.9	29
November	4,000	98,700	24.7	35
December	3,500	90,400	25.8	36
1919.				
January	3,419	81,085	23.8	33
February	3,000	81,700	27.2	28
March	3,120	61,200	19.6	27
April	1,078	31,000	28.8	40
May	498	10,700	21.7	30
June	553	10,800	19.5	29
July	579	10,100	17.5	24

The labor employed at this plant on the day shift of 10 hours consists of 4 men filling bins with powdered coal; 1 man on conveyer leading to drier; 1 man unloading coal and looking after crusher; 1 man on driers; 2 men pulverizing, 1 in each room; 2 men working continuously on repairs, principally to conveyer screws and feeders; 1 foreman.

The greatest distance the coal is conveyed from the pulverizers at this plant is about 400 feet.

The operating costs per ton were as follows in 1917 and 1918:

Operating costs per ton.

	1917.	1918.
Producing labor	$0.34	$0.429
Repairs and supplies	.37	.545
General expense	.32	.273
Total	1.03	1.247

This plant could be remodeled so as to reduce considerably the operating costs; and the chief engineer has estimated the operating costs of pulverizing the coal and conveying it to the furnace for a new plant at 85 cents per ton.

ROLLING MILL—AIR-SUSPENSION TRANSPORT.

At some plants the costs were much higher; for instance, at a rolling mill, where the coal was pulverized in two shafts and delivered in suspension by a fan blast, and where three men were employed on each shaft the actual operating costs and estimated operating costs at a higher output were:

Operating costs at a rolling mill.

Items.	555 tons.		1,000 tons, estimated, per ton.
	Actual.	Per ton.	
Labor	$986	$1.79	$0.99
Repairs	450	.81	.81
Power cost	250	.45	.45
Total operating costs	....	3.05	2.25

These costs show the effect of operating at different loads. No additional labor or equipment would have been required to operate at 1,000 tons per month.

OTHER OPERATING COSTS.

Other operating costs obtained were $1.90 per ton, $1.75 per ton, and $2.21 per ton, respectively.

OPERATING COSTS AT MILWAUKEE.

Mr. John Anderson, the chief engineer of the power plants of the Milwaukee Electric Railway & Light Co., has forwarded to the writer a pamphlet in which the following costs of preparation, operation, and maintenance appear for the Oneida Street power station at Milwaukee:

Costs at the Oneida Street station, Milwaukee.

Cost of labor per ton of coal operation	$0.143
Cost of fuel for drying plus fuel for electric energy—coal at $4 per ton	.119
Cost of lubricants per ton of coal, grease at 9 cents per pound	.007
Cost of labor per ton of coal for maintenance	.036
Cost of material for maintenance	.020
Total cost per ton of coal	.325

Mr. Anderson says:

> The cost per ton depends upon the size of the plant and the quality of fuel handled, but ordinarily will vary between the limits of 25 and 50 cents.

REASONS FOR DIFFERENCE IN OPERATING COSTS.

The foregoing wide ranges of operating costs must be attributed chiefly to greater costs of repairs and to the use of more labor in some plants than others. The wide difference in labor employed may be seen in the following table, which compares the approximate labor hours in different plants:

Labor hours at different plants.

Mean output per day.	Labor per day.	Labor per ton of coal.
Tons.	*Hours.*	*Hours.*
30–15	60	2–4
35	50	1.4
40	10	.25
25–50	40–60	1.6–1.2
60	70	1.2
100–170	120	1.2–0.7
200	400	0.5

The labor costs in many of these plants could be reduced were the plants redesigned. The third plant mentioned in the above table has extremely low labor costs. Here, screw conveying is used, the furnaces and bins are easily accessible from the pulverizer room close at hand, and one man attends to the drying, pulverizing, and conveying of the coal.

The power costs for pulverizing vary with the degree to which the coal is pulverized, and the conveying costs with the distance to which coal is conveyed and the system used. The air-suspension method of conveying requires much more power than the screw-conveying system, but some allowance should be made for this air being used to burn the coal and for no bins and feeders being required.

REPAIR COSTS.

The chief repair costs are those due to parts of the pulverizer breaking down. Some makes of pulverizers are more reliable than others, and care should be taken to select a pulverizer with a good reputation of service elsewhere. The frequent repairs to some pulverizers are not always entirely due to faulty construction but may be attributed also to neglect. High costs of repair have also been encountered with fans used in the air-transport system. Thus at one plant it was necessary to renew the fan impeller 11 times to deliver 2,500 tons of coal. But, on the other hand, at a neighboring plant only two new fan impellers were required to deliver 2,000 tons of coal. The following table gives particulars of the total repair costs of the pulverizers and distribution system where the coal was distributed directly to the furnaces in a current of low-pressure air:

Repair costs at plant with air-transport system.

