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DEPARTMENT OF MINES

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The Preparation, Transportation, and Combustion of Powdered Coal

BY

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PREFACE

The Division of Fuels and Fuel Testing, since the organization of the Mines Branch, Department of Mines, in 1907, has been engaged in conducting investigations which have had as their objective the development of the fuel resources of the Dominion.

Owing to the long haul from the coalfields in the extreme east and west of the Dominion, the immense intervening territory—which is highly industrialized, but devoid of any coal deposits of economic value—is practically isolated from our great national assets of coal. This unfortunate isolation has made it imperative (1) that the most efficient methods be employed for converting the coal imported from the United States into heat and power for industrial purposes; and (2) that effective methods be devised to make it possible to utilize the extensive areas of low-grade fuels found in the intermediate provinces—such as peat and lignite—for domestic and other purposes.

With this end in view, investigations involving a large amount of research work have been conducted, from time to time, to show how peat fuel can be utilized for the generation of power through the media of the gas producer and gas engine, and also through the steam boiler and steam engine. Tests on a commercial scale have been carried out with western coals, both bituminous and lignite, for the purpose of determining their special value for steam raising, and the production of a power gas when burned in a gas producer. Research work of a very important character has also been under way for several years, in the carbonization and briquetting of the Saskatchewan lignites. The investigation on which the following report is based, logically follows the practical work already done.

The utilization of powdered fuels for steam raising is not new. A steam boiler designed for burning powdered coal was operated some years ago in eastern Canada; and experiments were conducted at the Baldwin Locomotive Works, Philadelphia, U.S.A., with regard to the burning of powdered coal in locomotives. Moreover, peat powder has, for some time, been successfully burned in place of coal on certain of the Swedish State Railways. During the last few years, however, very important developments have taken place in the methods and apparatus for burning powdered coal—not only for the generation of steam, but also for metallurgical and other purposes. The advancing price of coal, due to increased cost of labour, and, to some extent, to increased difficulty in mining and preparing the coal for the market, has made it possible in certain instances to economically generate power from the lower grades of coal, by burning them in the powdered form; but the economy of any process for burning coal in the powdered form for the generation of power depends on the cost at which a good grade of coal can be obtained suitable for steam raising, when burned under a boiler in the usual manner. Higher efficiencies, it is true, can be realized with powdered coal systems properly installed and designed; but unless the saving in coal bills due to these higher efficiencies, coupled with the resulting reduction in labour costs, more than offsets the cost of burning the higher grade coals in the ordinary manner for the generation of power, it would not pay to re-design old power plants for burning powdered coal. It is quite possible, however, that the lower grade lignites of western Canada, which rapidly disintegrate when exposed to the weather, may be efficiently burned in the powdered state for the generation of power and other purposes. The accompanying report will show how the lower grade fuels can be advantageously employed for metallurgical and steam raising purposes, when burned in the powdered form.

The field studies on which the report is based, were undertaken during August and September in 1919. Mr. Blizard resigned from the Mines Branch in March, 1920, to accept the position of fuel engineer to the United States Bureau of Mines at Pittsburgh; and although the compilation of the report was not completed until after he had left Ottawa to assume his new duties, the information submitted has been brought well up-to-date.

Mr. E. S. Malloch, of the Division of Fuels and Fuel Testing, devoted a large amount of time to reading, correcting, and rearranging the report, and, in general, putting it in shape for the press.

(Signed) **B. F. Haanel,**
Chief Engineer,
Division of Fuels and Fuel Testing.

July 6, 1921.

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INTRODUCTORY

In the following pages, the writer has endeavoured 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 cannot 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, which energy 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; COMPOSITION

Size.—Since the coal has to be pulverized, it is usually better to purchase slack coal since it 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 which melts 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. I. Gadd, in the Journal of the Franklin Institute (Vol. 182 No. 3) states that coal used in heating and puddling furnaces should fulfil approximately the following requirements:—

Volatile matter, not under..	30·00	per cent.
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:—

Volatile matter, not under..	36·00	per cent.
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 labour 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 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 low fusing point ash in large quantities in the coal 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 (Mines Branch bulletins 23 to 26).

The approximate analyses and sulphur content of some of these coals, on the dry basis, are quoted below. The moisture content referred to 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	Crow's-nest	Nanaimo
Ash, per cent............	9·2	3·4	4·4	8·5	9·0	8·6
Volatile matter, per cent..	33·7	33·3	31·5	41·4	26·3*	40·4
Fixed carbon, per cent....	57·1	63·3	64·1	50·1	64·7	51·0
Sulphur, per cent.........	0·6	0·9	0·4	0·2	0·5	0·5

*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 to burn it; 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.

By far the more common of the two systems is the multiple system, which consists of many different pieces of machinery and apparatus, which differ considerably in design in different plants; but the small unit systems are all very similar in design. The unit system will be first described, 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: (1) UNIT SYSTEM; (2) MULTIPLE SYSTEM

Unit System described.—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 Fig. 1; the paddles for pulverizing and the fan for propelling the air are shown in Fig. 2.

Fig. 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.

Fig. 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 sufficient room to install them near the furnaces, and where the

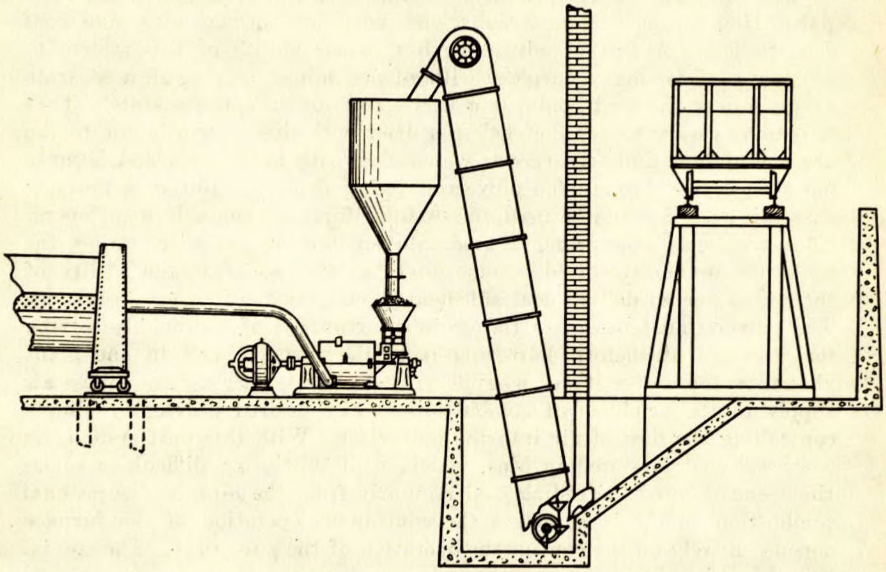


Fig. 1. Aero pulverizer supplying pulverized coal to rotary kiln.

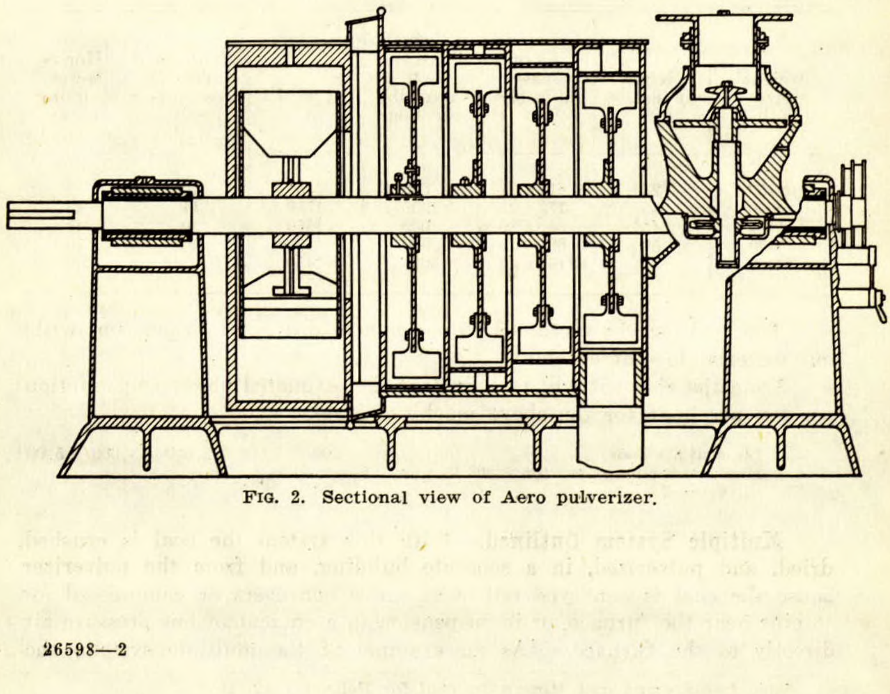


Fig. 2. Sectional view of Aero pulverizer.

quantity of coal used would not warrant expenditure upon 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 preliminary drying in a separate dryer, unless the coal contains a very great amount of moisture. That it is unnecessary to dry the coal in a drier with this system is due to the absence of bins and feed screws which clog with moist coal, and because the air passing through the pulverizer partly dries it. 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 simply 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 continuous 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:—

Weight Size in lb.	Height (in inches)	Floor space (in inches)	Normal load soft coal (lb. per hour)	R.P.M.	Normal power consumption H.P.	Horse-power of motor recommended
A 2250....	28¾	61¾ x 27¾	600	2050	10	15
B 4000....	45	77½ x 29	1000	1750	14	25
D 5400....	46¾	85¾ x 29	2000	1550	30	40
E 5900....	50	89 x 33	3000	1450	40	50
G 12000....	59	116 x 40	5000	1450	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:—

Lb. coal per hour........................	600	1,000	2,000	3,000	5,000
Horse-power hours per ton (2000 lb.) pulverized............................	33	28	30	27	26

Multiple System Outlined.—With this system the coal is crushed, dried, and pulverized, in a separate building, and from the pulverizer house the coal 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. *As an example of the multiple system, the

* See *Engineering and Mining Journal* for February 12, 1916.

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.

Coal in railway cars.
|
80-ton receiving coal bin.
|
Two 30″ x 30″ Jeffrey single roll crushers.
|
Two vertical chain elevators.
|
36″rubber belt conveyer.
|
1,000-ton crushed coal storage bin.
|
2-24″ belt conveyers at right angles.
|
24″ x 26″ "Ding" magnetic pulley.
|
16″ chain elevator.
|
Chute to No. 1 dryer and 14″ screw conveyers to No. 2 and No. 3 dryers.
|
3-40 ft. by 80″ Ruggles Coles dryers (dust fired).
|
3-34″ by 20″ Jeffrey coal disintegrators.
|
14″ screw conveyer.
|
Chain elevator (18″ bucket).
|
14″ screw conveyer system.
|
10, Raymond 5—roller mills (54″).
|
10. No. 11 Raymond special exhausters.
|
10, 7 ft. cyclone dust collectors.
|
10, 4 ft. auxiliary cyclone dust collectors.
|
14″ screw conveyer system (also 6″ conveyer to dryer fireboxes).
|
9-50-ton pulverized coal bins, one at each reverberatory furnace.
|
Warford 4″ screw coal burners.
|
Supply of air from 16 oz. blowers.
|
9 reverberatory furnaces.

The above flow sheet is typical of many multiple systems of powdered coal installations. A good diagrammatic illustration of a similar system is shown in Fig. 3. The American Industrial Engineering Company of Chicago prepared this diagram. From the flow sheet and the diagram (Fig. 3) it will be observed that the coal is first crushed. The general size to which it is reduced is from ¾-inch to 1-inch lumps. It is next passed over a magnetic separator to remove tramp iron, which consists of bolts, nuts, rivets, nails, railroad spikes, etc., for if this iron were not removed it would damage, and possibly cause an explosion in the pulverizer. After leaving the magnetic separator it passes to the dryer, 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 dealt with in separate chapters.

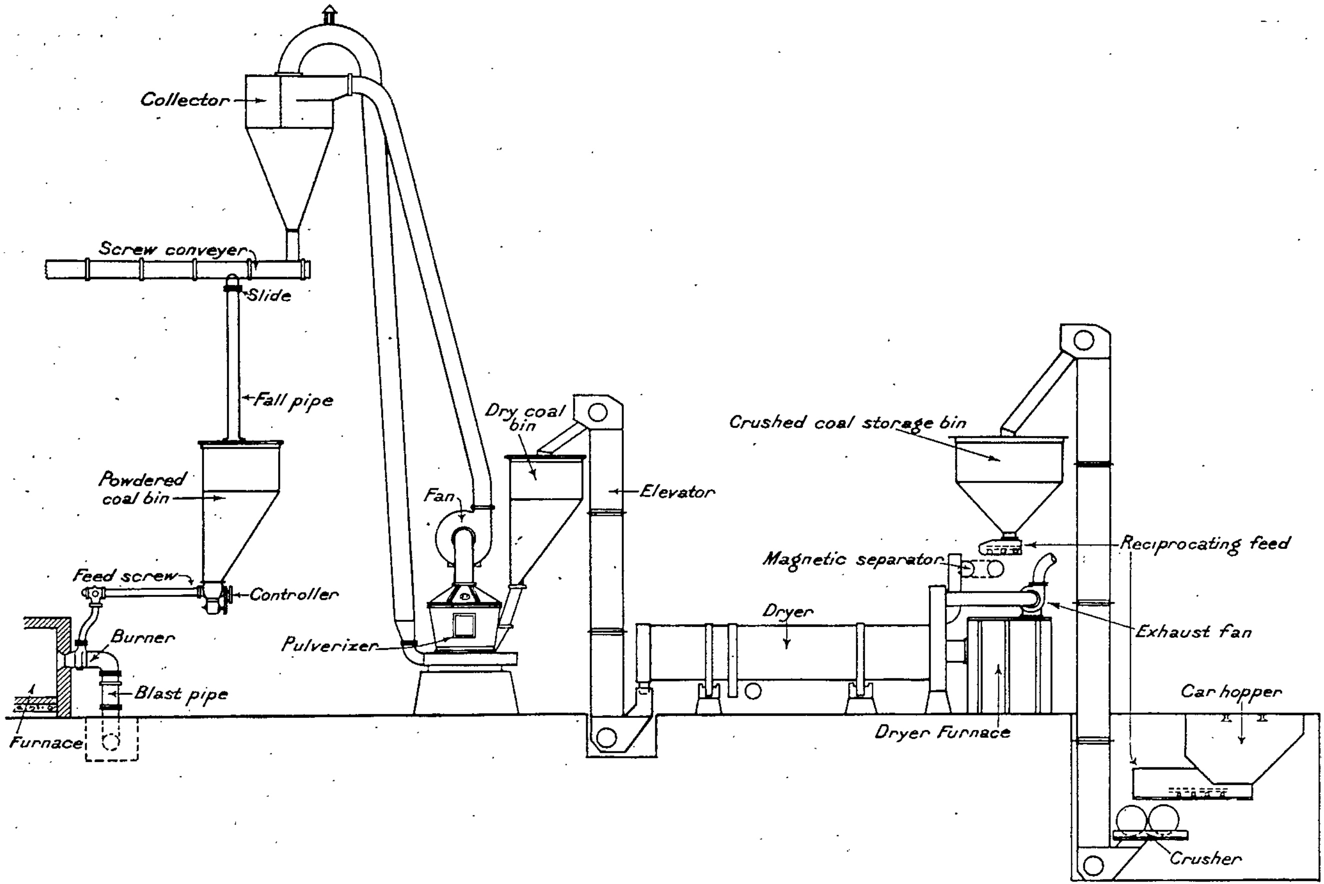


FIG. 3. General arrangement of machinery for drying, pulverizing and conveying coal to burner at furnace.

CHAPTER II

PREPARATION OF POWDERED COAL

DRYING

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

Description of Dryers.—In the usual dryer employed, coal is fed into the upper end of an inclined cylindrical shell, fitted with rollers, on which it is rotated slowly by an electric motor. The speed at which the coal moves through the dryer may be varied by changing the inclination of the shell and the speed of rotation. The dryer shell usually rotates 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 dryer, and passing the hot gases from the furnace either immediately over the coal to be dried, or first over the shell of the dryer; and, after being cooled, through the inside of the shell in contact with the coal. The best and safest dryers are those of the latter, or indirect type; so constructed that the flames and burning gases do not touch the coal until they have been cooled by losing heat to the coal to be dried, indirectly through the shell. The gases of combustion and the steam evaporated from the coal leave the dryer 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.

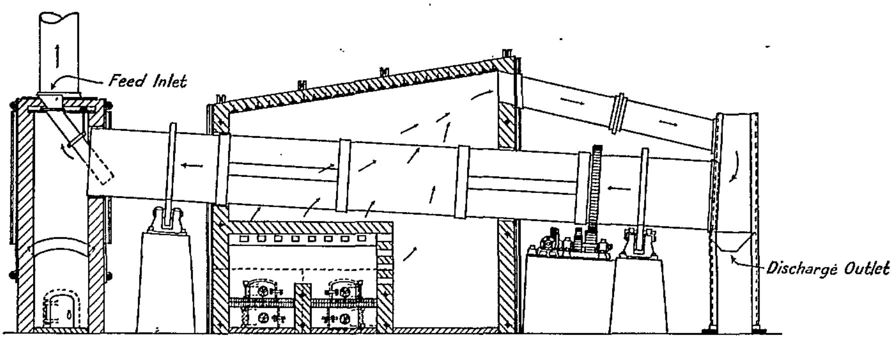


FIG. 4. Indirectly fired rotary dryer. Fuller Lehigh Company.

Fig. 4 illustrates an indirectly fired rotary dryer made by the Fuller-Lehigh Company, 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 Dryers.—A dryer is somewhat cumbersome, and the large, hot, uninsulated cylinder gives out a considerable quantity of heat which may render the drying room uncomfortably hot.

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

Tons coal per hour	Size
4	3′ 0″ x 30′ 0″
6	3′ 6″ x 30′ 0″
8	4′ 6″ x 30′ 0″
10	4′ 6″ x 42′ 0″
14	5′ 6″ x 42′ 6″
20	6′ 0″ x 42′ 0″
25	6′ 6″ x 42′ 0″

Fuel used for Drying.—The quantity of fuel used per 100 pounds of coal leaving the dryer, 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 dryer; the temperature of the gases leaving the dryer; and the thermal efficiency of the dryer.

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 $1082+0.48T-t$: where t is the temperature of coal entering the dryer, and T is the temperature of the gases leaving the dryer.

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 dryer.

In the following table will be found the quantities of undried coal to be burned to dry coal containing from 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	14,000 B.Th.U. per lb.
Temperature of coal entering dryer	70° F.
Temperature of coal leaving dryer	240° F.
Temperature of gases leaving dryer	200° F.
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 dryer

Moisture in coal entering dryer.........	4	6	8	10	12	14	per cent.
Moisture evaporated from coal..........	2·1	4·3	6·5	8·9	11·4	13·9	lb.
Heat to evaporate moisture from coal..	2300	4700	7200	9900	12600	15500	B.Th.U.
Heat given to 100 lb. coal..............	4100	4100	4100	4100	4100	4100	B.Th.U.
Total heat used............	6400	8800	11300	1400	16700	19600	B.Th.U.
Coal burned 70 per cent efficiency.......	0·68	0·95	1·25	1·58	1·93	2·32	lb.
Coal burned 60 per cent efficiency.......	0·79	1·11	1·46	1·84	2·26	2·71	lb.
Coal burned 50 per cent efficiency.......	0·95	1·34	1·76	2·21	2·71	3·25	lb.

It is usual to fire the coal used in dryers 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 dryer to too high a temperature.

Power used for Drying.—Very little power is used to rotate the shell of a dryer. The following table gives the estimate of the power used to rotate the shell of a Fuller-Lehigh dryer:—

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

Precautions to be taken in drying the coal.—In selecting a dryer it is better to choose a dryer too large rather than too small. When a dryer 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 dryer. Further, the higher the temperature at which the coal leaves the dryer 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 on leaving the dryer should, if possible, be interlocked electrically with the dryer, so that there may be no danger of coal remaining too long in the dryer becoming very hot, and giving off combustible gases which may mix with air, ignite, and explode. All elevators and bins which elevate and store hot coal should be well ventilated to permit any gases given off 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 than this, 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 as the coal is pulverized more finely.

Power to Pulverize Coal.—A table is here reproduced from the transactions of the American Society of Mechanical Engineers (Vol. 36), which shows the horse-power 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 H.P. required	H.P. 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 Company publish the following particulars of their pulverizing mills, for pulverizing to 95 per cent through 100 mesh:—

Size	Size of feed	Output per hour	Horsepower
24″....................................	Through $\frac{3}{4}$″ ring	1000 to 1200 lbs.	10
33″....................................	Through $\frac{3}{4}$″ ring	2 to $2\frac{1}{2}$ tons	30 to 35
42″....................................	Through 1″ ring	4 to 6 tons	45 to 50
57″....................................	Through $1\frac{1}{4}$″ 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 $\frac{3}{4}$ horse-power hours, or about the equivalent of 1900 B.Th.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, 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, tc 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 coals is shown in Fig. 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 and 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.

Fig. 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.

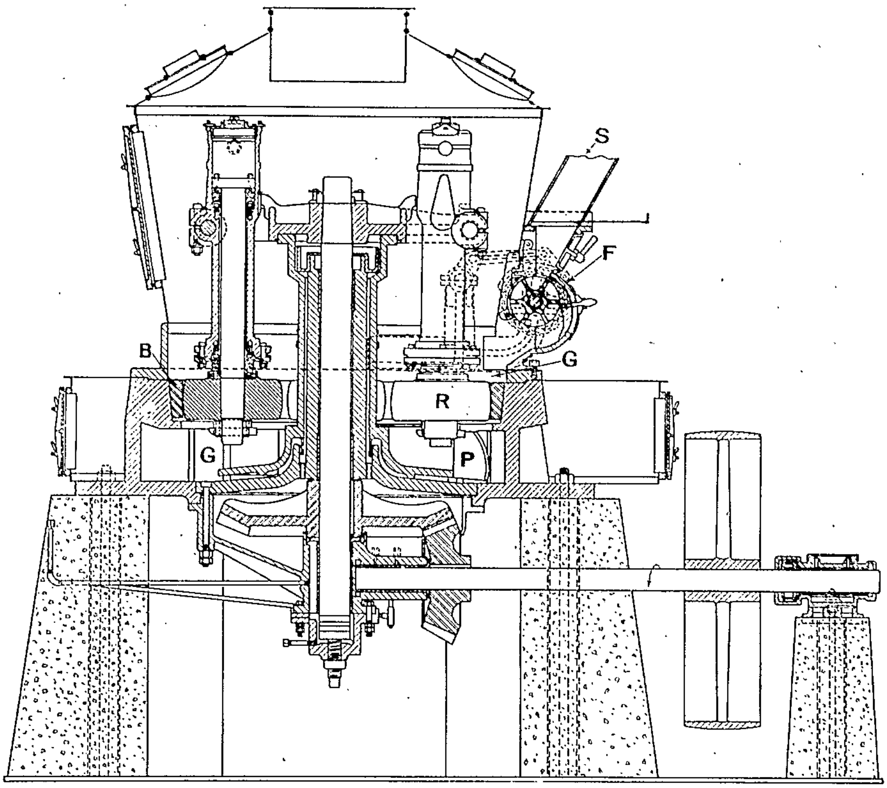


FIG. 5. Cross section of Raymond Bros.' four roller pulverizing mill.