	Labor.	Material.	Coal to pulverized plants.	Repairs per ton.	
				Labor.	Material.
			Tons.		
December, 1915	$61.82	$72.77	118	$0.52	$0.62
January, 1916	143.47	68.93	178	.80	.39
February, 1916	138.55	279.47	203	.68	1.38
March, 1916	188.11	122.70	510	.37	.24
April, 1916	220.00	211.68	740	.30	.29
Total and average	751.95	755.55	1,749	.43	.43

Thus the total repair costs per ton at this plant for five months were 86 cents. These are very high compared with the large manufacturing plant using screw conveyers, where the costs were only about 15 cents per ton.

AERO PULVERIZER CO. (UNIT SYSTEM).

The Aero Pulverizer Co. has estimated that the operating costs with its unit system of pulverizing and delivering the air and undried coal to the furnace are as follows:

	Per ton.
Unloading	$0.04
Pulverizing and conveying Air for control Air for combustion	.22
Upkeep and repairs	.04
Labor	.07
Total	.37

This estimate is based on using a size D 30-horsepower Aero pulverizer, with a capacity of 2,000 pounds coal per hour, power at 1 cent per kilowatt hour, and one man at 40 cents per hour operating six machines. An Aero pulverizer unit costs about $3,500.

From the foregoing it is obvious that actually installed plants show very wide ranges of costs, dependent on the design and size of the equipment. Other variables affecting operating cost are the cost of power and of labor.

It is clear, therefore, that each plant must be considered carefully by itself, and that bad design or the installation of a poor system may render the costs exorbitantly high as cited above for plants already installed. On the other hand, capable engineers have shown that plants with properly designed equipment and of reasonably large size may supply and prepare pulverized coal for less than $1 per ton.

CHAPTER VIII.—DANGER FROM USE OF POWDERED COAL.

INTRODUCTION.

Although men have been killed by explosions and fires in powdered-coal plants, the causes of such accidents are known and precautions may be taken that they may not recur.

Greater precautions are required with some systems than with others. For instance, dangerous fires and explosions have occurred more frequently with the direct low-pressure air system of transport than with the indirect screw-conveying or compressed-air transport systems, although the indirect transport system has not been entirely free from disasters.

The possibility of a dangerous fire or explosion in a well-designed, well-managed powdered-coal plant is remote and should not influence the prospective user of powdered coal against installing it.

CAUSES OF EXPLOSIONS.

Explosions have been caused either by igniting a mixture of inflammable gas and air or by igniting a mixture of coal dust and air.

GAS EXPLOSIONS.

Inflammable gas may be driven off in a drier, if the coal is heated too strongly, either by drying the coal at too high a temperature, or by leaving the coal too long in the drier, or by leaving coal in the drier until it slowly oxidizes and rises to a temperature where it may burst into flame and ignite the inflammable gas.

DUST EXPLOSIONS.

As lean a mixture as 1 pound of coal dust per 500 cubic feet of air has exploded. Two obvious conditions are essential for an explosion—the formation of the dust cloud and its ignition.

FORMATION AND IGNITION OF DUST CLOUDS—COAL-CONVEYING LINES—LOW-PRESSURE SYSTEMS.

Several fatal accidents have occurred through an explosion wave traveling along a low-pressure pipe used to convey coal suspended in air.

At one plant using the low-pressure air direct-distribution system in the manufacture of bolts and rivets a mixture of coal dust and air exploded and killed one man and injured two others. The mixture exploded in the fan which propelled the mixture of powdered coal and air through the distribution line. It probably started in the distribution line from smoldering coal ignited by a back draft from the furnace. The distribution pipe was strong enough to resist the force of the explosion, and the flame probably swept back through the explosive mixture of coal dust and air until it reached the fan. This explosion occurred soon after the system started and might have been avoided had the distributing main been first thoroughly cleared, so that no hot coal remained in the main to ignite the supply of coal and air.

With the air-transport system, it may happen that the coal-and-air fan stops while the secondary fan continues to blow secondary air. Or the secondary air fan may be started before the coal-and-air fan. When the secondary air fan alone is running, the secondary air may penetrate back into the coal-air line and carry with it a spark which may ignite the coal-air mixture when the coal-air fan is restarted. The secondary air is more likely to penetrate the coal-air distribution line when the burner opening into the furnace is clogged, as it may be unless relieved of the caked coal dust which collects at the burner mouth. To avoid this penetration of the secondary air into the distribution line, care should be taken to see that the burner mouth is free and that the secondary air fan delivers no air unless the coal-air fan is already delivering coal and air or the supply valve admitting it to the burner is closed.

To avoid this penetration of secondary air, at the Trumbull Steel Co.'s plant at Warren, Ohio, where the coal is distributed by the Holbeck system, whistles blow automatically in the hot-mill department and the pulverizing room if the coal-air distributing lines fail to deliver coal and air to the furnace. On hearing the whistles the crews close the supply valves to every furnace, which prevents the secondary air from entering distribution lines.[27]

PULVERIZER EXPLOSIONS.

At a plant using a directly fired drier and air-separation pulverizer and low-pressure air-transport system, with an output of from 50 to 100 tons per day, a violent explosion in the pulverizing house damaged the building, smashed the pulverizer, killed two men, and badly injured two more.

Mr. L. D. Tracy, of the United States Bureau of Mines, investigated this explosion and found that many fires had occurred pre-

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[27] Knox, J. D., Liberty Steel Co.'s plant at Warren, Ohio: Iron Trade Rev., vol. 66, Feb. 19, 1920, p. 552.

viously at this plant in the distribution line near the furnaces and in the storage bins. The particularly disastrous explosion happened at a time when the temperature of the gases leaving the driers had just risen from 150° F. to 350° F., and the coal delivered to the pulverizer was probably so hot as to cause the coal and air mixture to ignite in the pulverizer. The drier used was a Bonnot; in this the coal leaving the drier comes into contact with the gases leaving the drier furnace. The makers of this drier intended it to be so operated that cold air passes over the fuel bed and so reduces the temperature of the gases leaving the furnace below a temperature that may overheat the coal.

UNCONFINED DUST CLOUDS.

Dust clouds in a mill or boiler room are always a source of danger and should not be allowed to form. One dust-cloud explosion occurred in a pulverizing house when a man opened a compressed-air tank, which contained a deposit of powdered coal, before making sure that the tank was at atmospheric pressure. The compressed air blew out coal dust, which, mixed with air, ignited at a near-by fire, and exploded.

Another explosion occurred through the overflow of a storage bin near a furnace. The falling dust reached some hot slag, ignited, and burned a man to death.

Dust clouds may be formed also if dust is permitted to accumulate on the floor or ledges in a building, for by a sudden gust of wind, or other means, the accumulated dust may be swept from a ledge to ignite at a naked flame, red hot metal, or sparking commutator.

SAFETY IN POWDERED-COAL PLANTS.

Mr. L. D. Tracy, of the United States Bureau of Mines, has formulated the following rules for reducing the explosion hazard to a minimum in powdered coal plants:

> Absolute cleanliness and freedom from any accumulation of dust, both in the pulverizing plant and in the buildings in which the pulverized coal is being used as fuel.
>
> Never brush or sweep up accumulations of dust on the floor or machinery without either wetting the dust or thoroughly mixing with an excess mixture of fine incombustible material.
>
> Adequately ventilate and light all coal-pulverizing plants, and, when practicable, install some method of cleaning by vacuum systems.
>
> All open lights in and around coal-pulverizing plants should be prohibited, and employees should not be allowed to smoke while in the building. This rule should apply to superintendents and other officials who casually visit the plant as well as to regular attendants.
>
> The drier and drier furnace should be separated by a fireproof partition from the pulverizing mills, conveying machinery, and storage bins.
>
> Where furnaces or boilers are equipped with individual fuel bins, these bins, if possible, should be isolated from the boilers or furnaces.

All pulverized-coal bins should be tightly closed and never opened if there is any possibility of ignition from an open flame. Bins should be equipped with automatic indicators to indicate the amount of coal in the bin.

Only men of known reliability should be intrusted with the direct operation of a drier. It may be more economical in the long run to pay a higher wage to a good man than a smaller wage to an unreliable man or boy.

Especial care should be used in order to not overheat the coal in the drier, and recording pyrometers should be installed to enable the officials of the plant to check the operation of the drier.

The operation of the drier should never be stopped while it contains a charge of coal.

Fire in the drier furnace should never be started with paper, shavings, or any light combustible material.