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, passes upward round the roller (R) and pulverizer ring (B).

This mill will pulverize coal varying in size from ¼ inch to 1½ inch, to a fineness of about 95 per cent through 100 mesh. When it is necessary to grind coal more finely than this, Messrs. Raymond Brothers recommend a mill with a similar pulverizing system, but a more elaborate separating system.

Bonnot Pulverizer.—Fig. 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 enclosing 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.

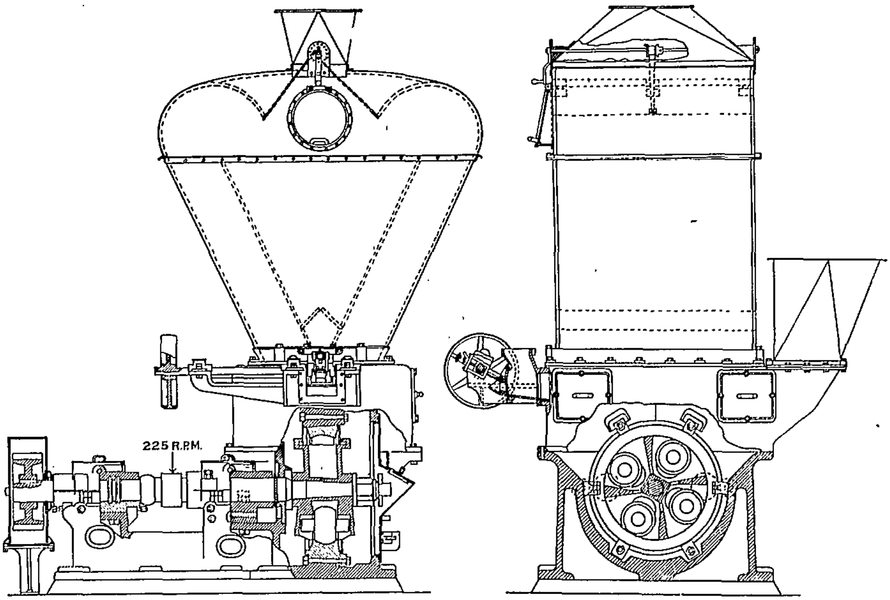
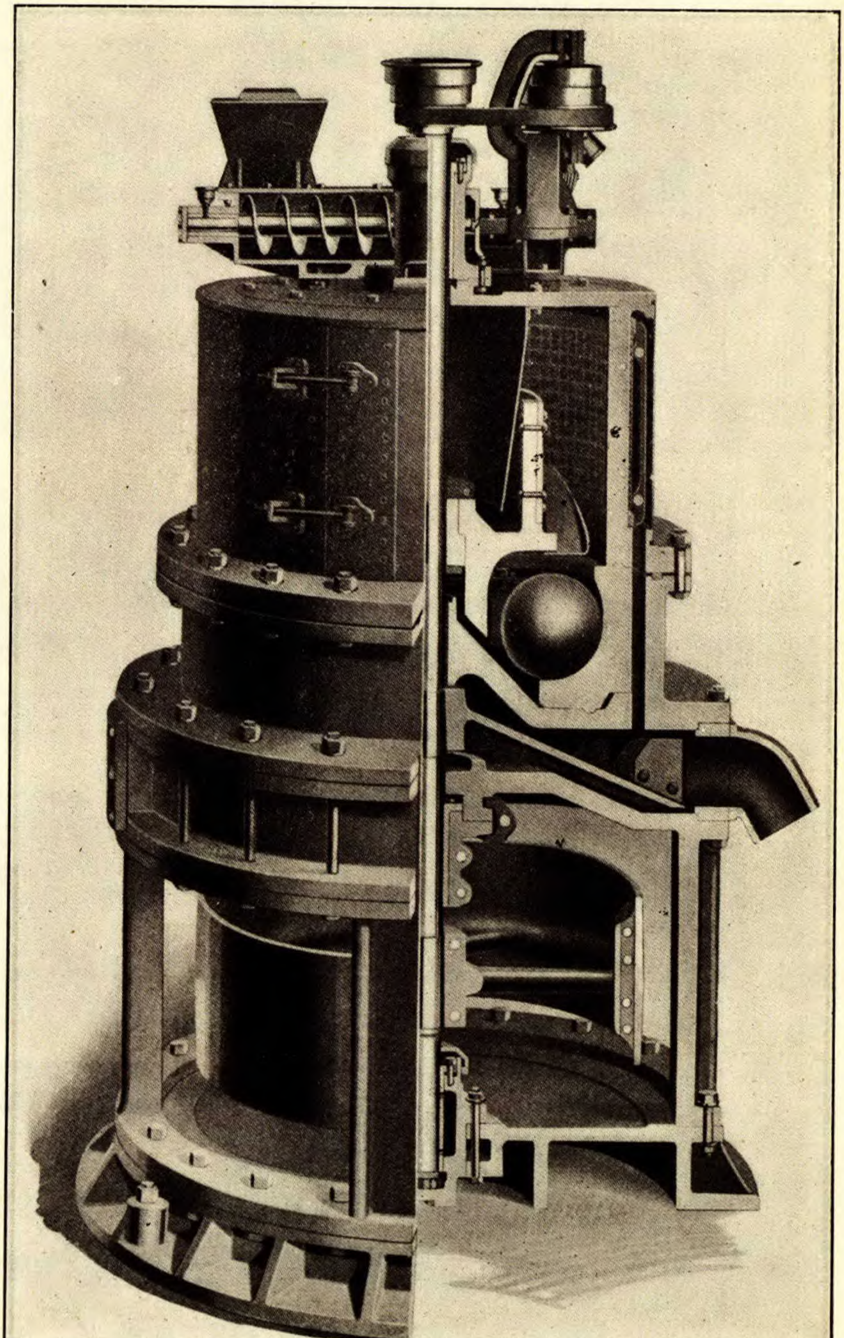


FIG. 6. Cross section of Bonnot coal pulverizer. Capacity 4 to 5 tons per hour.

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 with 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.

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, so as 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 require no additional fan mounted on a separate shaft like the Bonnot and Raymond mills require. 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 with usage wear and assume an ellipsoidal shape, then the mills become very noisy. The balls wear more rapidly when the coal is fed irregularly. The Fuller-Lehigh Company manufacture 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" Fuller pulverizing mill, fan discharge, pulley driver, 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 furnaces; namely, the indirect, and the direct system. The coal may be distributed indirectly to the furnaces by screw conveyers, or compressed air, to bins situated near the furnaces, whence the coal is fed by a screw or other means to the furnaces; or it 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 less danger from explosion, due to the greater control over the rate of feeding the coal to the furnace, and by the 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 Fig. 3 (see general arrangement, p. 20), 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, since 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 Fig. 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, comparatively 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 one horse-power 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 Company have developed a system whereby coal, after being aerated slightly, is forced through pipes by a small helical

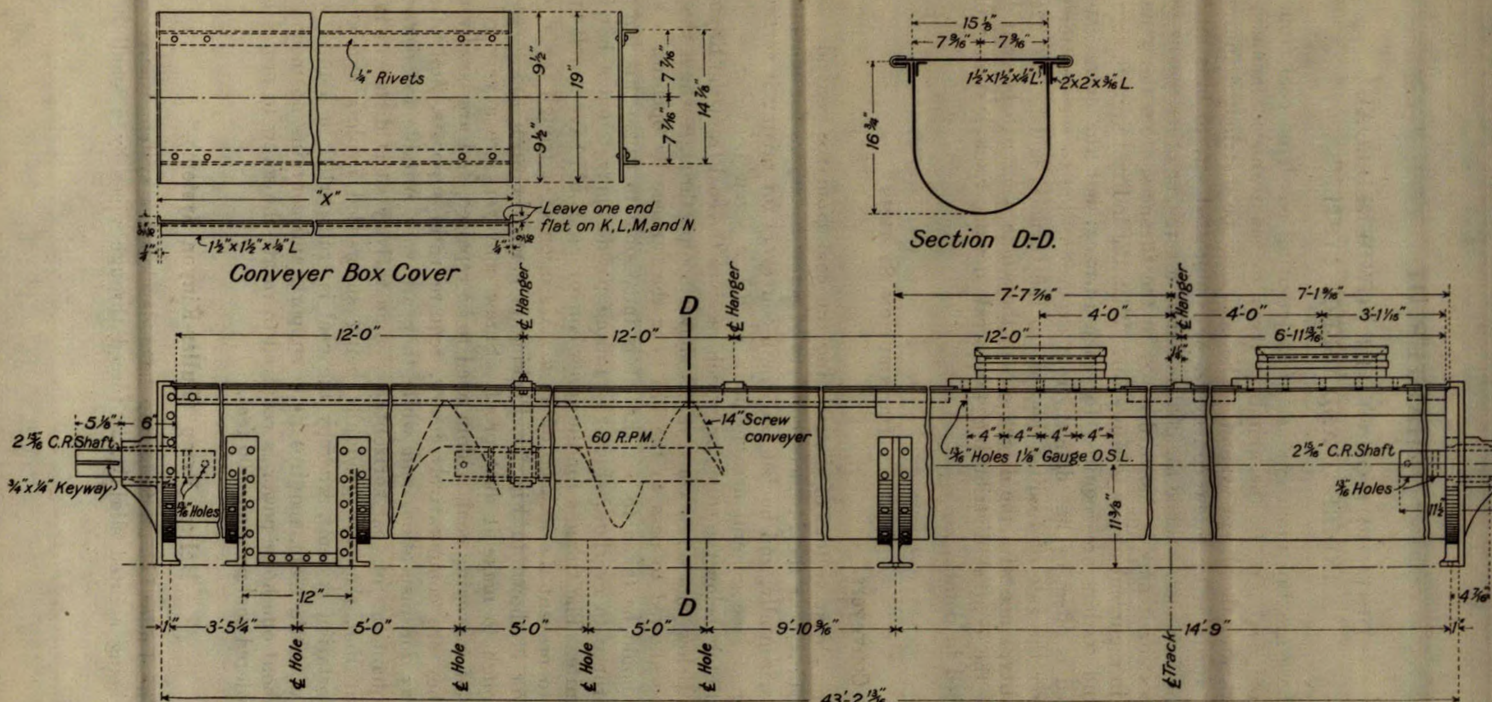


FIG. 7. Screw conveyer for powdered coal.

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 on to 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 one horse-power is required to propel one ton at the rate of 9 tons per hour 350 feet, and 5 horse-power to propel one 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 one cubic foot of pulverized coal.

The Fuller-Lehigh Company state 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 Company, 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." Also, he states: "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 gauge."

The writer saw this system of air transport working successfully at the plant of Messrs. Dilworth Porter & Company, 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 x 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.

Fig. 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 Fig. 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 2 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 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 it 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 and Patterson Installation.—Messrs. Heyl and Patterson also install a compressed air transport system. Mr. E. C. Covert, contracting engineer for Messrs. Heyl and Patterson, has designed and installed an air transport system at the Oliver Iron and Steel Company, which installation was seen by the writer.

At this installation, 60 tons a day are conveyed 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 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 Company.—The International Nickel Company have constructed an air transport system for powdered coal, at Copper Cliff, Ont. Messrs. E. P. Mathewson and W. T. Wotherspoon refer to this system in a paper on the application of pulverized coal to blast furnaces (Canadian Mining Institute Bulletin, July, 1919), and state 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.

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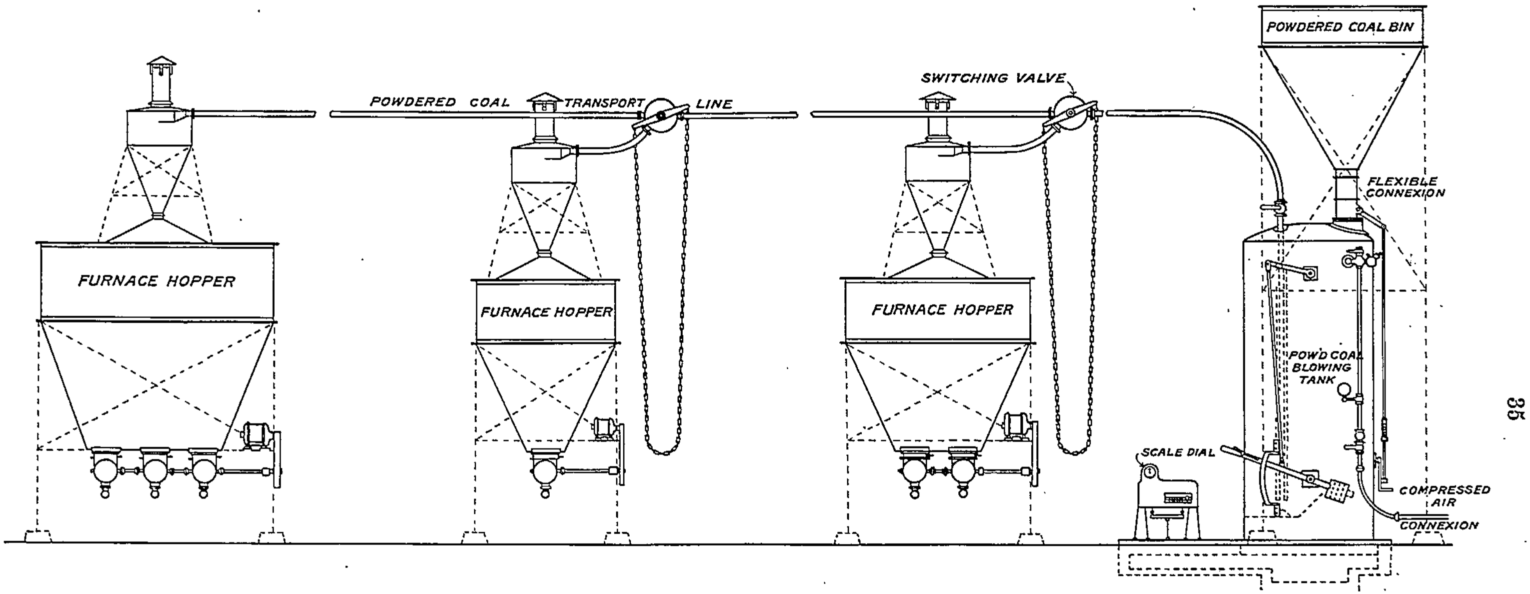


FIG. 8. General arrangement of powdered coal transport system, manufactured by Quigley Furnace Specialities Co.

Bonnot Compressed Air Transport (combined with Direct Delivery System).—The Bonnot Company have 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 sub-stations 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 sub-station in 8 minutes, with 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 sub-station, and the method of distributing coal in suspension in air from the sub-station bin. The details of the flow of coal to the furnaces are indicated below:—

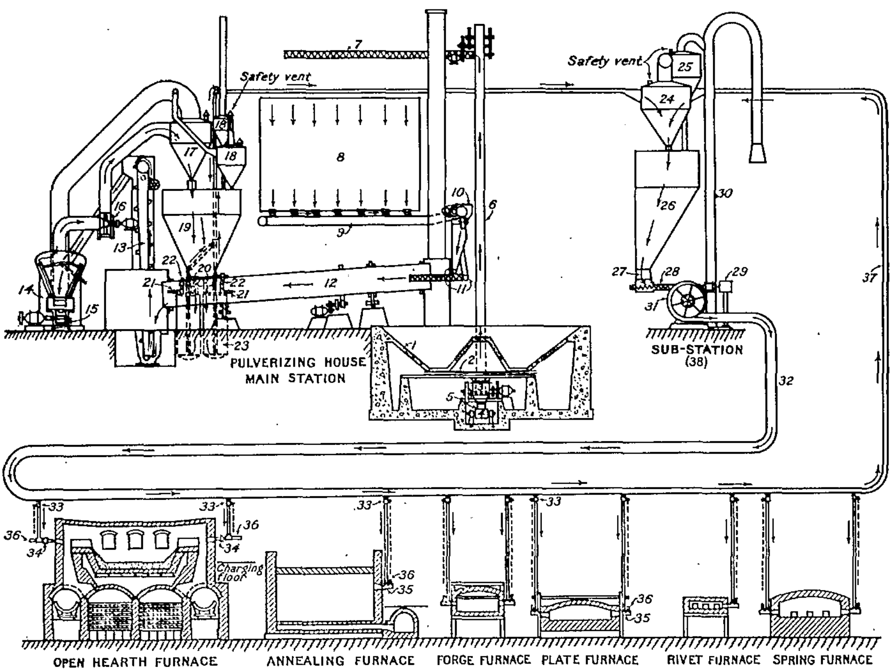


FIG. 9. General arrangement of a powdered coal system with sub-station, Installation in plant of Pressed Steel Car Co., by Bonnot Co.

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 same to coal dryer.
12—Rotary dryer.
13—Centrifugal discharge bucket elevator to deliver coal from dryer 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 same 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 sub-stations through a 3-inch pipe line by means of compressed air.
24—Pulverized coal collector, at sub-station, 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, thus 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.
38—At McKees Rocks plant there are five sub-stations, 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 miscellaneous order department and one for plate heating furnaces in pressing department. The mixture of air and pulverized coal in 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.

(From the Iron Age, Vol. 102, No. 12.)

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 Fig. 9, and is used to distribute the powdered coal directly from the sub-station 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 sub-station, 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 which 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 and Tin Plate Company's plant, an additional blower was installed at about the farthest

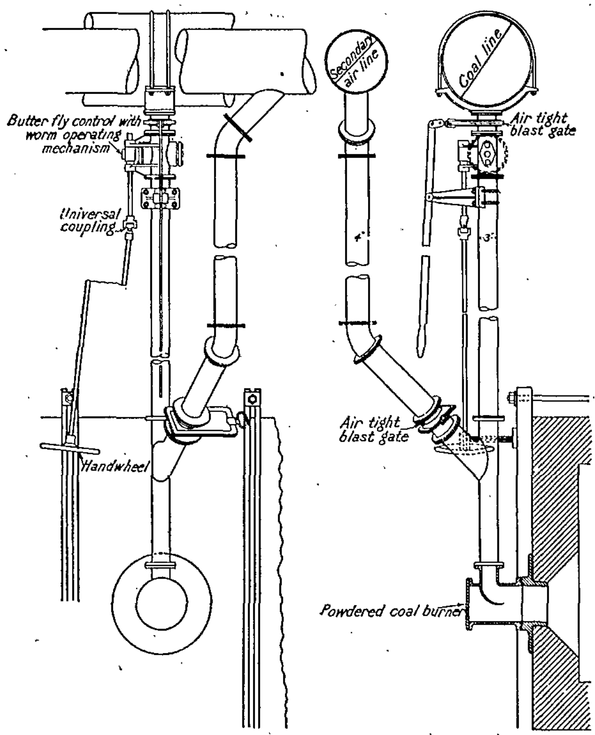


FIG. 10. Coal and air control, Holbeck system, Bonnot Company.

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 Fig. 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. Fig. 11 shows details of an adjustable baffle, for deflecting

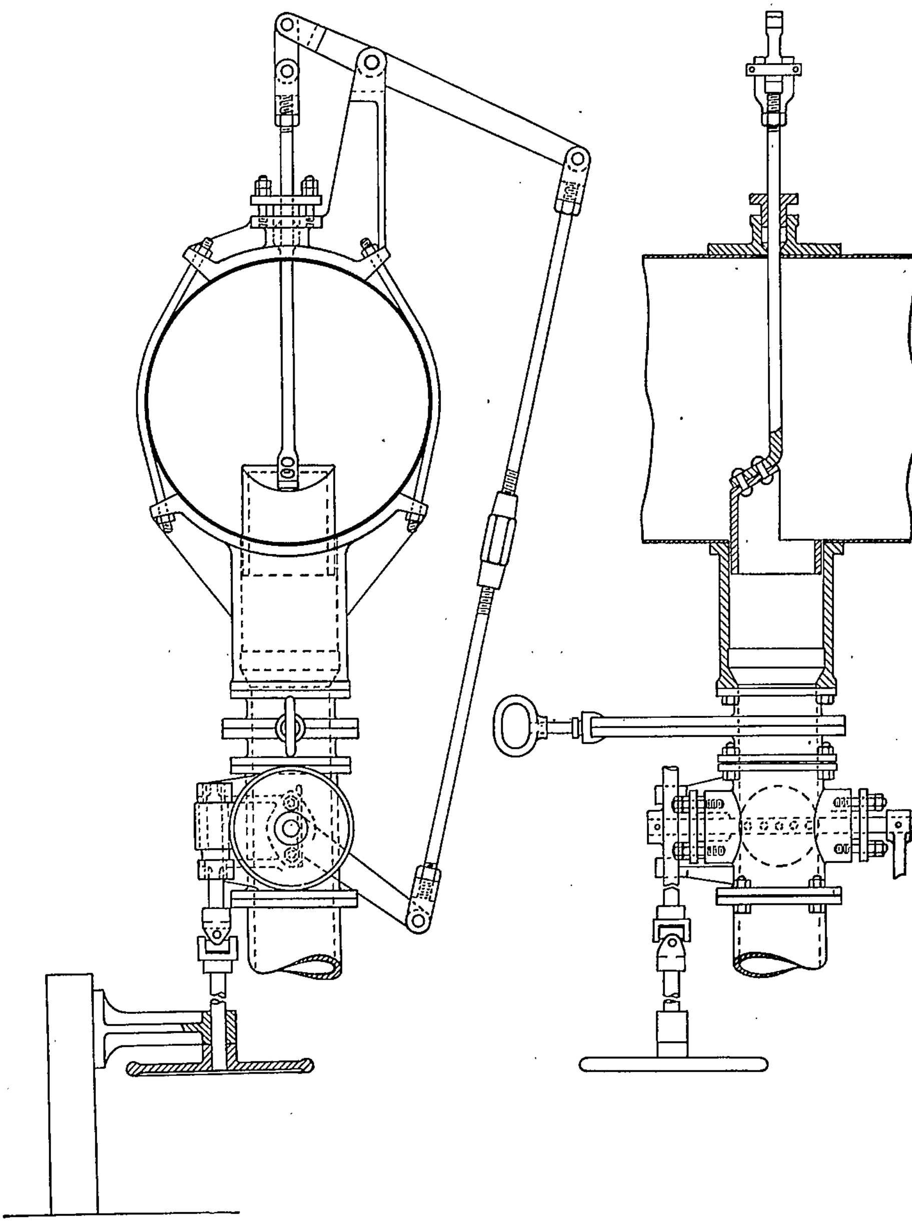


FIG. 11. 5″ Butterfly control wth adjustable baffle. Holbeck system, Bonnot Company

the coal and air from the trunk to the branch line, and of the gate and butterfly valve in the branch line.