Fine coal at a temperature over 150° F. should never be stored in a bin, because of the liability of spontaneous combustion.

For the same reason, pulverized-coal storage bins should never be placed in close proximity to furnaces, boilers, steam pipes, or flues..

Whenever a plant is to be shut down for a few days, if possible, all storage bins should be emptied of coal.

Where it is not possible to empty the bins they should be thoroughly inspected for hot coal before the plant is again put in operation.

In the direct system of using pulverized coal the primary air pressure should always be maintained at a much higher pressure than that of the secondary air.

If a coal-transport line becomes plugged up, the furnace should be immediately cut out and the secondary air stopped.

After the line has been closed it is essential that no smoldering particles of coal be left in the line, and before starting the fan a thorough examination of the line should be made.

Burners should be frequently inspected, and any coke burned thereon should be removed.

Transport lines should be blown clean of coal when shutting down at the end of the day's work.

Never ignite the mixture of air and coal in the furnace by reaching in or opening the doors.

All conveyers and elevators should be tightly inclosed and should never be opened while running. Stop the machinery and allow the dust to settle before opening.

Never open a coal line, compressed-air tank, or storage bin in the vicinity of a flame or open light.

Inclose all electric wires and cables in conduits as far as possible.

All switches should be placed outside the pulverizing plant or else placed in dust-proof casings.

Nonsparking motors or motors in dust-proof housings to be used in the pulverizing plant.

Guard against sparks from static electricity in all rapidly moving machinery by having it thoroughly grounded.

All electric-light bulbs should be kept from an accumulation of dust and all portable lights should have the bulbs protected by heavy wire guards, and care should be taken to prevent arcing from loose socket connections or imperfectly insulated cords.

Stop all leaks in pulverized-coal transport lines or storage bins as quickly as you would a leak in a gas line.

Prohibit smoking, open lights, or torches in a coal-pulverizing plant.

Educate all the men to the dangers of pulverized-coal dust.

CHAPTER IX.—CONCLUSIONS.

Powdered coal has proved an economical fuel for steam raising, cement making, metallurgical furnaces, and many other purposes. For steam raising, with a properly constructed boiler and furnace, a continuous efficiency of over 80 per cent may be maintained. For other purposes a high temperature with no regenerators may be maintained by using powdered coal, with less coal consumption than when using producer gas, stokers, or hand firing.

The unit system alone is economically applicable for small installations, where less than about 10 tons a day are used.

For larger installations the multiple system, with Raymond or Fuller mills and with indirectly fired driers, seems to be preferable.

To distribute the coal, screw conveyers are recommended to convey large quantities of coal short distances, and either the Fuller Kinyon pump or compressed air to convey it long distances.

The Quigley weighing tank is a valuable adjunct to the compressed air distribution.

The direct low-pressure system of distribution should be used solely to distribute coal short distances to small furnaces, where the cost and inconvenience of using separate bins and feeders for each furnace is unwarranted.

APPENDIX.

BOILER TESTS WITH PULVERIZED COAL.[28]

By Henry Kreisinger and John Blizard.

This paper gives the summary of the results of a series of 11 tests made on a 468-horsepower Edgemoor boiler equipped with a Foster superheater and fired with pulverized coal at the Oneida Street station of the Milwaukee Electric Railway & Light Co., Milwaukee, Wis. The tests were made by the fuel section of the United States Bureau of Mines in cooperation with the research department of the Combustion Engineering Corporation. The powdered-coal equipment was designed and installed by the Locomotive Pulverized Fuel Co. The coal burned in these tests came from the Illinois coal field. The object of the tests was to determine what over-all efficiency can be obtained with pulverized Illinois coal under various conditions of furnace operation and different preparation of coal as to degree of fineness and percentage of moisture.

The tests were made in a thorough manner, everything being done to make the results accurate and reliable. The pulverized coal was weighed in specially designed tanks placed on platform scales as it was supplied to the furnace. The tests were of 17 to 25 hours' duration.

Tests 28 to 30, inclusive, were made with the usual preparation of coal as it is burned in the plant under ordinary operating conditions. Test 31 was made with the same condition of coal as in the three previous tests, but with the furnace provided with a cooling coil over the hearth and along the walls near the bottom of the furnace to facilitate the removal of ash. Tests 32 to 35, inclusive, were made with the same furnace arrangement as test 31, but with the coal pulverized to a lesser degree of fineness. Tests 36 to 38, inclusive, were made with the same furnace arrangement as in the previous four tests, but with undried coal.

Figure 37 shows the arrangement of the burner and the cooling coil over the hearth and near the bottom of the furnace. The cooling coil consisted of three lengths of 2-inch pipe over the hearth and two lengths along the side walls and the rear wall. The total surface of the coil was 48 square feet.

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[28] Paper presented at meeting of American Society of Mechanical Engineers, May, 1921. See Mech. Eng., vol. 43, 1921, p. 321.

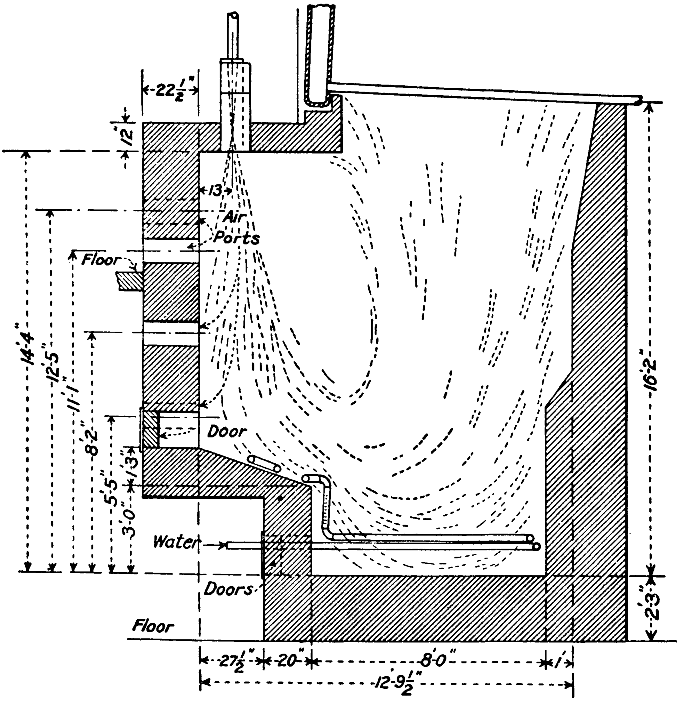

FIGURE 37.—Section through furnace, showing arrangement of burner and cooling coil over hearth and near bottom of furnace.

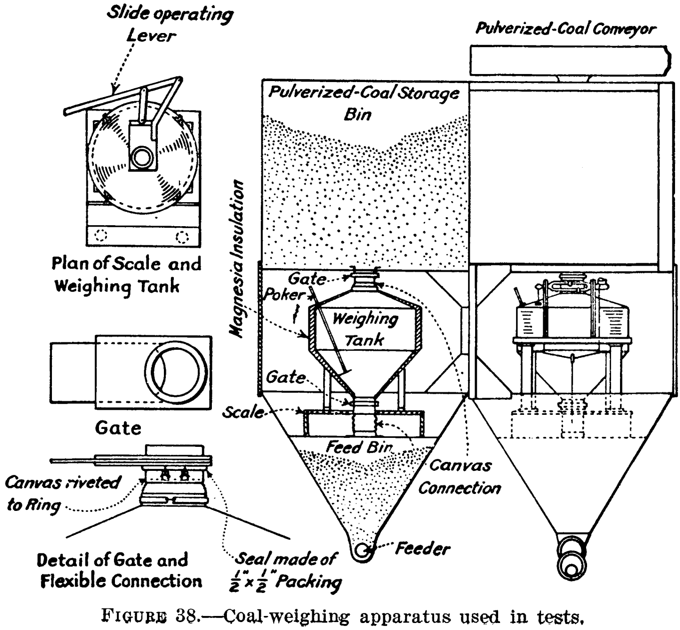

FIGURE 38.—Coal-weighing apparatus used in tests.

Figure 38 shows the coal-weighing apparatus, which was placed between the storage bin and the feed bin. There were two burners and two feeders, and the coal to each feeder was weighed separately. The weighing tanks were connected to the storage bins and the feeder bin by flexible canvas connections to permit weighing and to prevent the coal dust from escaping into the room when the weighing tanks were being filled and emptied. The tests were begun and closed with the feeder bins empty.

The feed water was weighed in two water tanks placed on platform scales. The water supplied to the cooling coil was measured by a 2-inch water meter which was calibrated at the rate of feeding the water through the cooling coil, and its measurements were found reliable to within less than one-half of 1 per cent.