Fig. 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 the 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 view the burning coal.

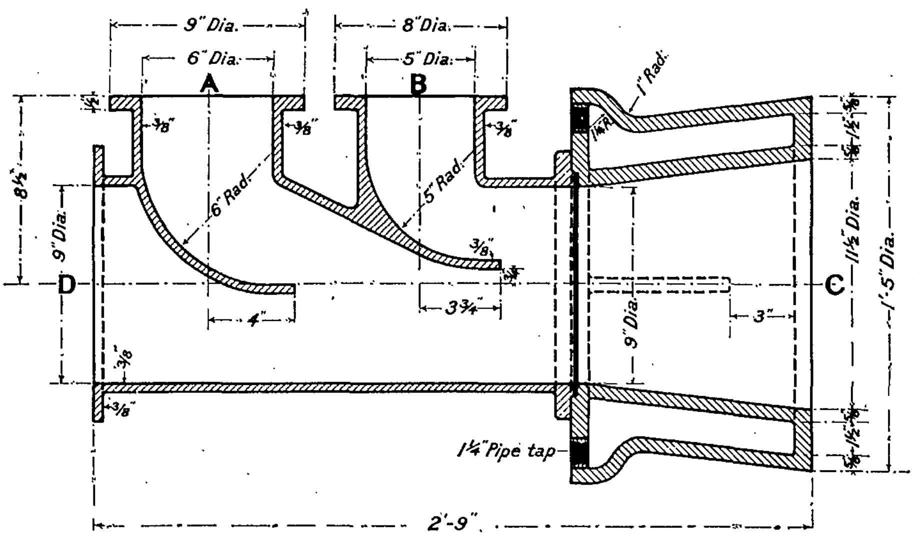


FIG. 12. Longitudinal section of 5" Standard water cooled burner. Holbeck system, Bonnot Company.

The Bonnot Engineering Company appear to use the coal in suspension system entirely, and usually distribute 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 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, since there are no bins near the furnace containing a reserve supply of powdered coal with separate mechanism for feeding it to the furnace.

The fan has to keep air and coal in continuous motion; and while the larger portion of the air is used to burn the coal, it has travelled 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.

At the plant of the Bethlehem Steel Company, 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.

Horse-power used to drive conveying fan..	26·55
Air discharge per minute..	3,826 cu. ft.
Quantity of coal delivered with air per minute.. ..	29·68 lb.
Air discharged into furnace per minute..	3,082 cu. ft.
Coal discharged into furnace per minute..	23·91 lb.
Cubic feet of air used per pound of coal..	129
Mean velocity of air in 12″ pipe..	4,900 ft. per min.
Velocity head for mixture of coal and air..	1·4 in. water.
Pressure of mixture leaving fan..	10·2 " "

In the above test the power consumption to deliver 2,000 pounds of coal per hour and most of the air required to burn it was 37 horse-power; a greater expenditure of energy than would be required to convey 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 were well satisfied, and the substitution of powered coal for hand firing had reduced the coal consumption considerably, and enabled them to use a cheaper coal than they had 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.

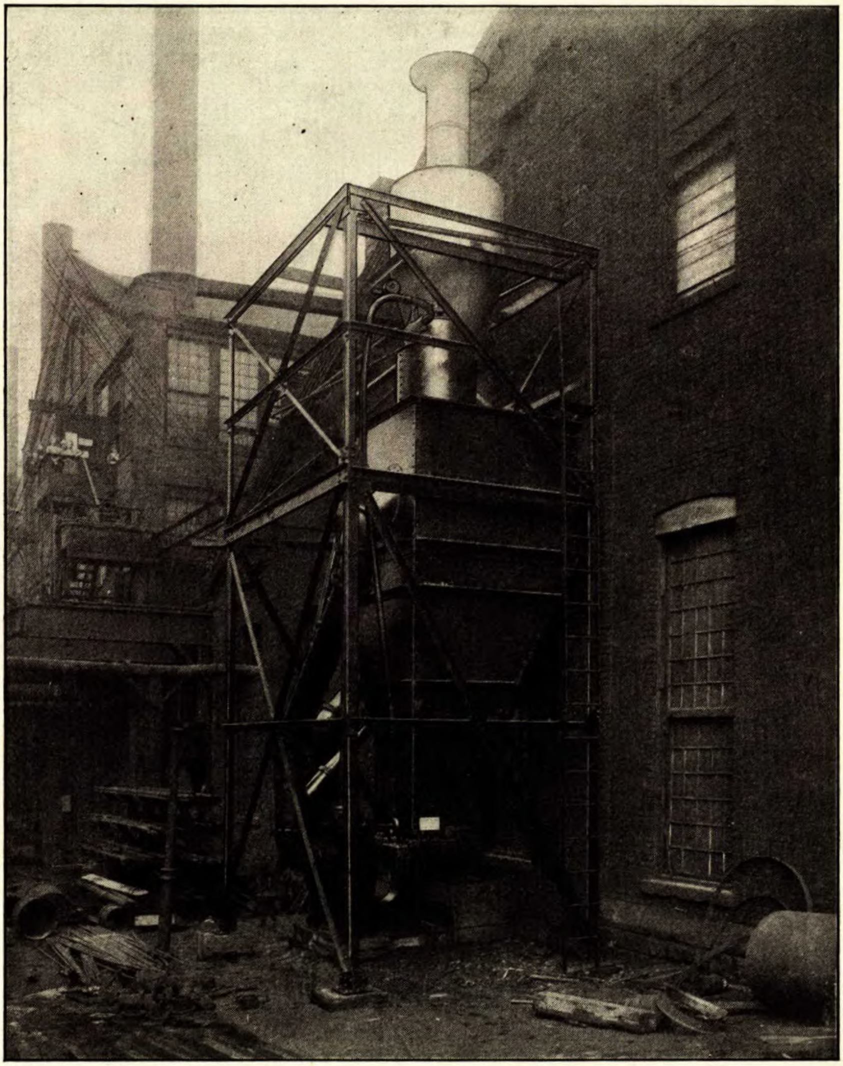
A good description of a Bonnot powdered coal installation appears in "Mining and Metallurgy," February, 1920. In this article, Mr. R. E. H. Pomeroy describes the coal pulverizing plant at the Nevada consolidated copper smelter, and states that after 14 months continuous operation the plant proved entirely satisfactory. At this 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 at this plant, 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 this 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 non-return 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 30 kw. hr. per ton of raw coal pulverized.

Mr. Longuenecker, of the Bonnot Engineering Company, states 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 and Patterson Installations.—Mr. E. C. Covert, of Messrs. Heyl and 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 Messrs. Heyl and Patterson's 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 which has been 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.



Sub-station for Covert system. Messrs. Heyl and Patterson.

CHAPTER IV

FEEDERS, MIXERS, AND BURNEDS (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 its dryness, aeration, and fineness. It will frequently adhere to the sides of the bin, arch, fall down and enclose 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. While 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 on to the bin sides, and almost the sole remedy used, lies in drying the coal sufficiently, and cooling 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 Company.

Fig. 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, detachable pipes, into two 14-inch screw conveyers. A 10 H.P. 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 5 openings, through each of which the coal falls into a specially constructed screw conveyer, which propels the

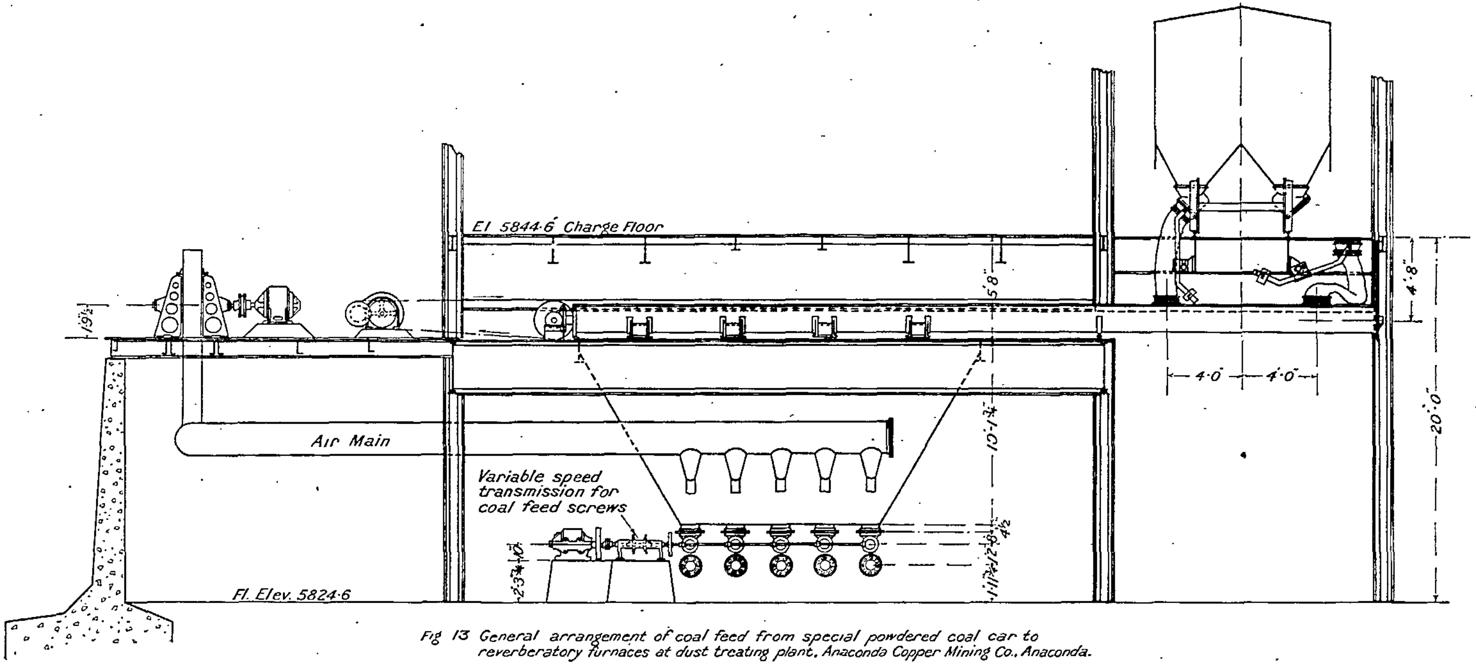


FIG. 13. General arrangement of coal feed from special powdered coal car to reverberatory furnaces at dust treating plant. Anaconda Copper Mining Co., Anaconda.

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 75 horsepower motors. A 10 horsepower motor drives the five screw conveyer feeders, through a "Reeves" variable speed transmission of pulleys and bevel gears. Fig.14 shows the coal feeding screw, and the air and coal

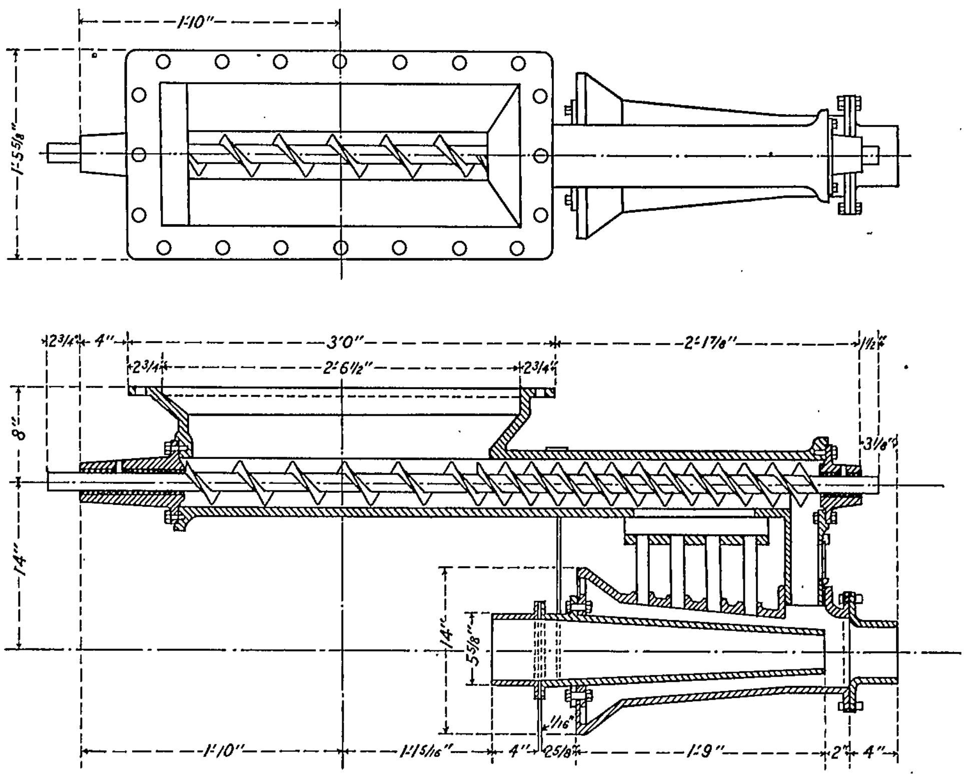


FIG. 14. Warford coal feeder and coal and air mixer.

mixer in a chamber beneath 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 inches to 28 inches of water through a conveying pipe in the centre 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 air from the blower, induced air and coal, passes from the mixer into a blast pipe, where more air is drawn in, and from which the air and coal enter the furnace. Fig. 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.

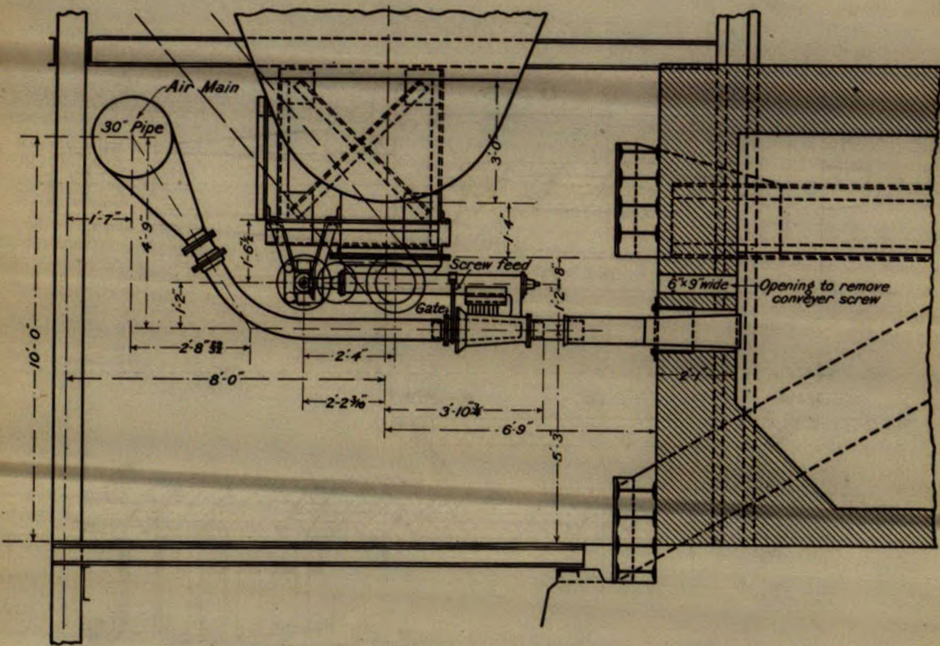


FIG. 15. View showing bottom of coal bin, screw feed, air main and burner for the reverberatory plant at Anaconda.

Fuller-Lehigh Feeder, Mixer, and Burner.

The Fuller-Lehigh Company install a pulverized coal feeder, similar to that used at Anaconda. The feed screw is long, and revolves in a cylinder bored to neatly fit it. 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 size of feeders generally supplied by the Fuller-Lehigh Company are as follows:—

Size feeder	Capacity at 30 R.P.M. lb. per hour	Capacity at 60 R.P.M. lb. per hour
3"..........................	300	600
4"..........................	650	1,300
5"..........................	1,300	2,600

A motor of about 1 H.P. is of ample power 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. Fig. 16 shows a design of coal and air mixer, and burner designed by the Fuller-Lehigh Company. 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.

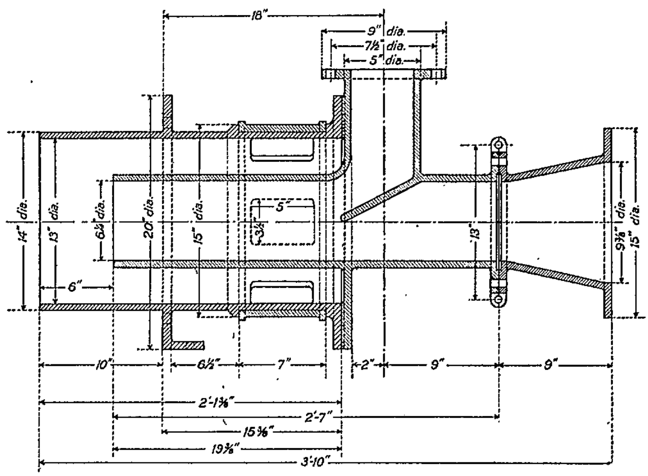


FIG. 16. Longitudinal section, mixer and burner.
Fuller Engineering Company.

American Industrial Engineering Company Feeder, Mixer, and Burner.

The American Industrial Engineering Company install powdered coal bins, with screw feed. They recommend a screw not less than 3 feet long, and specially design the casting at the bottom of the bin, so that the mean velocity of the coal decreases as it reaches the screw. They also recommend that the screw should revolve completely not less than 20 times per minute, to keep the coal from stricking between the flights. The screw conveyer casting at the end of the screw, remote from the bin, has a hole on the top 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 makes it possible to place 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 frequently made fairly long. Fig. 17 shows a general assembly of the American Industrial Engineering Company'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 one 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 falls through the top opening

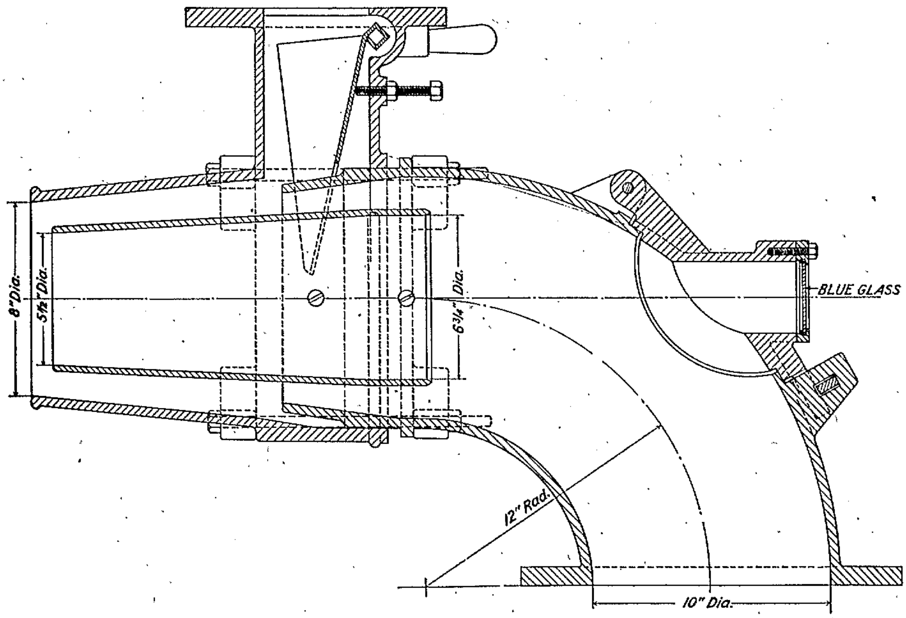


FIG. 17. Longitudinal section of powdered coal burner, type A. American Industrial Engineering Company.

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 Company feed 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 swinging two 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 back. Here, it meets the secondary air supply, under a pressure of about one inch of water, and the combustible mixture passes to the furnace. This system of regulating the fuel and air, is illustrated in Fig. 18.

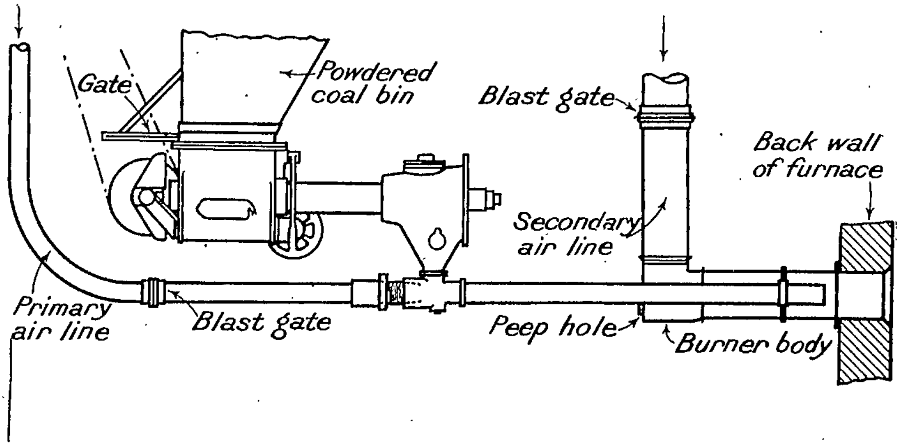


FIG. 18. Diagram of apparatus for regulating fuel into burner. Quigley system.