Flue-gas samples were taken at six points in the uptake and collected over one-hour periods. Flue-gas temperatures were measured with thermocouples at the same six points where samples were drawn for analysis, and readings were taken every 15 minutes. The flue-gas temperature given in the table below is the average of the measurements with the six couples.

Heating surface:		
Boiler	square feet	4,680
Superheater	do	594
Furnace coil	do	48
Total heating surface	do	5,322
Draft: Natural.		
Burner: Lopulco vertical.		
Coal feed: Screw and air blast.		
Rating of boiler	horsepower	468
Volume of furnace	cubic feet	1,600
Greatest height of furnace	feet	16.7
Greatest width of furnace	do	9.3
Greatest length of furnace	do	13.3

Summary of results of 11 steaming lists on an Edgemoor boiler burning powdered coal at Oneida Street power station, Milwaukee, Wis.

Test No. and duration:											
1. Test No.	28	29	30	31	32	33	34	35	36	37	38
2. Duration ... hours	22.90	23.72	18.17	23.62	23.60	22.47	25.22	23.53	23.43	23.33	16.73
Coal as fired:											
3. Per cent through 100 mesh	96.10	95.80	....	95.40	93.20	93.10	90.80	88.60	....	94.40	95.40
4. Moisture content ... per cent	1.42	2.92	2.75	2.55	3.79	3.07	3.60	3.47	7.69	8.23	8.23
5. Volatile matter ... do	36.62	36.66	37.45	36.58	36.57	36.29	37.17	36.27	35.82	34.42	34.70
6. Fixed carbon ... do	48.16	46.63	46.08	48.07	48.43	49.01	46.39	48.87	45.74	46.39	44.67
7. Ash ... do	13.80	13.79	13.72	12.80	11.21	11.63	12.84	11.39	10.75	10.96	12.40
8. Sulphur ... do	2.66	3.64	3.49	2.92	2.40	2.66	3.43	2.99	2.10	2.21	2.90
9. Calorific value ... B. t. u.	11,956	11,860	11,875	12,085	12,172	12,178	11,889	12,188	11,565	11,508	11,245
10. Total fuel fired ... pounds	40,214	39,862	52,746	46,613	43,947	45,469	47,459	41,250	43,729	41,640	36,315
11. Coal fired per hour ... do	1,756	1,681	2,903	1,973	1,862	2,024	1,882	1,753	1,866	1,785	2,171
12. Coal fired per hour per cubic foot of combustion space	1.10	1.05	1.81	1.23	1.16	1.26	1.18	1.09	1.16	1.12	1.36
Ash and refuse:											
13. Carbonaceous content in furnace slag ... per cent	0	0	0	0	0	0	0	0	0	0	0
14. Carbonaceous content in second and third pass refuse ... per cent	4.15	3.49	5.00	5.25	9.52	7.19	7.52	7.37	4.97	4.32	4.49
15. Carbonaceous content in uptake dust ... do	4.95	5.24	7.35	5.13	7.70	6.45	7.81	5.57	3.91	3.50	3.28
16. Calculated total carbon in refuse, of coal fired ... do	.50	.54	.62	.36	.87	.61	.67	.30	.24	.22	.26
17. Softening temperature of coal ash ... °F	....	2,050	2,210	2,120	2,120	2,110	2,060	....	....	....	....
Ash account (per cent of ash fired):											
18. From bottom of furnace	29.20	25.50	41.50	48.10	10.10	24.10	37.80	59.40	48.10	47.10	41.60
19. From second and third pass	12.10	11.60	5.80	10.40	10.30	7.00	9.10	10.50	8.30	7.70	8.70
20. From dust collector	31.50	25.00	33.20	29.20	27.50	29.00	25.50	30.10	32.80	26.00	26.30
21. Unaccounted for	28.20	37.90	19.50	12.30	52.10	39.90	27.60	0	10.80	19.20	23.40
Air:											
22. Temperature, air at furnace ... °F	83	90	80	76	85	71	64	74	79	72	75
23. Pressure air at feeder ... inches of water	5.00	5.30	7.50	5.10	5.60	5.50	6.40	5.90	5.70	5.50	6.20
24. Excess air in flue gas ... per cent	30	22	18	18	19	15	20	25	19	16	20
Flue gas:											
25. Carbon dioxide ... per cent by volume	14.10	14.90	15.40	15.50	15.30	15.80	15.10	14.60	15.50	15.80	15.40
26. Oxygen ... do	4.80	3.80	2.90	3.30	3.20	2.40	3.60	4.10	3.20	2.90	3.60
27. Carbon monoxide ... do	0.0	0.0	0.3	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0
28. Dry flue gas per pound of coal ... pounds	12.40	11.20	10.60	11.00	11.30	10.80	11.00	11.70	10.70	10.40	10.60
29. Temperature of gases in uptake ... °F	517	492	610	483	457	472	470	486	484	466	514

Summary of results of 11 steaming lists on an Edgemoor boiler burning powdered coal at Oneida Street power station, Milwaukee, Wis.—Continued.

Draft:											
30. At uptake .... inches of water..	.12	.10	.27	.09	.06	.08	.05	.09	.10	.05	.15
31. Top of furnace .... do....	0	.02	0	0	.01	0	.01	.02	.02	.03	.03
Steam and water:											
32. Steam pressure, absolute .... pounds..	184	186	196	189	188	187	185	186	183	182	185
33. Degrees superheat	60	59	80	58	53	61	67	79	74	70	102
34. Temperature of feed water .... °F..	108	99	99	101	101	100	100	103	98	100	99
35. Temperature of water to coil .... do....	(1)	(1)	(1)	54	53	52	50	48	46	46	46
36. Temperature of water from coil .... do....	(1)	(1)	(1)	129	146	145	118	151	139	130	144
Rates of heat absorption:											
37. Per cent of builder's rating (boiler only)	106.6	103.9	167.4	111.7	102.7	112.4	103.4	104.8	101.9	94.4	113.5
38. Horsepower developed (boiler only)	498.8	486.5	779.0	523.2	480.	526.0	484.0	490.5	477.0	442.0	531.5
39. Horsepower developed (superheater only)	15.8	15.3	32.9	16.3	13.7	15.0	15.4	20.5	18.4	16.3	27.9
40. Horsepower developed (furnace coil)	(1)	(1)	(1)	49.7	55.0	59.7	45.9	[2] 7.5	32.0	29.1	26.8
41. Total horsepower developed	514	502	812	589	549	601	545	528	527	487	586
B. t. u. absorbed per square foot of heating surface per hour:											
42. By water in boiler	3,567	3,482	5,575	3,743	3,437	3,758	3,466	3,508	3,413	3,207	3,798
43. By steam in superheater	892	861	1,856	920	772	845	869	1,155	1,039	934	1,573
44. By water in furnace coil	(1)	(1)	(1)	33,900	37,600	40,770	31,270	33,190	21,920	20,160	18,440
Heat absorbed per pound of coal as fired, B. t. u.:											
45. By water in boiler	9,500	9,690	8,990	8,870	8,630	8,710	8,625	9,360	8,650	8,405	8,190
46. By steam in superheater	301	304	380	277	246	249	274	391	330	311	430
47. By water in coil	(1)	(1)	(1)	843	995	988	815	335	575	554	414
48. Total absorbed	9,801	9,994	9,370	9,990	9,871	9,947	9,714	10,086	9,465	9,270	9,034
Heat balance (per cent of heat in coal fired).											
Heat absorbed:											
49. By water in boiler	79.4	81.6	75.6	73.4	70.8	71.5	72.4	76.8	74.0	73.0	72.7
50. By steam in superheater	2.5	2.5	3.2	2.3	2.0	2.0	2.3	3.2	2.8	2.7	3.8
51. By water in coil	(1)	(1)	(1)	7.0	8.2	8.1	6.9	2.7	5.0	4.8	3.7
52. Total and thermal efficiency	81.9	84.1	78.8	82.7	81.0	81.6	81.6	82.7	81.8	80.5	80.2
Heat carried away:											
53. By dry gasses	10.8	9.1	11.4	8.9	8.2	8.6	9.0	9.5	9.0	8.5	9.9
54. By steam from burning hydrogen	4.1	4.3	4.2	4.1	4.1	4.2	4.2	4.0	4.2	4.1	4.2
55. By steam from moisture in coal	.1	.3	.3	.2	.3	.3	.3	.3	.8	.9	.9
56. By steam entering with air	.3	.3	.1	.1	.1	.1	.1	.1	.1	.1	.1
57. By carbon monoxide	0	.0	1.0	.1	.1	.2	.4	0	0	0	0
58. By carbon in ash and flue dust	.6	.6	.7	.4	1.0	.7	.8	.4	.3	.3	.3
59. By radiation	2.5	2.6	1.9	2.2	2.3	2.1	2.3	2.4	2.4	2.5	2.2
60. Heat unaccounted for	—.3	—1.3	1.6	1.3	2.9	2.2	1.3	.6	1.4	3.1	2.2
61. Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

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[1] No coil.