"Lopulco" Feeders.

The Pulverized Fuel Equipment Company, ("Lopulco" Equipment Manufacturers) have designed the feeder shown in Fig. 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 from 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.

Fig. 20 shows a horizontal burner designed by the Pulverized Fuel Equipment Company, 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 a further supply of air from a rectangular orifice beneath it, moving in a slightly upward direction, which helps the two streams of 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.

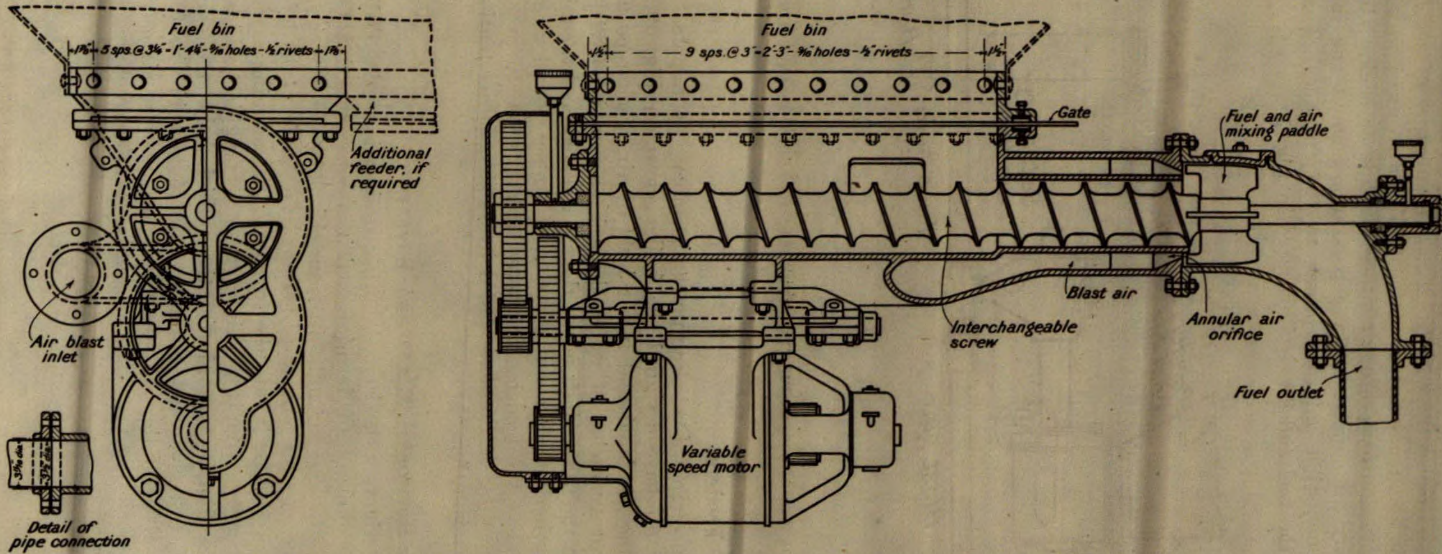


FIG. 19. Assembly of type G feeder, Pulverized Fuel Equipment Company.

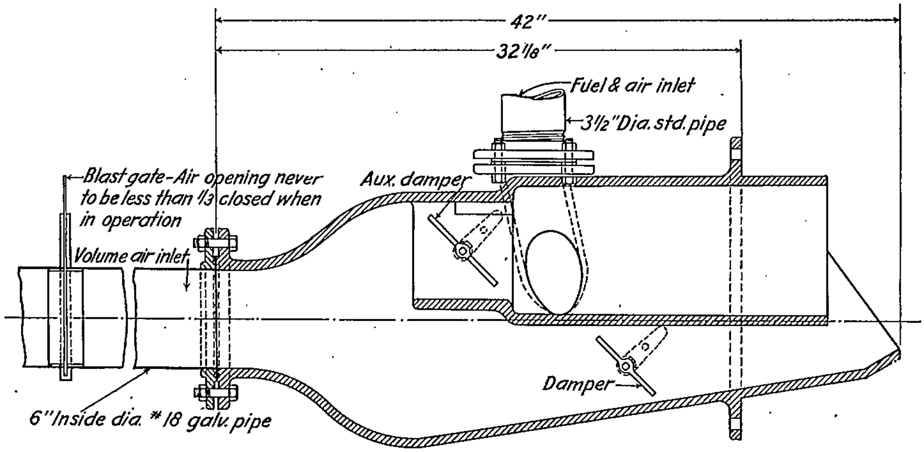


FIG. 20. Assembly of horizontal burner, type B, Pulverized Fuel Equipment Company.

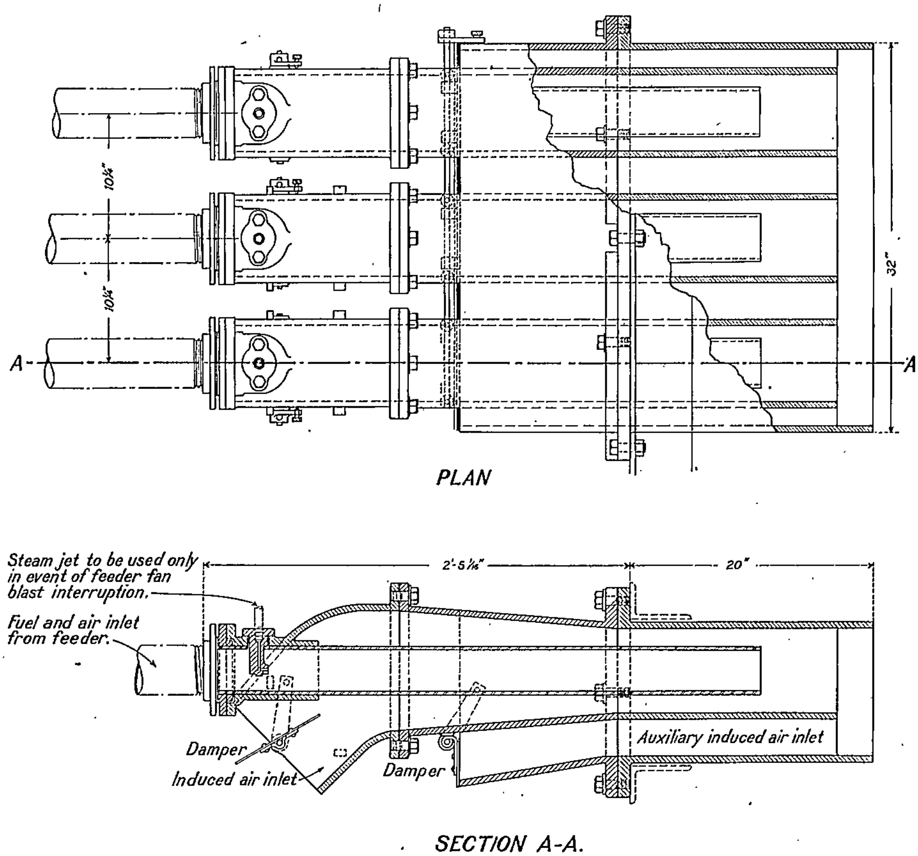


FIG. 21. Vertical triplex burner for boilers, Pulverized Fuel Equipment Company.

"Lopulco" Vertical Burner.

Fig. 21 shows a vertical triplex burner, designed by the Pulverized Fuel Equipment Company, 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 Fig. 31 and Fig. 32).

Heyl and Patterson Feeder.

Plate III shows a screw feeder developed by Mr. E. C. Covert of Messrs. Heyl and Patterson, Pittsburgh, Pa. The principal feature lies 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 entering 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.

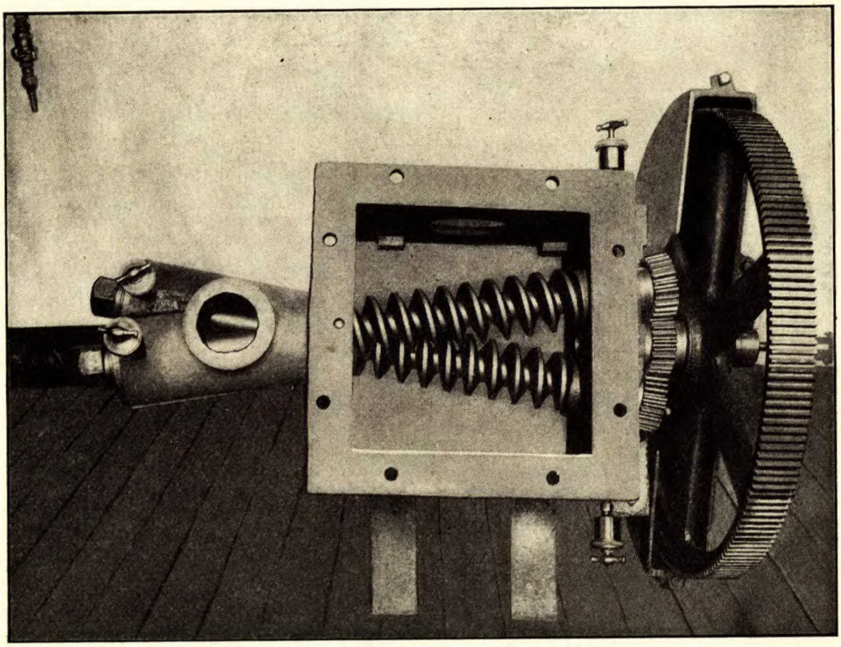
There are, however, on the market other burners and mixers in which very special precautions are taken to insure a very intimate and constant mixture of the coal and air. It may be that for a few very special purposes these burners are to be preferred, but there is no reason to suppose that for ordinary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

Powdered Coal Engineering and Equipment Company's Mixer.

The Powdered Coal Engineering and Equipment Company, Chicago, manufactures one of these special devices for mixing and feeding the coal and air. They term their process the "Carburization process"; and to quote from their pamphlet No. 6, their

"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 supply a "Carburetor in which is placed a stationary fan-like mixer, the outlet end of this carburetor is fan-shaped which causes the flame to spread across the furnace and to ignite more readily."

Ground Coal Engineering Company's Mixer.

Mr. Milton W. Arrowood of the Ground Coal Engineering Company, Chicago, also has devised an elaborate method of mixing the air and coal before entering the furnace. Fig. 22, which appeared in the transactions

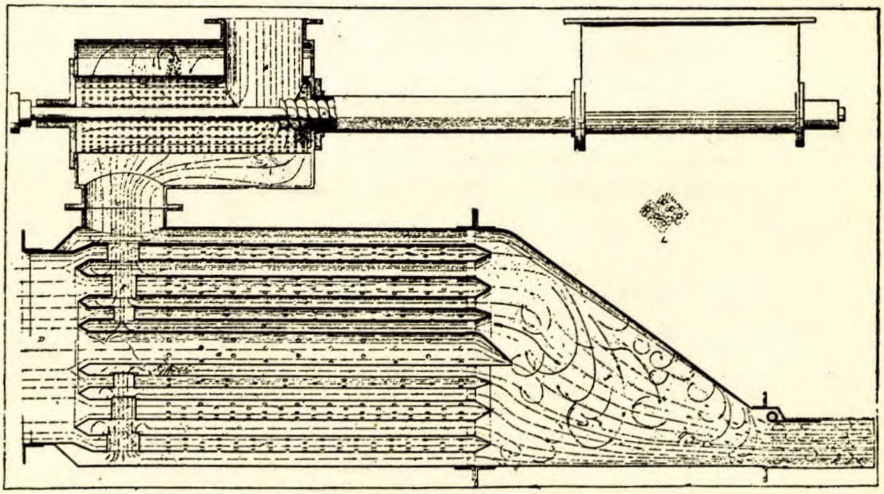


FIG. 22. Diagram showing Arrowood pulverized coal burner.

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 enclosed 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 installed in an air melting furnace in the malleable iron foundry at the works of the General Electric Company, 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 Company, but which was not seen in use elsewhere.

Screws also are dispensed with in some plants when compressed air is used to give the coal a high velocity.

Compressed Air Coal Injector.

Fig. 23 shows the compressed air system of firing and feeding coal to an open-hearth furnace, used until recently at the Homestead works

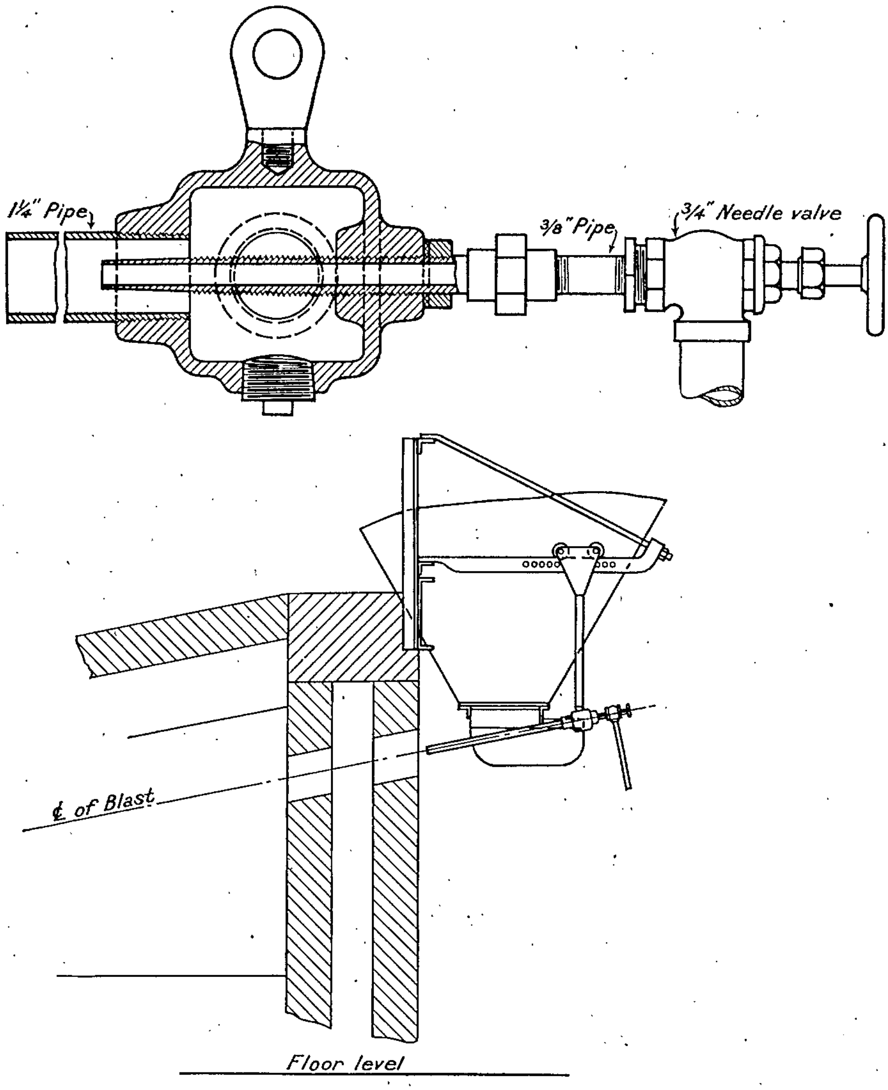


FIG. 23. Coal feeder and burner for open-hearth furnace.

of the Carnegie Steel Company. 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 cause the flame to 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.

Compressed Air Injector, Combined with Screw Feed.

At the open-hearth plant of the National Malleable Castings Company, 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 very many qualities to recommend its use. Its principal advantages over hand and stoker firing lie in the comparative ease of conveying it to furnaces and in its practically complete combustion 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 its 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 ITS USE

Cost.—Before powdered coal firing may 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. With grate firing the ash is left on the grates and in the ash pit. But with powdered coal, 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.—Nor, on the whole, can powdered coal plants 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.* 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,

* A notable exception to this is at the Oneida Street station of the Milwaukee Electric Railway and Light Company. The powered coal fired boiler room is far cleaner than the stoker fired boiler room beside it.

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 powdered coal firing, 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. At one plant visited, they 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 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 proved 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:—

(1) An open-hearth plant, using the coal suspended in air method of distribution, where it 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.

USE COMPARED WITH GAS AND OIL

Powdered coal, for the most part, has been used for those purposes which would be served by 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 are preferred. The reasons for this preference lie in 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 powdered coal preparation plant.

The actual flames of burning gas, oil, tar, and powdered coal differ both chemically and physically. For some purposes the rapid rate of heat radiation from the burning particles of coal account for its preference 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 today there are few purposes for which it has not competed with those fuels successfully, and whereas in some plants it has been discarded because of inherent defects of the system, 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. This loss of heat, not less than 20 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 other furnaces where 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 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.Th.U. per second may be liberated per cubic foot of combustion space. This rate of combustion is sometimes exceeded, but if very materially 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 it collects either on the hearth, whence it is removed when the furnace shuts down, or it is removed as a liquid slag. The ash which 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, no very radical alteration in design is usual. At most, the change consists usually in an enlargement of the furnace. But no furnace should be fired with powdered coal without consulting experienced engineers, who will either approve of 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.

Prof. Trinks and Mr. Barnhurst on Furnace Design.

Prof. W. Trinks in the "Blast Furnace and Steel Plant" (Jan. 1919), in discussing the design of heating and annealing furnaces, points out that the cost of a furnace is nearly proportional to its volume, and that it is essential to determine the rate of combustion per unit volume of combustion space. Since flames of burning gas, oil, or powdered coal may be oxidizing or reducing, long or short, the rate of combustion per unit furnace volume varies. Prof. Trinks states that as a rough average

"With oil or gas fire 3 B.Th.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. (In the former case 3 B.Th.U. per second can be developed per cubic foot of furnace). Under these circumstances only 1½ B.Th.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, chief engineer, Fuller Engineering Company, Allentown, in the course of a discussion of his paper on the General Utilization of Pulverized Coal before the Cleveland Engineering Society (Journal of Cleveland Engineering Society, No. 1917, page 160) 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, Kansas, 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.Th.U. per pound, then 40 cubic feet of furnace space per pound burned per minute is equivalent to the liberation of about 6 B.Th.U. per cubic foot of space per second, or, if the calorific value of the combustible is only 12,000 B.Th.U. per pound, to the liberation of 5 B.Th.U. per cubic feet of space per second.

Mr. Longuenecker on Drop Forge Furnaces

Mr. Charles Longuenecker of the Bonnot Engineering Company, 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 co-ordinating

"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 HAVE BEEN USED

Powdered coal has been successfully applied, and is commonly used, for the following purposes: Open-hearth furnaces; bushelling and puddling furnaces; continuous heating furnaces for blooms and billets; 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.—Fig. 24 shows a powdered coal fired furnace, used for heating blanks for drop forging. It is reproduced from an illustration

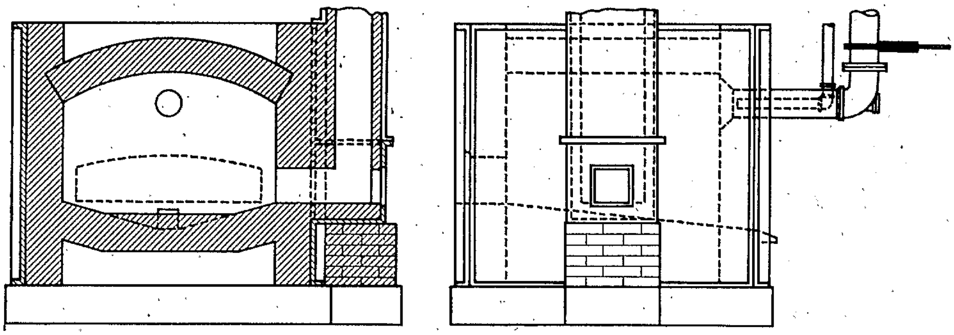


FIG. 24. Furnace for heating blanks, converted from oil firing to powdered coal firing.

in the Journal of the American Society of Mechanical Engineers (Oct. 1914), from an article by Mr. W. S. Quigley, of New York. It is a rebuilt oil fired furnace.

Puddling.

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

Mr. G. J. Gadd (Journal Franklin Institute, September, 1916) states that the saving over hand firing by using powdered coal for puddling is about 30 to 36 per cent.

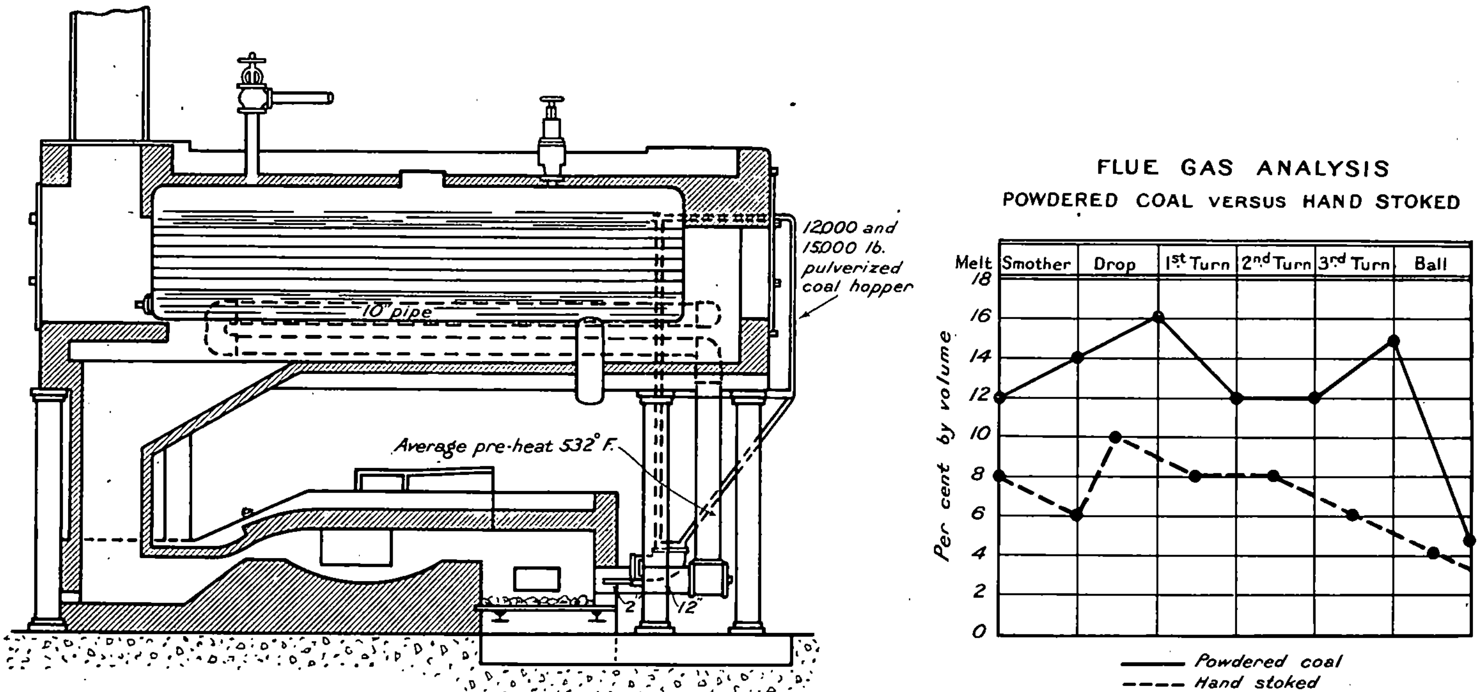


FIG. 25. Puddling furnace fired with pulverized coal, and diagram showing carbon dioxide content of flue gas with powdered coal firing (continuous) and hand firing (interrupted line.)

Mr. W. Simons, (autumn meeting Iron and Steel Institute, 1919) states also 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 annealing furnaces. One sheet mill firm visited by the writer, stated that after changing to powdered coal from hand firing they were using for their whole operation only as much coal as they used originally for the annealing furnace alone.

On the other hand, Mr. G. I. Hagan, 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 U.S.A. with automatic stokers for coal burning, and

"There are, no doubt, a few things in favour 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 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 favour of the stoker."

In spite of this, in an article in the Iron Age (Dec. 11, 1919) describing the powdered coal equipment of the Newport Rolling Mill Company, Newport, Ky., installed by the Quigley Furnace Specialties Company of New York, there appears the following:—

"Pulverizing 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 gauge to 34 gauge. 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 remodelled 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 due to 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) 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.

Where powdered coal is used for open-hearth work, the cost of repairing the furnace and chequer work has been found to be higher than with other fuels. But these costs are gradually being reduced as furnaces and chequer work 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 chequers has proved a serious drawback to the use of powdered coal in open-hearth work. It necessitates frequent cleaning and scraping of the chequers, 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 chequer work. But if the chequer 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 Company, presented to the writer a design of open-hearth wherein it is hoped the trouble due to the deposit of ash in the chequers may be considerably reduced. A view of this furnace is shown in Fig. 26. This view shows the slag chamber, at the base of which is a car in which the heavy oxides

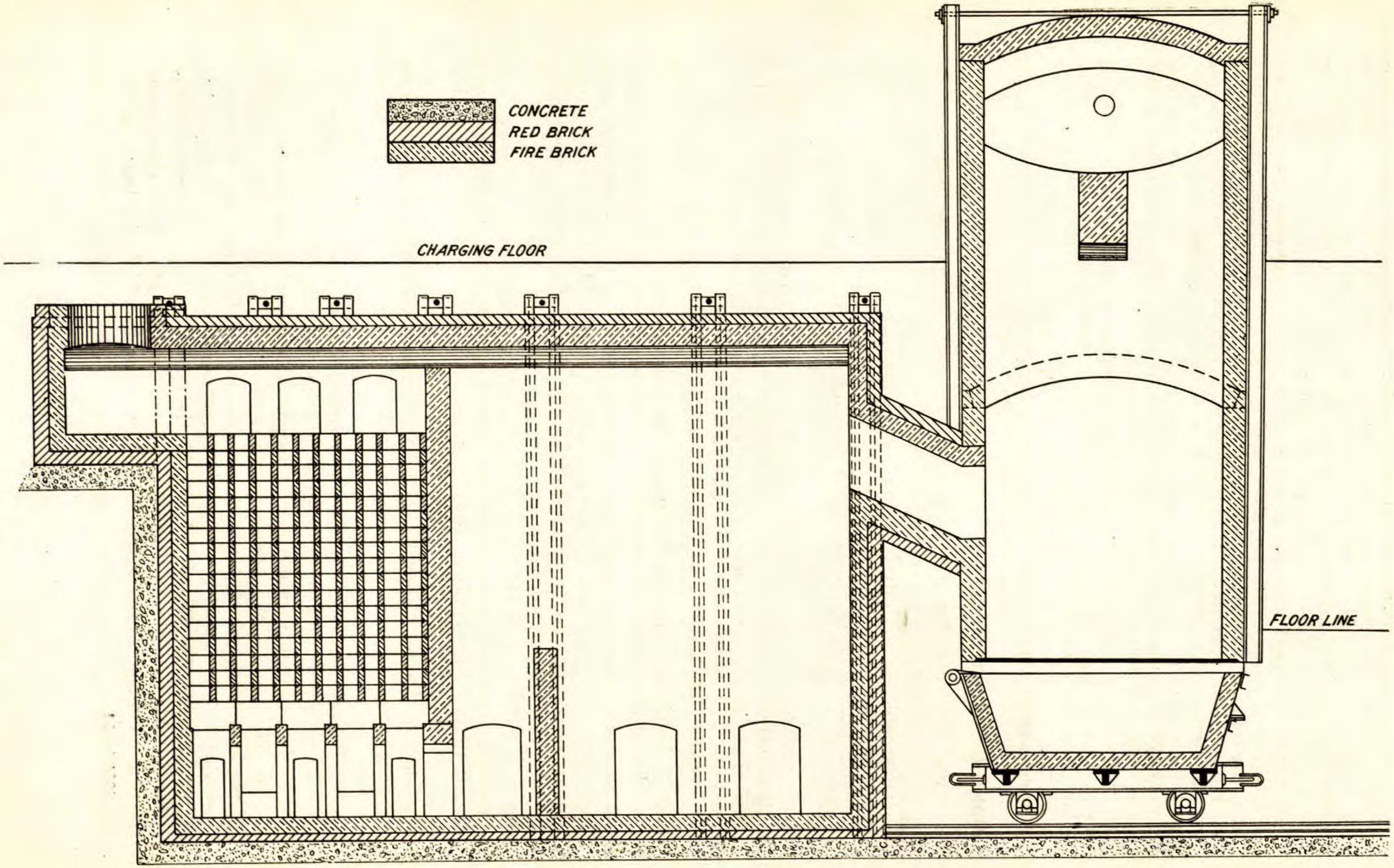


FIG. 26. Section showing slag chamber, dust chamber and regenerator of Perkins-Fitch furnace (patented), Fuller Engineering Company.

are precipitated; a dust chamber between the slag chamber and regenerative chamber in which the dust is intended to collect, and permit gases free from dust to rise through the chequer work of the regenerative chamber. At the time of writing, this design of furnace has not been used, but if successful would obviate the expense of time and labour in cleaning the chequers, and make it possible to put in sufficient chequer work to efficiently store up 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 that the hot gases pass up through the chequer work, which would be more likely to cause an uneven distribution of temperature in the chequer work 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.

Mr. N. C. Harrison (general superintendent, Atlantic Steel Company, Atlanta), in a paper published in the Journal of the A.S.M.E. (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 and Steel Manufacturing Company, 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 upstakes, 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″ by 9″, or better 9″ to 11″. 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, preferably 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.

"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 Company, 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 moulds, due to not being over-oxidized, as the coal coming directly in contact with the bath has a greater reducing action. All gashouse 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 was 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.

Kind of fuel	Remarks	Amount per ton steel	Rate cost fuel dollars	Cost of fuel and labour dollars	Cost per ton steel, dollars
Natural gas..............	....	3000 cu. ft.	0·04 per M.	....	0·24
Natural gas..............	....	6000 cu. ft.	0·12 per M.	....	0·72
Producer gas.	Hot metal.	510 lb. coal	3·40	3·93	1·00
Producer gas[1]............	Cold metal.	739 lb. coal	3·40	3·93	1·46
Fuel oil..................	....	40 gal.	0·02	....	0·80
Tar[2].....................	....	40 gal.	0·025	....	1·00
Pulverized coal...........	....	500 lb. coal	3·40	3·90	0·975
Electric power...........	....	500 Kw. hr.	0·0075	....	3·75

Above includes handling cost.
[1]Atlantic Steel Company, Atlanta, Ga.
[2]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 Company, at Copper Cliff, Ont., and for smelting the copper ores at the Tennessee Copper Company's plant. Its use was discontinued at Copper Cliff owing to the difficulty of burning the coal completely, and to leakage of coal dust from the tuyeres while being punched. But it is expected that after modifying the construction of the tuyeres and furnace, that powdered coal may be used

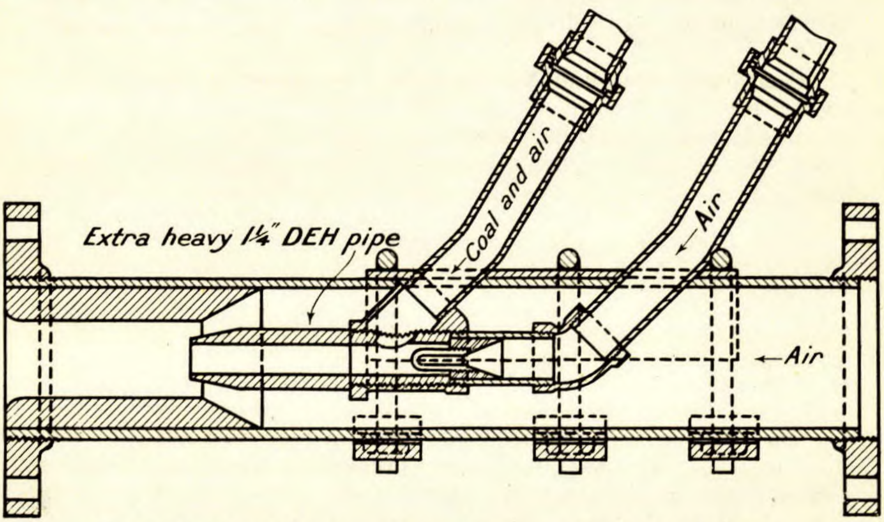


FIG. 27. Section of Tennessee Copper Company pulverized coal ejector.

successfully in blast furnace smelting of copper-nickel ores. (See Engineering and Mining Journal April 3, 1920, page 803).

Fig. 27 shows a view of a pulverized coal ejector, used on the copper blast furnace of the Tennessee Copper Company.

Reverberatory Copper Smelting.

Largely due to pioneer work at Copper Cliff in Canada, powdered coal has been used very successfully for smelting copper ores. This is shown from the following extract from Mr. Bender's paper:—

Mr. L. V. Bender, in a paper describing the coal dust fired reverberatory furnaces at Washoes Reduction Works, Anaconda, before the American Institute of Mining Engineers (Vol. 51, 1915) states 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 instead of burning it in the furnace 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.

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

COAL USED AT ANACONDA

	Moisture	Volatile matter	Ash	B.Th.U. per lb. dry
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, No. 7 furnace using Diamondville coal grate fired, No. 8 using Diamondville coal, dust fired.

	Tons smelted per furnace day	Total tons smelted	Tons coal	Tons smelted per ton coal	
				Excl. dryer coal	Incl. dryer coal
No. 7—(grate)	259	7,260	1,871	3·88	
No. 8—(dust)	475	14,272	1,985	7·19	7·08

The ash from the powdered coal burned in these furnaces gave very little trouble. The flue between the furnace and waste heat boiler is cleaned once a day by two men in 4 to 6 hours. The ash deposited from different coals varies; from one coal (22 per cent ash) it was light, fluffy, and easier to remove than from another coal (9 per cent ash) when it 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 centre of the furnace had the following composition:—

Sample	1	2	3
Carbon dioxide	16·0	13·0*	15·0
Oxygen	2·0	3·5	3·5
Carbon monoxide	0·0	0·0	0·0

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 (Vol. 51) of the transactions of the American Institute of Mining Engineers, Mr. D. H. Browne describes an earlier installation of coal fired reverberatory furnaces at the Canadian Copper Company's 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.

* Note.—The sum of the carbon dioxide and oxygen content here is so low as to lead to questioning the accuracy of the gas analyses.

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 air and coal sufficiently dry and pulverized to the furnace as required, in the correct proportions, and providing a furnace sufficiently large 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 enable it to be almost completely burned before reaching the tubes.

Troubles with Ash and Slag.

The temperature in the flame is so high that the ash fuses, and in settling on the hearth of the furnace 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 used to burn the coal 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 its passage through the boiler or passes off with the gases. Care must be taken to see that the ash may settle on no part of the heating surface, and that it may settle in parts whence it may 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 the correct shape may be constructed, and the gases pass through no tubes wherein ash may settle, 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 will 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 requires no dryer installations. 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 centre 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 the top is the steam drum exposed to the flame, and its sides are enclosed with fire-brick, on the outside of which are the vertical water tubes of the boiler.

The Bettington boiler was intended to be used with low grade fuels, to operate with a high efficiency, and to give no trouble with a high ash clinkering coal. The Canadian National Railways installed a Bettington boiler in the boiler room for supplying steam to their workshops at Moncton, N.B. It was their intention to burn a low grade coal. But it was found impracticable to generate steam with this coal, because the ash fused, and formed a ring on the wall of the combustion chamber round the burner. This slag deposit restricted the area through which the products of combustion pass, and occasionally pieces of slag fell into the burner whence it was difficult to remove it. After encountering many difficulties due to 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:—

Moisture	1·1 per cent.
Ash	20·3 "
Volatile matter	26·7 "
Fixed carbon	51·9 "

The mechanical analysis of the pulverized coal was as follows:—

Per cent by weight passing through	8-mesh screen	98·2
" " "	14 "	94·8
" " "	28 "	87·2
" " "	48 "	72·9
" " "	100 "	40·4
" " "	150 "	34·0
" " "	200 "	13·5

The proximate analysis shows the coal now used to contain a high percentage of ash, and the mechanical analysis shows that the coal is not well pulverized, since only about 40 per cent of the coal 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 and it is intended soon to remove it.

Franklin Boiler.

Fig. 28 shows a 300-horsepower Franklin boiler, equipped for burning powdered coal in 1913. This design of furnace was found unsatisfactory, and was changed to the design shown in Fig. 32. There are three burners. The coal is introduced into the main supply of air, which is under a pressure of about three-tenths inches 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 due to 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 Fig. 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, of Schenectady, in an interesting letter to the Journal of the American Society of Mechanical Engineers (December, 1916) 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, Mem. Am. Soc. M. E., 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 fireroom helper was readily taught to give the furnace all the attention ever required.

"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 Company, to install the furnace shown in Fig. 29, which suggested itself, and is

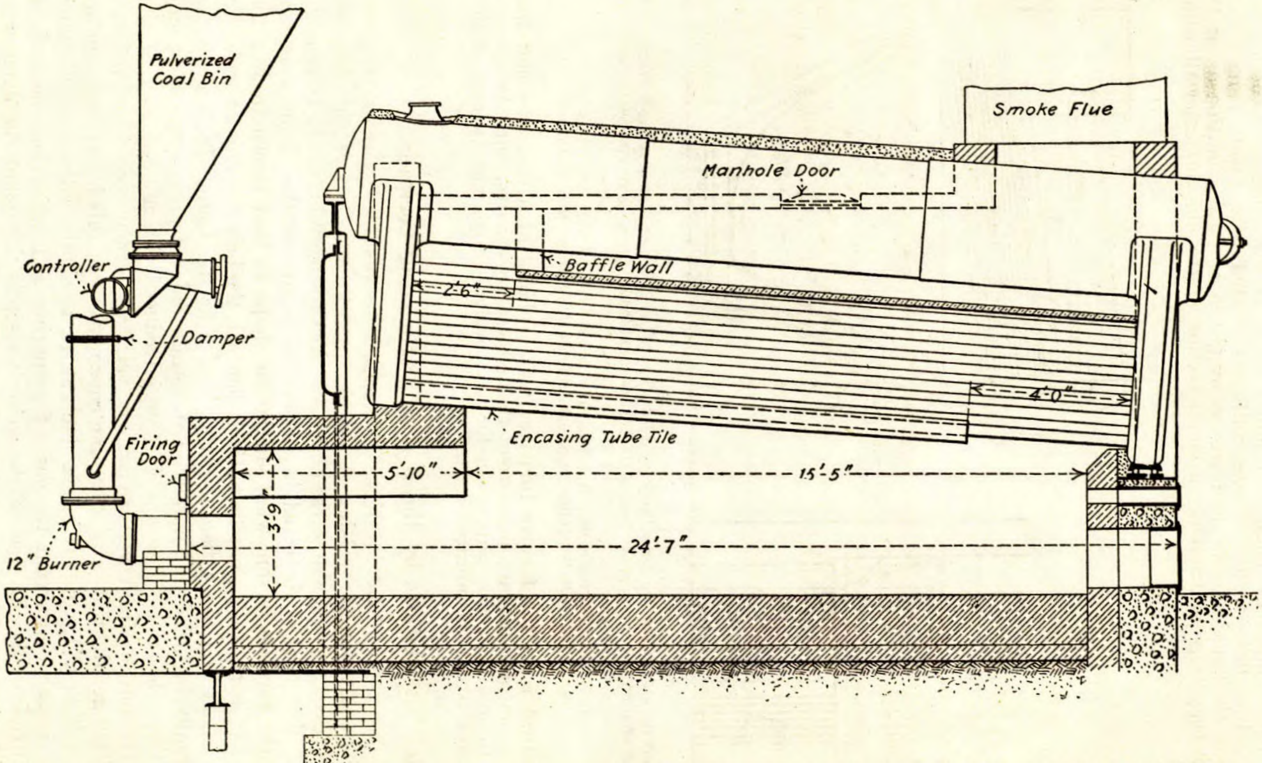
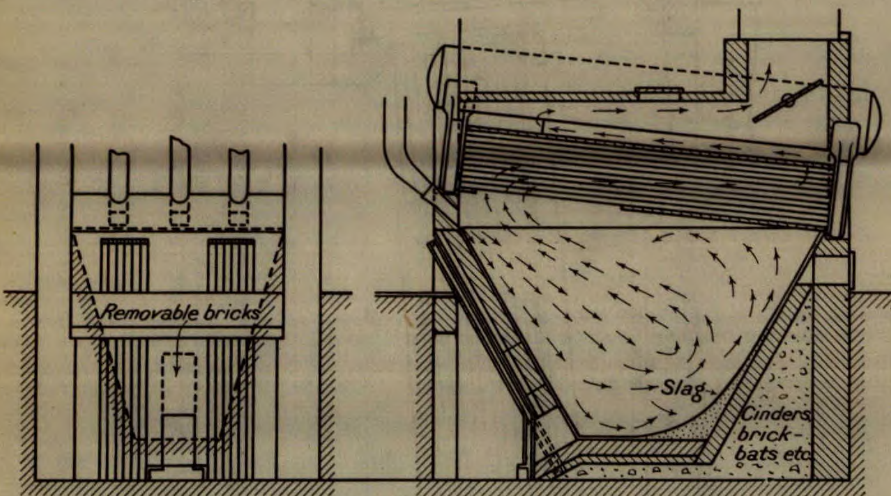


FIG. 28. 300 H.P. Franklin boiler, American Locomotive Company, as originally arranged for powdered coal firing.

shown as originally installed. This furnace now has been in continual service for eighteen months without a single repair expense on the hopper-shaped furnace walls. These walls are coated with about 1 inch to 3 inches thickness of slag, and are seemingly in as good condition as at the time they were built. Only a small section of the old vertical wall which



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.

FIG. 29. Furnace which replaced that shown in Fig. 31. The two sets of vertical pipes support the front wall of the furnace.

remained from the former furnaces was replaced at a cost of about five hours mason's labour; 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 Company.

The Bonnot Engineering Company have installed a powdered coal fired installation for raising steam in water tube boilers of the Babcock and Wilcox type, at the works of Messrs. Armstrong Whitworth, Longueuil, P.Q. The coal is delivered in suspension in air on the Holbeck system and the furnace is somewhat similar in shape to that shown in Fig. 29. But 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 Fig. 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 to either 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 to this plant the flame was not burning regularly, due to 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.