[2] Cooling coil in operation during first 8⅓ hours of test only.

RESULTS OF THE TESTS.

The results of the tests are given in the table. The quantities of heat absorbed by the boiler, superheater, and cooling coil, when the latter was used, are itemized separately. In the heat balance the losses by radiation are given by a separate item. In a series of tests with the same boiler and setting the radiation loss per square foot of exposed surface should be nearly constant and should vary only slightly by the capacity developed by the boiler. For the calculation of the radiation loss it was estimated that 250 B. t. u. were lost per square foot of the exposed surface per hour when the boiler was operated at 100 per cent of rating and 350 B. t. u. when operated at 200 per cent of rating. The radiation loss was calculated according to the percentage of rating developed. These calculations of the radiation loss leave the true "unaccounted for," which consists largely of errors. In a series of well-conducted boiler tests this true "unaccounted for" should be close to zero and should vary on both sides of the zero line according to whether the plus or minus errors predominate.

EFFECT OF FINENESS ON RESULTS OF TESTS.

It has been customary to state that in order to get good results the coal must be pulverized to a fineness of 95 per cent through a 100-mesh screen and 85 per cent through a 200-mesh screen. The table below gives the results of complete sizing tests of the coal burned in tests 32 to 35, inclusive. The coal was much coarser than specified by the foregoing statement. The results of these tests seem to indicate that it is not necessary to pulverize the coal to the extreme fineness of 85 per cent through a 200-mesh screen in order to get good combustion and efficiency. The completeness of combustion seems to be more a matter of a proper furnace and burner design and the right way of supplying air than of the fineness of the coal. The losses due to coarseness of coal would be shown by the greater percentage of carbon in the refuse. The average loss due to this cause for the four tests with the coarser coal is 0.7 per cent. The average of this loss for the previous four tests is 0.6 per cent. The averages of the efficiencies are very nearly the same.

The ability to burn coarser coal means increased capacity of the pulverizing mills and decreased cost of coal preparation.

EFFECT OF MOISTURE IN COAL ON RESULTS OF TESTS.

Another statement that has been generally accepted is that coal must be dried to about 1 per cent moisture in order to be successfully burned in pulverized form. In order to determine to what extent this statement is true, tests 36, 37, and 38 were run with undried coal. The results of the tests show that the completeness of combustion was as good as with the dried coal.

Results of sizing tests of coal burned in tests Nos. 32–35.

Test No.	Percentage of coal passing through screens.			
	20 mesh.	40 mesh.	100 mesh.	200 mesh.
32	99.9	99.2	93.2	67.0
33	99.9	99.2	93.1	70.1
34	100.0	98.9	90.8	65.5
35	99.8	98.0	88.6	64.0

There was no loss due to CO in the flue gases, and the losses due to combustible in the refuse averaged only 0.3 per cent for the three tests, which is in fact less than the average with the dried coal.

The losses due to moisture in coal, of course, increased 0.5 to 0.6 per cent, which increase is at the rate of about 0.1 per cent for every 1 per cent of increase of moisture in the coal. The average decrease in the boiler efficiency for the three tests is about 0.7 per cent, which checks closely with the increase in the losses due to increased moisture in the coal. It seems, therefore, that it is not necessary to dry the coal down to 1 per cent of moisture in order to get good boiler efficiency. In fact, it seems that most of the eastern coals can be pulverized and burned with good results without drying.

BOILER CAPACITY THAT CAN BE DEVELOPED WITH PULVERIZED COAL.

The boiler capacity that can be developed with pulverized coal depends entirely upon the size and shape of the furnace. With the present knowledge of the art of burning powdered coal the best results are obtained when the coal is burned at the rate of 1 to 1½ pounds per cubic foot of combustion space per hour. Good results can be obtained when the coal is burned at rates varying from one-half to 2 pounds per cubic foot of combustion space per hour, which gives a considerable working range. In the table on page 119 the rate of combustion is given by item 12. The range covered by this series of tests is from 1.05 to 1.8 pounds of coal per cubic foot of combustion space. If it is desired to operate the boiler at high rates of working, a large furnace must be installed and the combustion space must be so arranged that the flames are given the longest possible path through the furnace. The design of the burners and the admission of air are very important factors at high rates of combustion. It appears probable that future developments in the design of furnaces, burners, and the air supply may make possible higher rates of combustion than the limit given above.

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