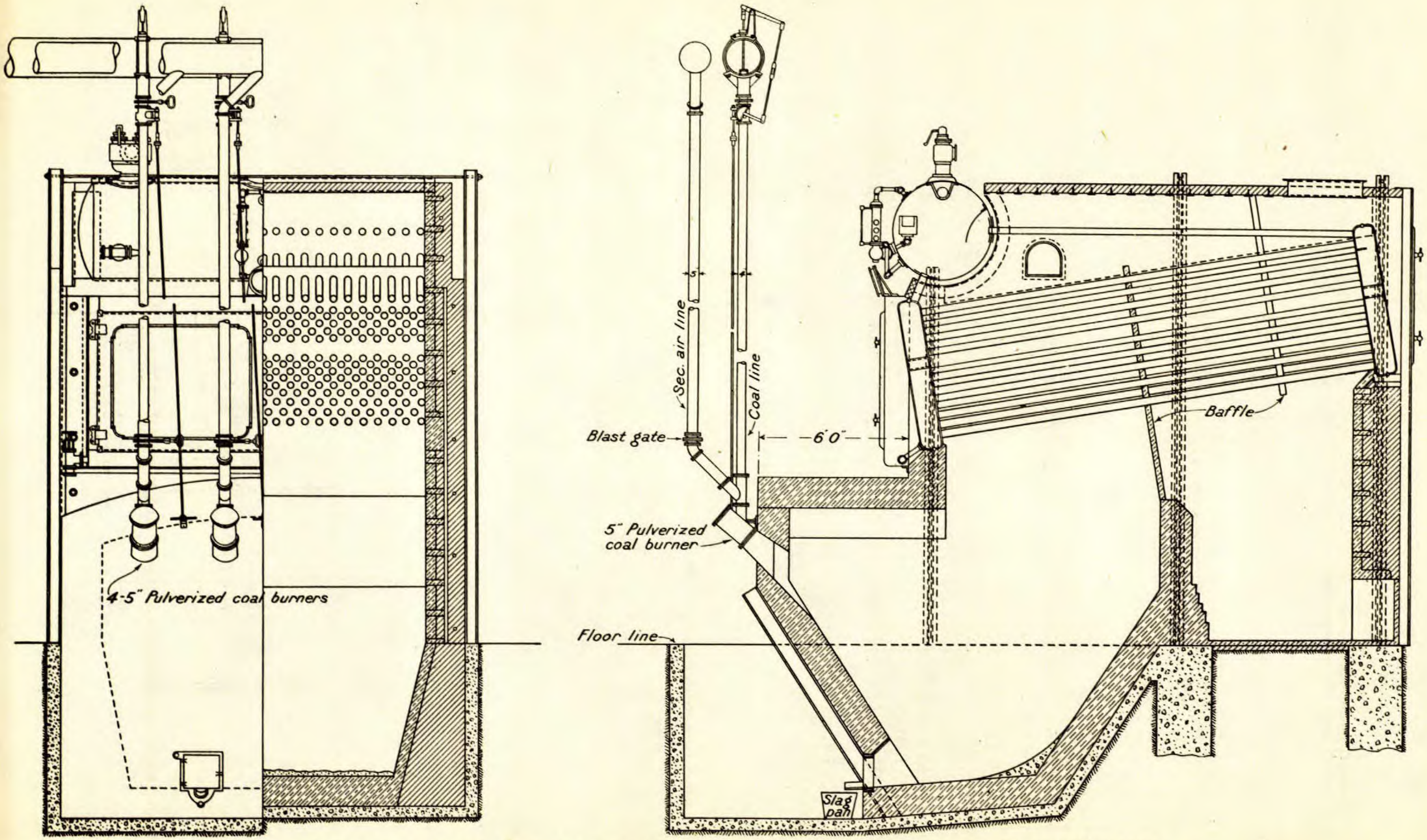


Fig. 30. Boiler setting for powdered coal firing. Holbeck distribution system, Bonnot Company.

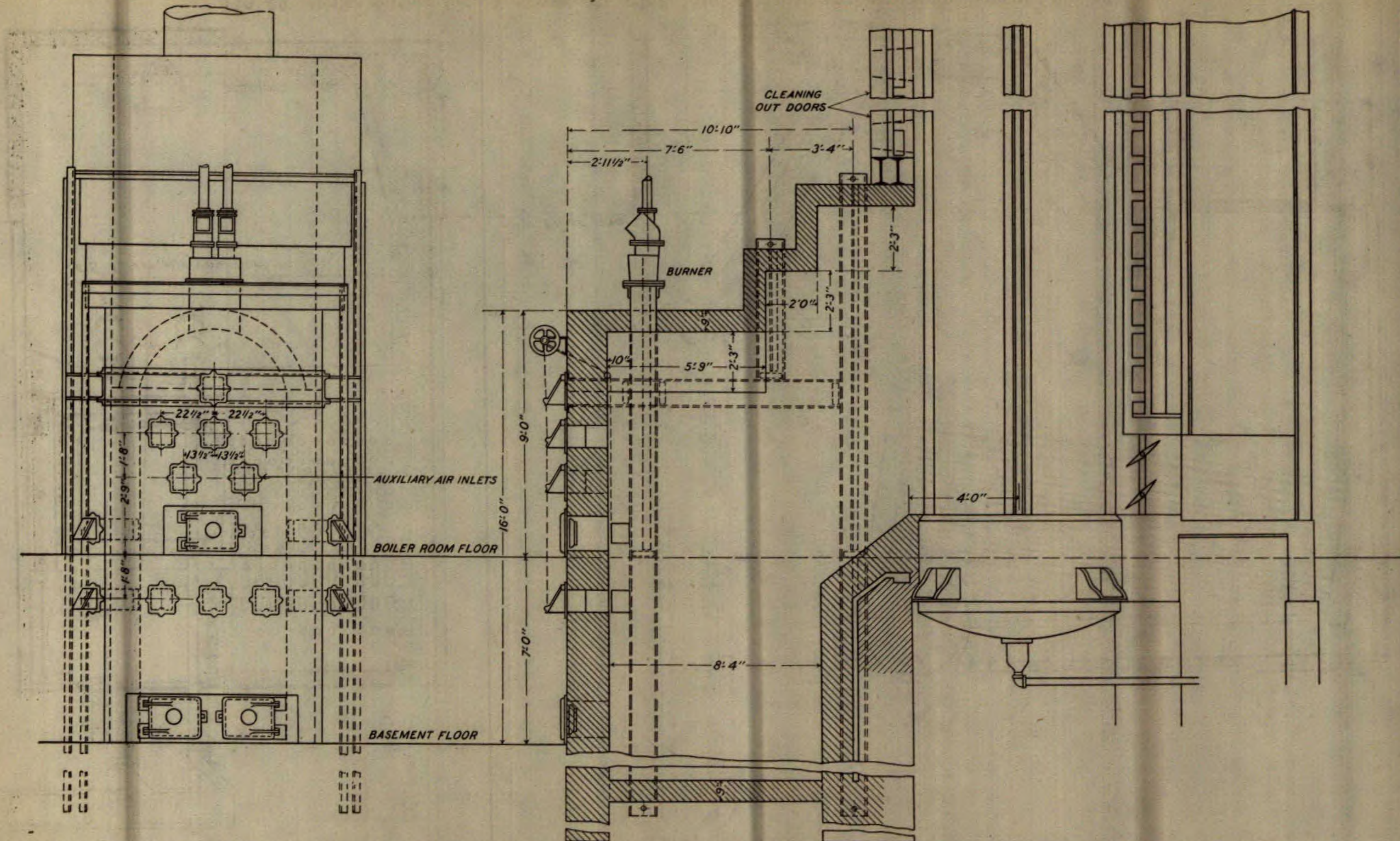


FIG. 31. Arrangement of combustion chamber for firing a Wickes boiler with powdered coal. Pulverized Fuel Equipment Company.

Wickes Boiler Pulverized Fuel Equipment Installation.

One of the most successful dust fired boilers seen by the writer was that shown in Fig. 31. The boiler is a 333-horsepower Wickes boiler, and was equipped for powdered firing by the Locomotive Pulverized Fuel Equipment Company. The burner delivers the coal vertically downward, the flame is U shaped, and the coal pursues a path sufficiently long to burn completely. The furnace is very deep (about 18 feet), to avoid heating the bottom of the furnace 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 there is is easily removed. At the time of the writer's visit the furnace had not been cleaned out for 4 days, and on the bottom of the furnace 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 where 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 two to three per cent of moisture and about twelve per cent of ash.

Pulverized Fuel Equipment Company's Installation with Edgemoor Boilers.

At the Oneida street power station of the Milwaukee Electric Railway and Light Company a battery of five boilers have been equipped by the Pulverized Fuel Equipment Company 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 Fig. 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 on enlarging the combustion chamber and adding auxiliary air openings there has been little trouble, when the flame was properly controlled. If the flame in its path through the combustion chamber too closely approaches 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 appear to cause any inconvenience to the nearby 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 Fig. 32, which is reproduced from a paper presented before the Technical League of the Employees Mutual Benefit Association, Milwaukee, February 19, 1920.

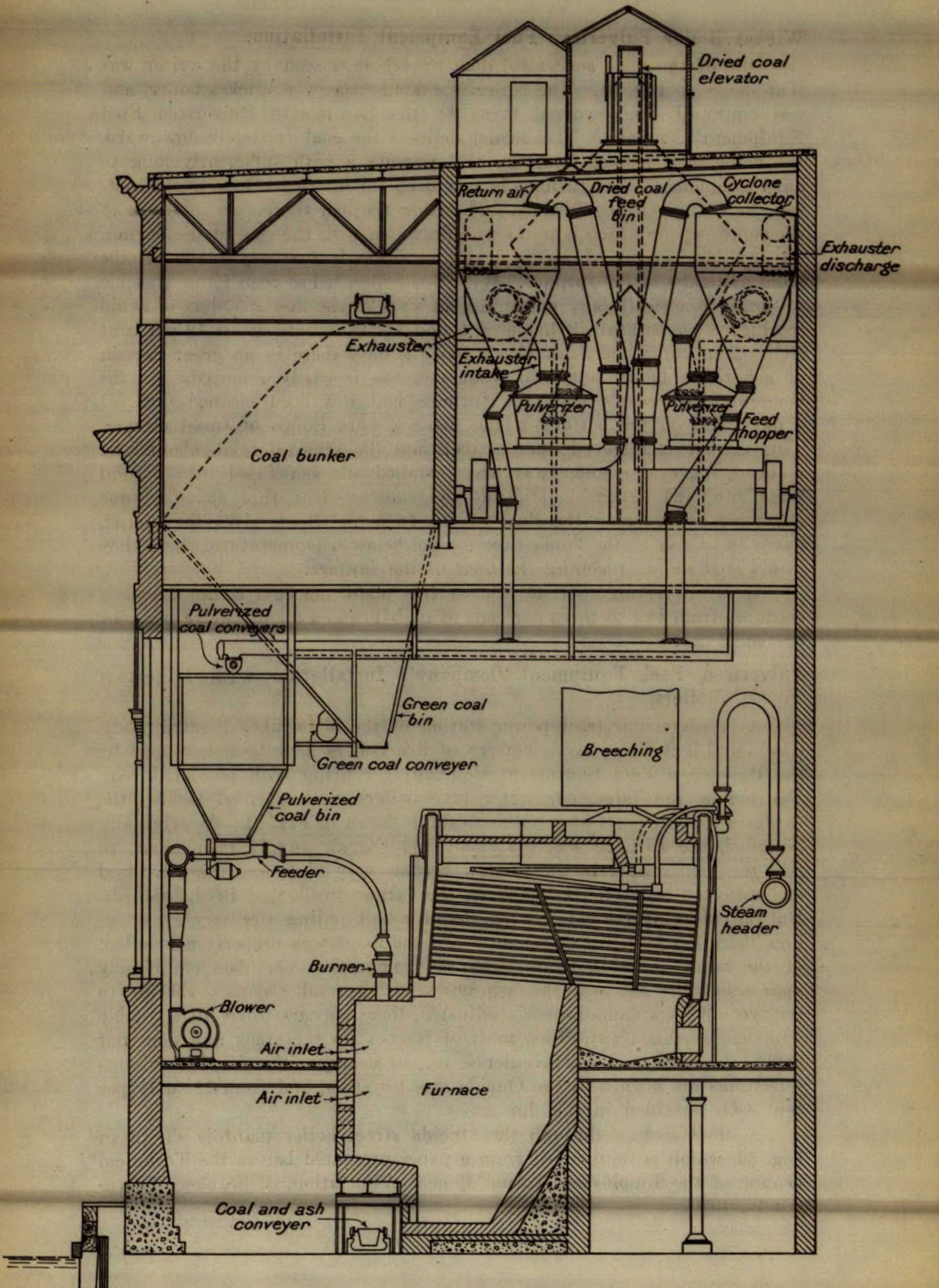


FIG. 32. Cross section through Oneida street boiler plant, Milwaukee.

The working of the Oneida street boiler plant with pulverized coal at Milwaukee 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 changing the operation of the plant by the operators to suit the 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 not properly regulated the coal may be so moist as to plug the feeders. At this station the 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 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 carbon dioxide in the flue gas is easily obtained, but cannot 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°F. 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 into 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 cannot 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 obtainable 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 brick work in a pulverized fuel furnace will stand up equally as well as a stoker installation, with a very great advantage in favour of the former, due to the elimination of all ironwork in the furnace or anywhere near the high temperature 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 plant 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 horse-power 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 labour 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 simillar 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

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:—

Coal

"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 dryer 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 dryer 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. and L. Company 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 cannot be followed. The levels 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 forty and one-half 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 forty and one-half tons capacity each were available during the test, all of which were filled once in twenty-four 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 twenty-four hours, although, without these considerations, sufficient coal could have been pulverized during the eighteen 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 dryer 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 twenty-four hours of the test, it appeared that moisture, with its attendant difficulties, was collecting in the storage bins. Cold air draughts through windows along the side of the bins caused this condition by rapidly condensing the vapour 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 fire room. 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 twenty-four 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, by-passes 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 twenty-four 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. and L. Co. Test of Five 468-h.p. Boilers—No. 1 to 5 inclusive

ONEIDA STREET POWER PLANT

November 11-15, 1919

Dimensions

1. Number and kind of boilers... Five Edgemoor 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, sq. ft., per boiler..	4,680
5. Superheating surface, sq. ft., per boiler (approximate)..	594
(a) Type of superheater.. .. .. Foster	
6. Total heating surface, sq. feet., per boiler..	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.. .. .. Nov. 11-15, 1919	
8. Duration, hours..	99
(a) Boiler hours..	495
9. Kind and size of coal—Mixture—50 per cent Youghiogheny screenings, 50 per cent Eastern Kentucky screenings.	
10. Steam pressure by gauge, lb. per sq. in..	167·8
(a) Barometric pressure, inches of mercury..	29·49
11. Steam pressure, absolute, lb. per sq. in..	182·3
12. Temperature of steam leaving superheaters, Deg. F..	441·9
(a) Normal temperature saturated steam at above pressure, Deg. F..	374·2

13. Temperature of feed water entering boiler, Deg. F..	156·3
14. Temperature of escaping gases, Deg. F..	496·6
(a) Temperature of flame above hearth, Deg. F..	2,767
(b) Temperature of furnace bottoms, Deg. F..	2,180
15. Draft under damper, inches of water..	0·173
16. Draft in furnaces, inches of water..	0·031
17. Air pressure at blower, inches of water..	6·36
(a) Pressure of air mixing with coal at screw feeder, inches of water..	6·00
(b) Pressure of air and coal mixture above burner outlet, inches of water..	1·00
18. State of weather—	
(a) Temperature outside, Deg. F..	28
(b) Relative humidity, per cent..	72*
(c) Room temperature, Deg. 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, pounds, total..	9,770
(a) Withdrawn from furnace bottom, pounds per hour, per boiler..	19·8
(B) Withdrawn from tubes, flues and combustion chamber, pounds, total..	9,862
(b) Withdrawn from tubes, flues and combustion chamber, pounds per hour, per boiler..	20·0
(C) Blown away with gases, pounds (difference between laboratory and actual weighed)..	87,549
(c) Blown away with gases, pounds per hour, per boiler..	176·8
(D) Percentage of total lost with gases..	82·8
(E) Percentage of combustible in slag and ash recovered, per cent (combined analysis)..	6·9
26. Total combustible burned, pounds..	781,622
27. Total weight of water fed to boilers, pounds..	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, pounds..	1,796
31. Water evaporated per hour, pounds, actual..	83,328
(a) Water evaporated per hour, per boiler, pounds, actual..	16,666
32. Equivalent evaporation per hour from and at 212° F., pounds..	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 sq. ft. of water heating surface, pounds..	4·09

Capacity

34. Evaporation per hour, from and at 212° F., per boiler, pounds..	19,121
(a) Boiler horse-power developed..	554
35. Rated capacity per hour, from and at 212° F., per boiler, pounds.	16,146
(a) Rated boiler horse-power..	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, pounds..	9·219
39. Water evaporated per pound of coal dry pounds	9·282
40. Water evaporated per pound of combustible, pounds..	10·554
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.Th.U...	12,810
46. Gross efficiency of boiler and furnace, per cent..	80·67
47. Efficiency of furnace, per cent..	99·79

Smoke Data

48. See notes.

Analyses of Flue Gases

49. Carbon dioxide, per cent..	12·26
50. Oxygen, per cent..	6·82
51. Carbon monoxide, per cent..	0·00

Analyses of Coal

52. *Proximate*—	As received	As fired	Dry
(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..	53·57
(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	13·76	Unknown
(c) Earthy matter..	99·41	86·24	....

Heat Balance

	B.Th.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 .67 of one per cent of moisture, only a small loss, .06 of one 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 .6 per cent. The efficiency of the dryer 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 scale 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 were without doubt the heavier particles.

Losses Due to Combustible Carried Away with Flue Gases, Unconsumed Hydrogen, Hydro Carbons, 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

Number	Proximate analysis				B.Th.U. per lb. dry coal	B.Th.U. per lb. as rec'd.	Ultimate analysis of dry coal					
		Dry coal										
	Moisture	Fixed carbon	Volatile matter	Ash				H	O	N	S	Ash
1........	8.3	55.71	33.47	10.82	13003	11924						
2........	4.2	55.89	32.10	12.01	12974	12389	76.88	3.04	5.73	1.36	1.38	11.61
3........	4.9	55.72	33.28	12.00	12988	12352						
4........	6.6	56.14	33.46	10.40	13539	12876						
5........	4.9	54.63	31.74	13.63	12729	11889	72.42	4.73	7.35	1.45	1.63	12.42
6........	9.7	51.37	35.41	13.22	12515	11301						
7........	10.0	52.11	35.50	12.39	12551	11296						
8........	8.8	52.74	34.74	12.52	12589	11481	72.16	4.63	8.07	1.21	1.72	12.31
9........	9.1	52.43	35.54	12.03	12573	11429						
10........	7.3	53.02	35.93	11.05	12983	12035						
11........	5.9	51.49	37.17	11.34	12601	11858	72.85	5.10	7.71	1.35	1.74	11.25
12........	7.0	51.44	37.21	11.35	12673	11786						
Average....	7.23	53.47	34.63	11.00	12810	11884	73.57	4.35	7.22	1.34	1.62	11.90

Test on Fuel Pulverizing Equipment

ONEIDA STREET POWER PLANT

December 11-15, 1919

General Conditions—Average Temperatures, etc.

1. Temperature of air entering dryer furnace, Deg. F.................. 93·8
2. Temperature of gases leaving dryer, Deg. F.................. 181·8
3. Humidity of outside air, per cent.................. 72·0
4. Draft through dryer, inches of water.................. 0·77

	No. 1	No. 2	
5. Vacuum in pulverizers, inches of water..........	5·0	5·16	aveg. 5·08

Coal Temperatures, Moistures and Fineness

6. Temperature of coal entering dryer, Deg. F.................. 88·2
7. Temperature of coal leaving dryer, Deg. F.................. 237·9
8. Temperature of coal leaving pulverizers, Deg. F.................. 169·7
9. Moisture of coal entering dryer, per cent.................. 5·59
10. Moisture of coal leaving dryer per cent.................. 1·61
11. Moisture of coal leaving pulverizers, per cent.................. 1·03
12. Fineness of pulverized coal, 200-mesh, per cent.................. 81·30
13. Fineness of pulverized coal, 90-mesh, per cent.................. 97·40
14. Fineness of pulverized coal, 80-mesh, per cent.................. 99·30
15. Fineness of pulverized coal, 60-mesh, per cent.................. 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, tons.................. 17·5

Dryer

18. Total coal dried, as received at dryer, tons.................. 471·2
19. Total coal dried, per hour of dryer operation, as received, tons.. 6·7

Pulverizer

20.	Total coal pulverized, coal from dryer, tons	447·4
21.	Capacity of pulverizer per hour, tons	5·0
22.	Coal pulverized per hour, dry, tons, total	7·90
23.	Coal pulverized per hour, dry, tons, per mill	3·95
24.	Coal pulverized per hour, per mill, as received at plant, tons	4·23

Consumption for Lubricants

25.	Total grease consumed by elevators and conveyers, pounds	6·0
26.	Grease per ton of coal, as received, pounds	0·012
27.	Total grease consumed by pulverizers, pounds	13·0
28.	Grease consumed per pulverizer per hour of operation, pounds.	0·112
29.	Grease consumed per pulverizer per ton of coal pulverized, pounds	0·028
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, quarts	0·036

Electric Energy and Coal Consumption

33.	Total energy consumed by crusher and green coal elevator			220·0
34.	Energy per ton of coal, as received, K.W.H.			0·47
35.	Total energy consumed by dryer, K.W.H.			735
36.	Energy per ton of coal, as received, consumed by dryer			1·53
37.	Total energy consumed by pulverizers, K.W.H. (fan and drive motor)			8,010
		Mill No. 1	Mill No. 2	
38.	Motor input per hour, H.P.	93·8	90·2	
39.	Energy consumed by pulverizer per ton of coal, as received, K.W.H.			16·72
40.	Energy consumed by pulverizer per ton of coal, as pulverized, K.W.H.			17·90
41.	Total energy consumed by pulverized coal conveyers, feeder blowers and feeders			1,789
42.	Total energy consumed by pulverized coal conveyers, feeder blowers and feeders per ton of coal, as received			3·73
43.	Total energy consumed by pulverized coal conveyers, feeder blowers and feeders per ton of coal, as fired			4·00
44.	Total energy consumed by all equipment on preparation and firing of pulverized fuel, K.W.H.			10,754
45.	Energy per ton of coal, as received, K.W.H. Grand total			22·45
46.	Coal equivalent for this energy at 1·5 pounds coal per K.W.H., pounds			33·68
47.	Total coal used in dryer furnace			12,291
48.	Coal per ton of fuel dried, pounds (based on coal as received).			25·66
49.	Total coal and equivalent consumed in preparation and firing of one ton of pulverized fuel, pounds			59·34

Cost of Preparation—Operation and Maintenance

50.	Cost of labour 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 labour 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

Number	Moisture in coal received at plant	Moisture in coal at dryer inlet	Moisture in coal at dryer outlet	Moisture in coal at pulverizer outlet	Moisture in coal 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	100·0
3...........	4.9	4.2	0.9	0.5	0.6	82.5	98.1	99.6	100·0
4...........	6.6	6.3	1.2	0.5	0.4	80.5	98.0	99.5	100·0
5...........	4.9	4.0	1.1	0.4	0.4	79.6	96.0	98.8	100·0
6...........	9.7	8.1	1.2	0.8	0.5	80.0	98.0	99.2	100.0
7...........	10.0	8.2	3.2	2.3	1.4	80.0	96.0	99.1	100.0
8...........	8.8	6.6	2.5	1.6	0.9	83.2	97.6	99.2	100.0
9...........	9.1	6.1	2.0	1.5	0.6	79.3	96.3	99.1	100.0
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	100.0
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 labour required to pulverize coal sufficient for five boilers through a twenty-four hour run per day.

Summary Sheet

Electric Energy and Fuel Consumption per Ton of Coal Pulverized

1.	Energy consumed by conveyers, crushers, elevators, dryer, blowers and feeders, K.W.H..	5·73
2.	Energy consumed by pulverizer, K.W.H..	16·72
3.	Total energy, K.W.H..	22·45
4.	Coal equivalent at 1·5 pounds per K.W.H., pounds..	33·68
5.	Coal consumed in dryer furnace, pounds per ton of fuel dried..	25·66
6.	Total coal and equivalent, pounds..	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.	Labour—Coal preparation..	0·143
9.	Labour—Firing..	0·112
10.	Labour—Ash removal..	0·025
11.	Dryer fuel—Coal at $4 per ton..	0·051
12.	Electric energy—Coal per K.W.H. at 1·5 lb..	0·068
13.	Maintenance (labour at 3·6 cents—material at 2·0 cents); manufacturer's estimate—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

Efficiencies

17.	Actual gross efficiency, per cent..	80·67
18.	Net efficiency, after all incidental costs have been accounted for, per cent..	72·32

CONCLUSIONS

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

Comparison of Costs and Net Efficiencies.

Electric Energy and Fuel Consumption per ton of Coal Burned.

	Pulv. Fuel System	Modern Stoker
Energy consumed by conveyers, crusher, elevators, dryers, fans and feeders, K.W.H.	5·73	Stokers and Blowers, K.W.H.10·94
Energy consumed by pulverizer, K.W.H.	16·72	......
Total energy, K.W.H.	22·45	10·94
Coal equivalent at 1·5 lb. per K.W.H., lb.	33·68	16·41
Coal consumed in dryer furnace, lb.	25·66	......
Total coal and equivalent, lb.	59·34	16·41

Cost of Fuel Preparation, Firing and Ash Disposal.

Labour—Coal preparation	$ ·143	$ ·000
Labour—Firing	·112	·140
Labour—Ash removal (in plant)	·025	·064
Dryer fuel—Coal at $4 per ton	·051	·000
Electric energy—Coal per K.W.H. at 1·5 lb.	·068	·033
Maintenance— Labour at $0·36—(Material at $·020 manufacturer's estimate—Lubricants at $·007	$ ·063	Labour at $·046 Material at $·049 Lubricants at $ ·002 ·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, per ton	4·462	4·334
Cost per ton of coal in P.F. System over modern stoker	·128	......

EFFICIENCY

Actual gross efficiency, per cent.	80·67	76·80
Net efficiency after all incidental costs have been accounted for, per cent.	72·32	70·88
Difference in favour of pulverized fuel system, per cent.	1·44	......

An extract from the remarks of Mr. Paul W. Thompson, technical engineer of power plants, Detroit Edison Company, 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 see that no 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 favour of the pulverized fuel. This is an item for serious consideration in plants designed with 4.5 K.W. 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 over anxiousness 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 forty-five minutes 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 and Light Company have found by test that it is possible to hold the boiler up to pressure for about ten 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 lb. coal consumed per B.H.P. 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 dryer 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. Overall 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 overall 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 and Light Company are 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 Company will equip six of these boilers with three vertical duplex burners per boiler. The Fuller Engineering Company 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

Fig. 33 illustrates a boiler furnace designed by M. A. Hanna and Company, of Cleveland, Ohio, for burning anthracite slush or silt, which

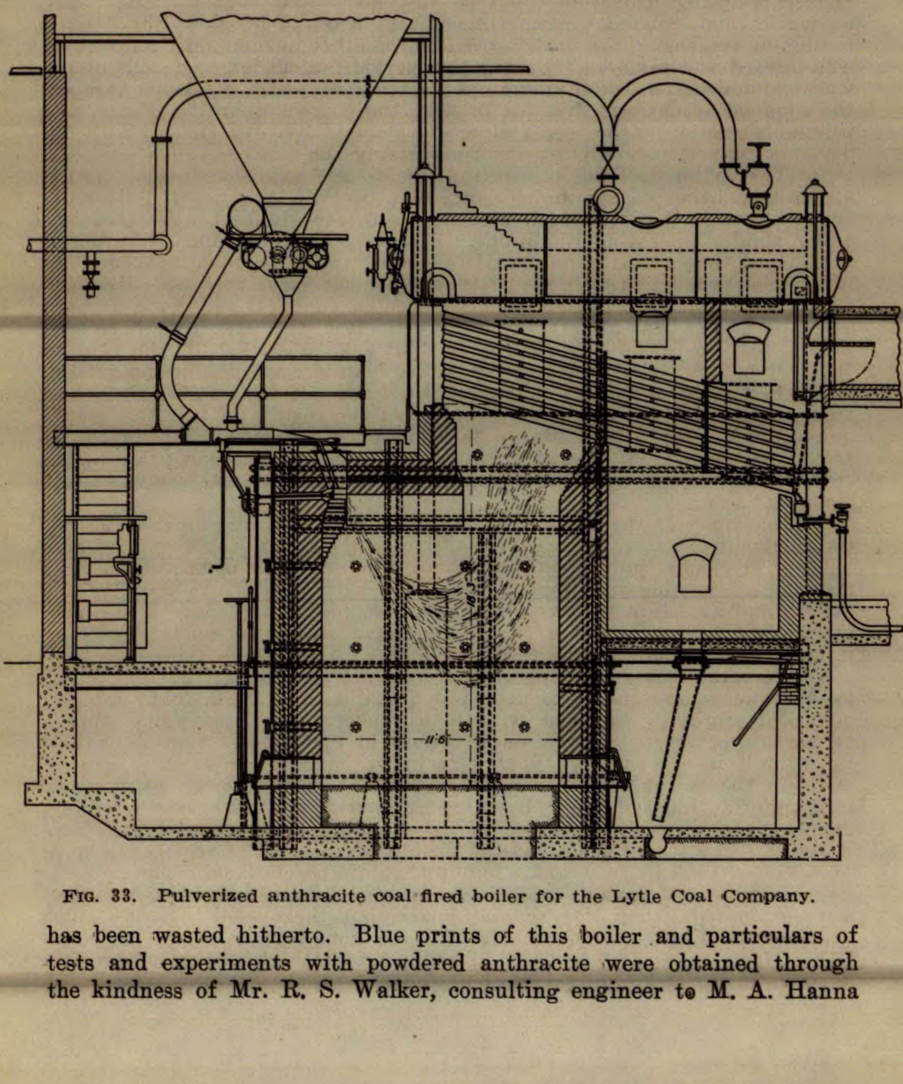


FIG. 33. Pulverized anthracite coal fired boiler for the Lytle Coal Company.

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 and Company. The boiler is installed in the power plant of the Lytle Coal Company.

M. A. Hanna and Company 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 out into a stream and forced against a water-cooled deflector, and ignited by the radiated heat from the flame itself instead of igniting it 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.

Later, the water cooled deflector was abandoned, and the design of furnace deflector plate and feeder evolved as shown in Fig. 33. The pulverized coal is removed from the hopper by two variable speed screws and flows horizontally in two streams which converge, 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 air and coal current. 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 colour 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 and Company 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 and Wilcox three pass boiler with 2,357 square feet of heating surface. The fuel used in the trial marked "A" is Dover, Ohio, coke braize; that in the trial marked "B" Nanticoke slush; that in the trial marked "C" Lykens seam dirt.

Trial	A	B	C
Duration of trial, hours	6·2	5·92	4·28
Steam pressure, lb. per sq. in.	117	111	112
Draft in flue behind boiler, in. water	0·329	0·327	0·388
Draft in furnace at bottom, in. water	0·196	0·186	0·172
Draft in furnace at top, in. water	0·054	0·044	0·048
Draft in boiler top 1st pass, in. water	0·049	0·033	0·036
Draft in boiler bottom 2nd pass, in. water	0·111	0·100	0·104
Draft in boiler top 3rd pass, in. water	0·116	0·110	0·124
Blast at rise on pipe, in. water	1·71	1·99	2·02
Flue gas temperature, °F.	562	574	617
Fuel, Proximate Analysis			
Moisture, per cent	0·99	0·98	0·60
Volatile matter, per cent	9·89	7·17	8·09
Fixed carbon, per cent	73·76	64·71	80·11
Ash, per cent	15·36	27·14	11·20
Calorific value, B.Th.U. per lb. dry coal	12,190	10,008	13,407

Fuel, Size			
Through 100-mesh, per cent..	98·3	88·5	97·9
Through 200-mesh, per cent..	92·6	80·8	89·5
Density of fuel, lb. per cu. ft..	57·5	54·4	58·5
Proximate analysis of refuse from the top of the 1st pass			
Volatile matter, per cent..	2·04	1·70	2·40
Fixed carbon, per cent..	12·48	20·90	9·12
Ash, per cent..	85·48	77·40	88·48
Equivalent evaporation from and at 212° per sq. ft. heating surface, lb. per hour..	4·44	3·83	4·34
Equivalent evaporation per lb. of dry fuel, lb..	9·49	7·20	11·02
Carbon dioxide, per cent by volume, at top of 1st pass..	11·96	13·1	10·8
Combined efficiency of furnace and boiler, per cent..	75·5	69 8	79·7

The carbon dioxide content of the flue gas in these trials is not as high as is anticipated commonly with powdered coal fired boilers, but is as high as that obtained in practice; and Mr. Walker, in a letter to the writer, says, 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 towards 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 and Company are installing four 500-horsepower Edgemoore boilers for the Short Mountain colliery at Lykens, Pa., and for the Pennsylvania colliery at Shamokin.

INSTALLATION AT PARSONS

Fig. 34 illustrates a powdered coal fired boiler equipment, designed by the Fuller Engineering Company. This company have designed several pulverized fuel boiler plants.

They prefer the horizontal burner, as shown previously in Fig. 16. One of their earliest boiler installations was at the shops of the Missouri, Kansas and Texas railway at Parsons, Kansas.

The boilers are O'Brien water tube boilers. After replacing the horizontal baffles on which ash accumulated, with vertical baffles, and enlarging and remodelling 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 labour, 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 size dryer must be used, or the expedient adopted of passing the lignite twice through the dryer. At Parsons, the lignite was passed through the dryer twice.

Extracts from results of tests on boilers at the Missouri, Kansas and Texas R. R. shops at Parsons, Kan.

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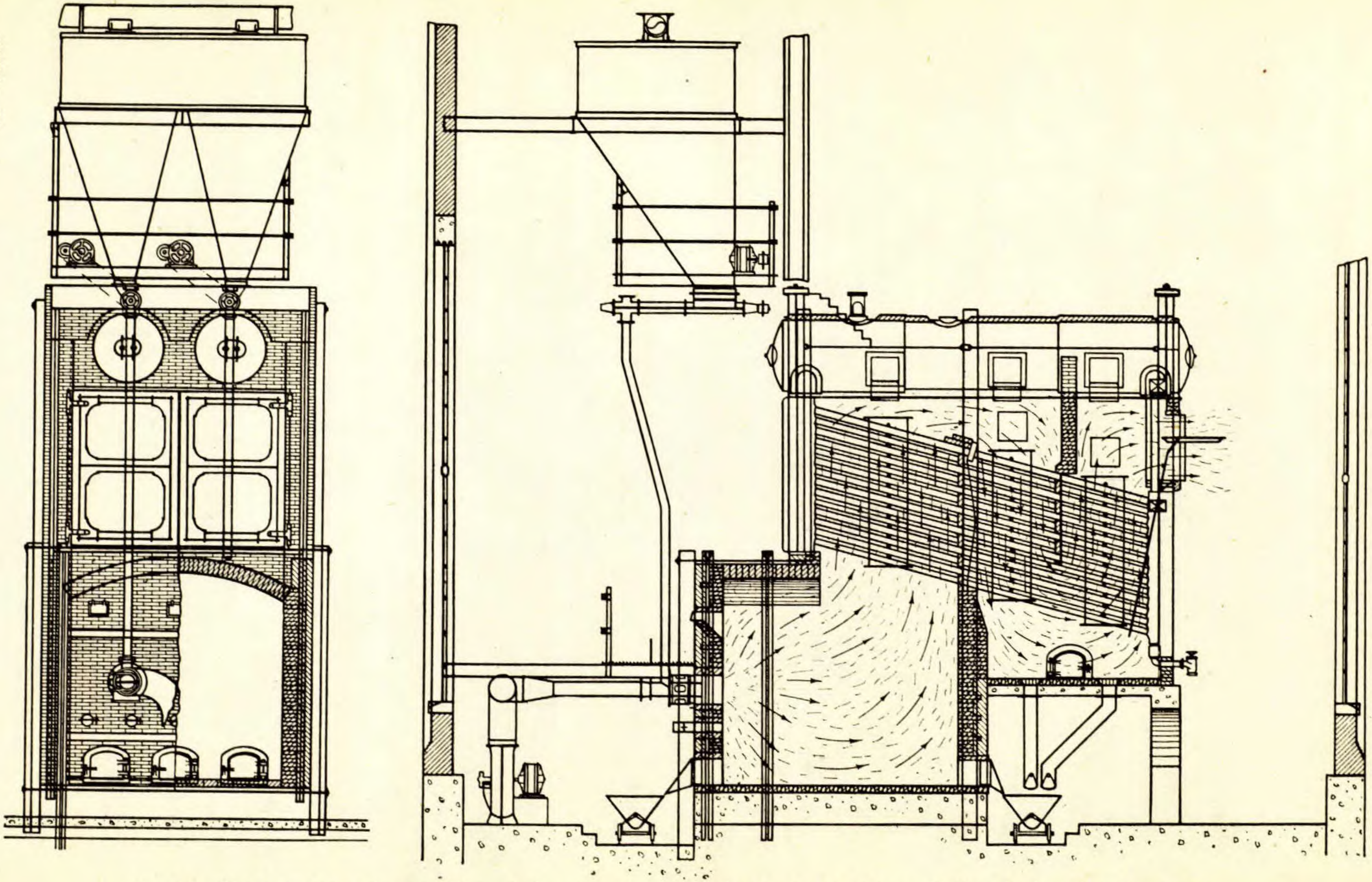

FIG. 34. 500 H.P. Babcock and Wilcox boiler, arranged for pulverized coal firing. Fuller Engineering **Company.**

No. of Test	Kind of coal	Rated boiler horse-power	Duration of test, hours		Steam pressure by gauge, lb.	Flue gas analysis				Prox. analysis dry coal			B. Th. U. per lb. dry coal
			Hr.	Min.		CO_2 %	O %	CO %	N %	Vol. %	Fixed car.	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	11*	0	79	47·1	35·4	10·5	11,250
5	Texas lignite.........................	191	1	13	130·6	12·5	8·5*	0	79	47·1	35·4	10·5	11,250
6	Cherokee mineral slack.............	382	1	24	126	10	11*	0	79	28·4	48·7	21·9	11,380
7	Cherokee mineral slack.............	191	2	0	123	13·5	7·5*	0	79	28·4	47·7	21·9	11,580
8	Cherokee mineral slack.............	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	Semi-anth. Kan......................	191	3	30	135·5	15·8	3·5	0	81·6	22·29	59·94	17·77	12,625

*NOTE.—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 analysed incorrectly.—J.B.

INSTALLATION AT VANCOUVER, FULLER ENGINEERING COMPANY

The Fuller Engineering Company have 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 and 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.Th.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 Company purpose installing a centrifugal separator to remove the ash from the flue gases. They have already tried removing the dust by precipitating it electrically; they were successful, but abandoned this electrical scheme because it would be too expensive.

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 entirely blow out the ash, since the draft tends to blow the ash towards 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 dryer 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 Company find powdered coal extremely suitable for their extremely irregular demand for steam, since 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 space of time when necessary. The British Columbia Sugar Refinery Company 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 cannot be definitely ascertained, but it is probably high."

Ten days later, another test, of 4 hours duration, was run on a Badenhausen boiler at a higher rate of steaming. Unfortunately, no flue gas analyses are given.

Coal used—Nanaimo bituminous slack, Vancouver Island

Weight of coal as fired (1·61% moisture)	lb.	13,870·86
Weight of water fed to boiler	"	104,357·5
Temperature of water entering boiler	deg.	185·5
Temperature of water entering economizer	"	93
Gauge steam pressure per square inch	lb.	76·6
Weight coal fired per hour	"	3,467
Weight water per hour from and at 212°	"	27,706
Water evaporated per lb. of coal from and at 212°	"	7·9
Rated H.P. of boiler		504
Horse-power developed		803·09
Percentage of rated capacity		159·3
Calorific value of coal, B.Th.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 and Power Company of Seattle, of the Pacific Coast Coal Company, and of Mr. Ralph Galt, now manager of the Fuller Engineering Company's Seattle office, many boilers are using powdered coal in Seattle.

The largest of the boiler plants is that of the Puget Sound Traction, Light and Power Company's steam heat plant. Much of the information about this plant is taken from the Stone and Webster Journal for August, 1919. This plant contains ten Babcock and Wilcox boilers, with an aggregate boiler horse-power of 4,100. They originally burned fuel oil, but now burn culm obtained from a dump consisting of washings from the Renton mine, where lignite is mined. The lignite has a calorific value of about 9,000 B.Th.U. per pound, 18 per cent of moisture, and 16 per cent of ash. The culm is received has a calorific value of about 7,300 B.Th.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 dryers, 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 fifteen 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 Fig. 35; taken from a blue print given to the writer

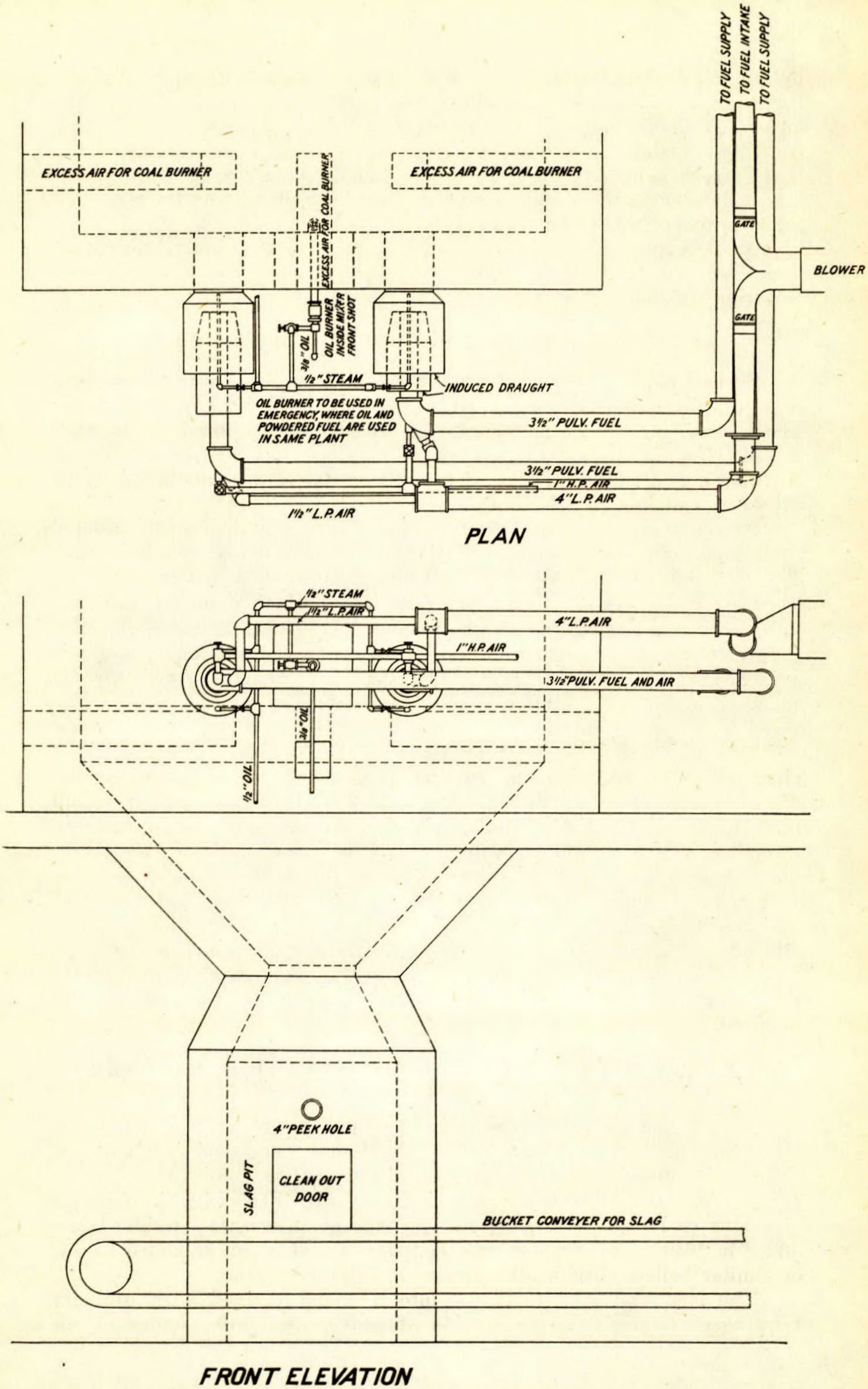

FIG. 35. General arrangement of burners and other apparatus for pulverized coal firing, designed by W. J. Santmeyer.

by Mr. W. J. Santmeyer. From Fig. 35 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 Fig. 35.

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. Fig. 36 shows this system as developed in Seattle by Messrs. Santmeyer and Galt, and applied to a horizontal return tubular boiler in Stockton, Cal. for Mr. R. N. Buell.

At the Stockton plant (see Fig. 36) 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 disc 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 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, since at one plant at Seattle the engineer gave this reason for using oil at the time of the writer's visit, when little steam was required.

ERIE CITY IRON WORKS BOILER FIRED WITH POWDERED COAL

Fig. 37 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

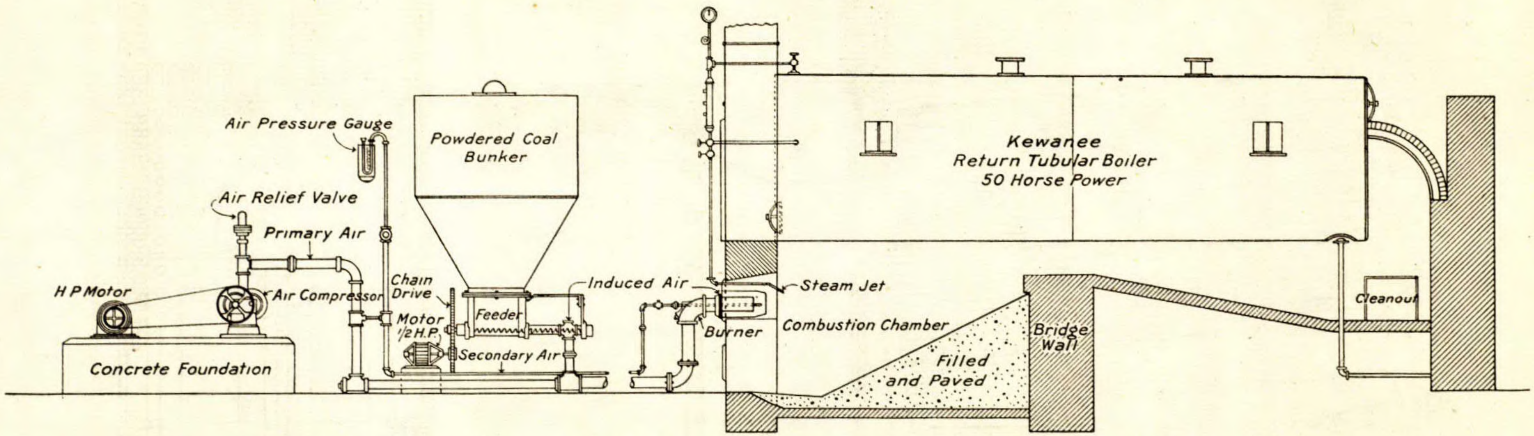

FIG. 36. System for burning powdered coal beneath small boilers used by Mr. R. N. Buell at Stockton, Cal. This system has been developed in Seattle by Messrs. Santmeyer and Gault, where the coal is delivered already pulverized.

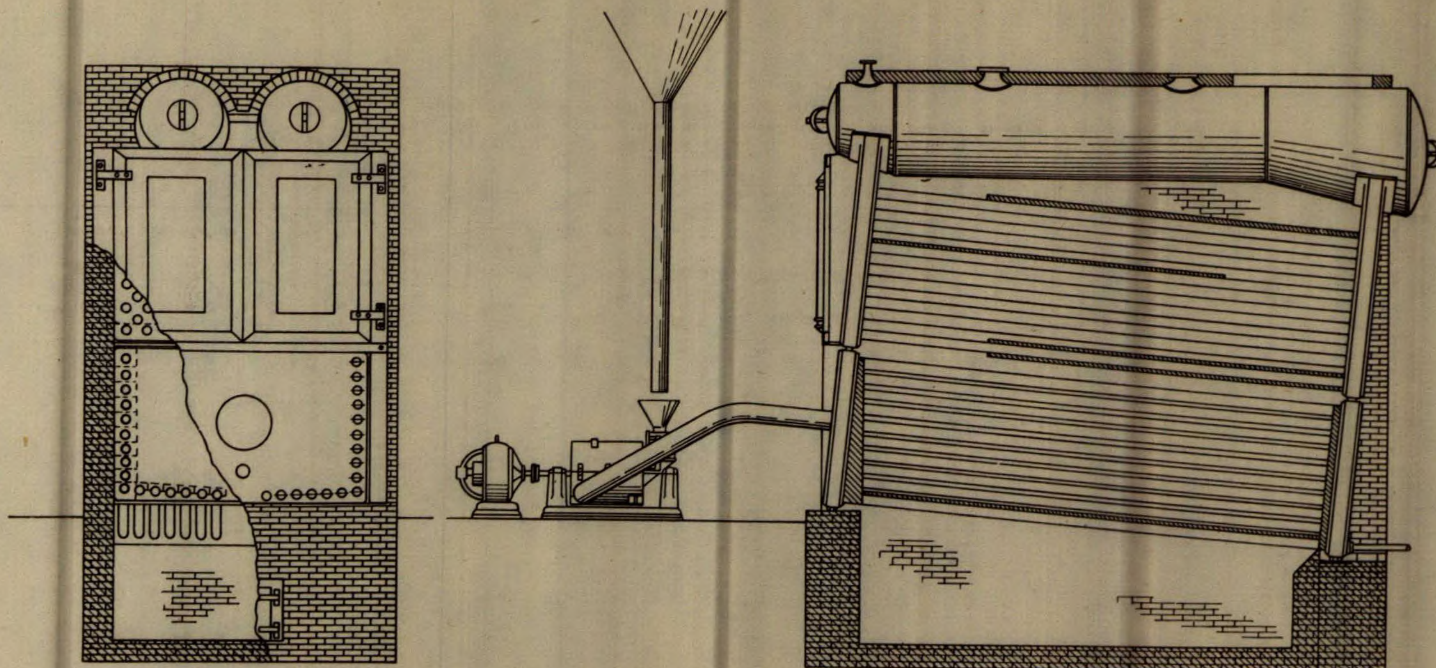

FIG. 37. System for pulverizing coal with Aero pulverizer and delivering directly to a water tube boiler with specially designed furnace.

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 ashpit. The molten ash in falling from the slot to the ashpit 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 ashpit 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 a 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 herewith appended.

Boiler trial at Erie City iron works, on Erie City horizontal water tube boiler, with special water jacketed furnace designed for use with pulverized coal.

Water heating surface	sq. ft.	4022
Date of test—December 23, 1919.		
Duration of trial—8 hours.		
Fuel—Bituminous, slack, pulverized.		
Steam pressure, gauge	lb. sq. in.	146
Flue gas temperature	°F.	508
Draft at damper	in.	0·44
Draft, at furnace	"	0·03
Coal analysis, as received—		
Moisture	per cent.	6·44
Ash	"	10·75
B.Th.U. per lb. of dry coal	"	13,134
Moisture in coal after being pulverized	"	1·78
Screen test of coal		
Per cent through 200-mesh	"	42
Per cent through 100-mesh	"	66
H.P. hr. used by pulverizer blower per ton of wet coal		41
Flue gas analysis—		
Carbon dioxide	per cent	16·4
Oxygen	"	2·1
Carbon monoxide	"	0·1
Water Rate—		
Equivalent evaporation per hour, from and at 212° F.	lb.	22,546
Equivalent evaporation per hour, from and at 212° F. per sq. ft. of heating surface	"	5·6
Economic results—		
Equivalent evaporation from and at 212° F. per lb. of dry coal	"	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 dryer 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 Company was seen at the time of the writer's visit to Allentown. It has 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 in a discussion on pulverized fuel before the American Society of Mechanical Engineers (see the Journal A.S.M.E., September, 1919) gives many interesting facts about its use on locomotives, and states 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 experimented with 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 FIRED VERSUS STOKER FIRED FURNACES

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 nor in any subsequent remodelling of stoker fired boilers. Its chief advantages lie in the possibility of obtaining high carbon dioxide content of the flue gas with very little or no combustible gas, its flexibility and almost complete combustion of coal. But to obtain the 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 of Johns Hopkins University on a Stirling boiler fired with an underfeed stoker, and reported on p. 675 of vol. 36 (1914) of the proceedings of the American Society of Mechanical Engineers.

Duration of trial.. .. ..hours.	25	24	24	12
Heating surface.. .. ..sq. ft.	10,134	10,134	10,134	10,134
Water evaporated from and at 212° F. per sq. ft. of heating surface.. ..lb.	5·41	3·68	5·17	6·83
Coal fired per hour.. .. ..lb.	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.. .. .. "	3·30	2·28	1·66	3·21
Carbon monoxide..	0·05	0·03	0·26	0·51
Moisture in coal.. .. ..per cent.	3·65	2·94	4·00	3·16
Ash in coal..	11·61	11·65	11·87	12·47

B.Th.U. per lb. 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 basis				
Heat absorbed by boiler.. ..per cent.	73·22	81·08	74·93	72·30
Heat loss due to hot flue gas.. "	11·14	9·04	10·38	14·05
Heat loss due to combustible in ash.. .. .. "	3·35	2·31	2·86	5·31
Heat loss due to moisture in coal.. .. .. "	0·35	0·28	0·39	0·32
Heat loss due to burning hydrogen .. .. "	4·43	4·12	4·25	4·60
Heat loss due to carbon monoxide.. .. .. "	0·18	0·10	0·86	1·81
Heat unaccounted for.. .. .. .. "	7·33	3·07	6·33	1·61
Horse-power, stoker motor..	....	7·13	8·51	10·91
Horse-power, fan motor..	....	25·09	28·34	41·04
Total horse-power fan and stoker.. ..	....	33·22	36·85	51.95
Total horse-power per 2,000 pounds coal fired per hour..	....	19	14	14 ..

There is little room for improving on 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 horse-power 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 cannot 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 that 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. J. W. 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 Company blast furnace plant where the Pulverized Fuel Equipment Company 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 Company.

Remarks on Ford Motor Company's Plant.

The following remarks on the Ford plant by Mr. W. F. Verner, mechanical engineer, Ford Motor Company, Detroit, Mich., during a discussion on powdered coal fired boilers before the American Society of Mechanical Engineers, are interesting (Journal A.S.M.E. August, 1919, p. 661).

W. F. Verner gave estimates that had been prepared covering the comparative costs of operating six 2,400-horsepower boilers at the Ford Motor Company'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 labour, (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 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 connexion 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 favour 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:—

(*a*) 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.

(*b*) 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.

(*c*) No mechanism is exposed to the high furnace temperature, and the costs of installation, maintenance, and operation of the boiler firing machinery will be less than in a stoker plant.

(*d*) Very little labour 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.

(*e*) The ash, if the furnace be properly designed, gives less trouble and costs less to remove than the ash in stoker plants.

(*f*) The powdered coal fired furnace is quickly and simply adapted for burning gaseous or liquid fuels should they be available at a cheap price.

(*g*) In every day running the efficiency will be higher than with stoker fired boilers, due to the smaller loss due to unburnt fuel and the smaller loss due to using less air to burn the coal.

The above advantages are offset by the first costs, 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 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 dollars 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, where the cost is about 80 to 90 cents a ton.

Capital Costs

The capital cost of plants vary considerably with the design of plant. Here follow some estimates of the capital costs of two well known engineering firms. It will be observed that the capital cost per daily output decreases with the size of the plant.

Fuller Engineering Company's Estimated Costs of Equipment

The Fuller Engineering Company in May 1919, prepared the following table of the size of preparation plant buildings required for the various daily capacities shown in the table. They point out that this estimate will always require revision for any particular plant; for instance, the floor space might be materially reduced by placing the dryer on a floor above the pulverizers:—

Daily output	No. and size of pulverizer	Size of dryer	Floor space, preparation plant
30 to 40 tons	1–33″ mill	1–3′0″ x 42′	23′ x 64′
75 to 80 tons	1–42″ mill	1–3′6″ x 42′	23′ x 64′
150 to 160 tons	2–42″ mill	1–4′6″ x 42′	24′ x 96′
230 to 240 tons	3–42″ mill	1–5′0″ x 42′	34′ x 90′
310 to 320 tons	4–42″ mill	1–6′0″ x 42′	34′ x 124′
390 to 400 tons	5–42″ mill	1–6′0″ x 42′	34′ x 132′
470 to 480 tons	3–57″ mill	2–4′6″ x 42′	36′ x 120′
600 to 640 tons	4–57″ mill	2–5′6″ x 42′	36′ x 128′
750 to 800 tons	5–57″ mill	2–6′0″ x 42′	40′ x 140′
900 to 960 tons	6–57″ mill	2–6′6″ x 42′	40′ x 150′
1060 to 1120 tons	7–57″ mill	2–6′6″ x 42′	40′ x 160′

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

Capacity tons per day	Total cost	Building only
100	$ 50,985 00	$ 10,700 00
200	67,980 00	12,500 00
300	81,376 00	14,750 00
400	96,305 00	15,300 00
500	109,901 00	16,000 00
600	124,630 00	17,500 00
700	139,359 00	18,500 00
800	154,480 00	19,500 00
900	167,684 00	20,500 00
1000	182,413 00	21,750 00

At the time of the writer's visit (August 5, 1919), to the Fuller Engineering Company, they gave the following estimate of the costs of pulverized coal plants and buildings:—

Daily capacity, net tons	Total cost	No. of Fuller mills required
20	$ 33,716 00	1-33" mill
30	33,716 00	1-33" mill.
40	33,716 00	1-33" mill.
80	40,000 00	1-42" mill.
120	52,000 00	3-33" mills.
160	55,000 00	2-42" mills.
240	72,280 00	3-42" mills.
320	94,173 00	4-42" mills.
400	103,000 00	5-42" mills.
480	106,000 00	3-57" mills.
640	117,000 00	4-57" mills.
800	157,000 00	5-57" mills.
960	180,000 00	6-57" mills.
1120	195,000 00	7-57" mills.

American Industrial Engineering Company's Estimate

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

Capacity per day machinery running 7 hrs. out of each 8 hr. shift			Pulverizers	Total cost
1 Shift.	2 Shifts	3 Shifts	(Single unit plant)	
17 T.	34 T	51 T.	1 3-roller mill	$30,000 00
26 T.	52 T.	78 T.	1 4-roller mill	35,000 00
32 T.	64 T.	96 T.	1 5-roller mill	40,000 00
			(Double unit plant)	
34 T.	68 T.	102 T.	2 3-roller mills.	55,000 00
52 T.	104 T.	156 T.	2 4-roller mills.	60,000 00
64 T.	128 T.	192 T.	2 5-roller mills.	65,000 00.

Plants include all machinery from car hopper to Cyclone collector, motor for direct current.

Foundation and erection work under favourable 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: Messrs. Scheffler and Barnhurst

Messrs. F. A. Scheffler and H. S. Barnhurst (both with the Fuller Engineering Company), in their paper read before the American Society of Mechanical Engineers in June, 1919, 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	Interest
Repairs and maintenance	Depreciation
Coal for drying	Insurance and taxes
Labour	

Power.—The power required in an up-to-date pulverized coal plant is from 12 to 13 Kw-hr. 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 Kw-hr. 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 Kw.hr. per net ton. In the following paragraphs the cost of power has been assumed at ¾ cents per Kw.hr.

Repairs.—The item of repairs, including material, labour, 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.

Dryer 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 dryer coal will be 6 cents.

Labour.—This item is the greatest variable in connexion 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 labour at 40 cents per hour, a plant of 100 tons daily capacity, properly designed and equipped, will require approximately 34 labour hours to prepare the fuel and deliver it to the conveyers, whereas in a plant having a daily capacity of 1,000 tons, approximately 115 labour hours are required. Therefore the labour 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 Kw. output in a 5,000 Kw. plant down to $4.80 per Kw. in a 50,000 Kw. plant, and $4.12 in a 100,000 Kw. plant (assuming a turbo-generator water rate of 16 lb. 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 Kw. plant, using 100 tons of pulverized coal daily, is approximately $64,000, and for a 50,000 Kw. 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 dryers 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 pant, 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 dollars per net ton	1000 ton plant dollars per net ton
Power at ¾ cents per Kw. hr. and 17 Kw. hr. per net ton	$0·1275	$0·1275
Labor at 40 cents per hour	0·14	0·04
Dryer coal at $5 per net ton delivered	0·06	0·06
Repairs	0·07	0·07
Total actual cost of pulverizing per net ton	$0·3975	$0·2975
Interest at 6 per cent	0·105	0·039
Depreciation	0·12	0·04
Taxes and insurance	0·035	0·013
Total cost per net ton	$0·6575	$0·3895

Total Costs: American Industrial Engineering Company

Mr. L. H. Bergman, of the American Industrial Engineering Company, (September, 1919) prepared 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. Two ten ton per hour capacity dryers and three five ton per hour Raymond pulverizers were allowed for.

He recommends the operation of the dryers so that the outgoing coal will have a temperature not greater than 125°F., and for the storage of dried coal for 3 hours before entering 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 4 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 00
Foundation	3,000 00
Machinery: crusher, elevators, magnetic separator, raw coal storage bin, feeders for dryers, two 10-ton dryers, dry coal elevator, dry coal bins, three Raymond pulverizers, etc.	50,000 00
Motors: One 25 H.P. motor for crusher, one 7½ H.P. motor for raw coal elevator, two 25 H.P. motors for dryers, one 7½ H.P. motor for dry coal elevator, three 100 H.P. motors for pulverizers, one 15 H.P. motor for conveyers	10,000 00
Erection of machinery	8,000 00
Electric light and wiring	1,000 00
Four 50 ton concrete bins	12,000 00
Powdered coal conveyer 125 feet long	2,000 00
Total	$85,000 00

To insure continuous operation, machinery will be so arranged that either dryer 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
1 foreman per shift at $6	$12 00	4·8 cts.
2 operators in pulverizing plant per shift at $5	20 00	8·0 "
1 operator on conveyer per shift at $4	18 00	3·2 "
1 oiler and repair man per shift at $5	10 00	4·0 "
20 per cent overhead on labour	10 00	4·0 "
Drying cost 16 lb. per ton at $4	8 00	3·2 "
Power 18 Kw. hours per ton at 1 cent	45 00	18·0 "
Stores and purchased material at 4·8 cents per ton	12 00	4·8 "
Interest and depreciation at 10 per cent on $85,000 per year of 300 days	28 00	11·2 "
	$153 00	61·2 cts.

Cost per ton $153÷250=$0·61.

Operating Costs: Mr. Harrison

Mr. N. C. Harrison in his paper on pulverized coal as a fuel before the American Society of Mechanical Engineers, in June, 1919, gives the following actual operating costs per net ton at the Atlantic Steel Company's plant:—

Daily Output 80 Tons Per Day

	Cost per ton
Labour	$0·22
Repairs	0·19
Power	0·134
Dryer coal	0·0218
Total cost	$0·5658

Daily Output 90 Tons Per Day

Labour..	$0·195
Repairs..	0·19
Power..	0·134
Dryer coal	0·0218
Total cost..	$0·5408

Daily Output 100 Tons Per Day

Labour..	$0·176
Repairs..	0·19
Power..	0·134
Dryer coal..	0·0218
Total	$0·5218

Total coal pulverized Jan. and Feb. 1919.. .. .. 5,275 tons

Power: 17·9 Kw. hr. per ton coal pulv. at ¾c... .. $0·134 per ton

Labour: 1 man 16 hr. at $0·40.. .. ..$ 6 40

2 men 16 hr. at $0·35.. .. .. 11 20

Daily cost.. .. ..$17 60

(—$0·22 for 80 tons output, $0·195 for 90 tons, $0·176 for 100 tons).

Dryer coal: Cost of dryer fuel 2·18 cents per ton, based on 2·62 per cent moisture. Coal at $5 per ton, 6 lb. evaporated per lb. of coal burned or 8·7 lb. 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).

Operating Costs: Large Manufacturing Plant

The lowest operating and repair cost figures obtained by the writer from a manufacturing plant were at a large up-to-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 6 months, labour 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 labour costs for operating and repairs were about 40 cents a ton, and the total power costs were about 16 cents a ton.

Operating Costs at a 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 5 pulverizers, 2 in one building and 3 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 was taken as 1·4 cents per Kw. hr.

Month	Tons of coal	Kw. hours	Kw. hours per ton	Power cost
January, 1918	4300	70700	16·4	23 cents
February "	3750	72700	19·4	27 "
March, "	5200	86400	16·6	23 "
April, "	5200	88900	17·1	24 "
May, "	4800	84500	17·6	25 "
September "	4600	81700	17·8	25 "
October, "	4650	97300	20·9	29 "
November, "	4000	98700	24·7	35 "
December, "	3500	90400	25·8	36 "

Month	Tons of coal	Kw. hours	Kw. hours per ton	Power cost
January, 1919	3419	81085	23·8	33 cents.
February, "	3000	81700	27·2	28 "
March, "	3120	61200	19·6	27 "
April, "	1078	31000	28·8	40 "
May, "	498	10700	21·7	30 "
June, "	553	10800	19·5	29 "
July, "	579	10100	17·5	24 "

The labour employed on the day shift of 10 hours at this plant consists of:—

4 men filling bins with powdered coal.
1 man on conveyer leading to dryer.
1 man unloading coal and looking after crusher.
1 man on dryers.
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:—

	1917	1918
Producing labor	$0·34	$0·429
Repairs and supplies	0·37	0·545
General expense	0·32	0·273
Total	$1·03	$1·247

This plant could be remodeled so as to considerably reduce 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 Operating Costs, 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:—

Tons of coal a month	555 $ (actual)	555 $ per ton	1000 (estimated) $ per ton
Labor	986	1·79	0·99
Repairs	450	0·81	0·81
Power cost	250	0·45	0·45
Total operating costs per ton		3·05	2·25

These costs show the effect of operating at different loads, no additional labour 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. J. W. Anderson, the chief engineer of the power plants of the Milwaukee Electric Railway and Light Company, 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:—

Cost of labor per ton of coal operation	$ ·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 9c. per lb.	·007
Cost of labor per ton of coal for maintenance	·036
Cost of material for maintenance	·020
Total cost per ton of coal	$0·325

Mr. Anderson states:—

"The cost per ton depends upon the size of the plant and the quantity of fuel handled, but ordinarily will vary between the limits of twenty-five and fifty cents."

Reasons for Difference in Operating Costs

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

Mean output per day in tons	Labour hours per day	Labour hours per ton of coal
30 to 15	60	2 to 4
35	50	1·4
40	10	·25
25 to 50	40 to 60	1·6 to 1·2
60	70	1·2
100 to 170	120	1·2 to ·7
200	400	0·5

The labour costs in many of these plants could be reduced were the plants re-designed. The third plant referred to in the above table has extremely low labour 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 the facts that this air is used to burn the coal, and that no bins and feeders are required.

Repair Costs

The principal 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 in 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 eleven times to deliver 2,500 tons of coal. But on the other hand, at a neighbouring 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 labour	Repair material	Coal to pulverized plants	Repair costs cents per ton	
				Labor	Material
December, 1915..................	$61 82	$72 77	118 tons...	·52	·62
January, 1916......................	143 47	68 93	178 tons...	·80	·39
February, 1916....................	138 55	279 47	203 tons...	·68	1·38
March, 1916........................	188 11	122 70	510 tons...	·37	·24
April, 1916..........................	220 00	211 68	740 tons...	·30	·29
Total and average.........	$751 95	$755 55	1749 tons...	·43	·43

Thus the total repair costs per ton amounted to 86 cents at this plant for this period of time, which are very high compared with the large manufacturing plant using screw conveyers, previously referred to, where they were only about 15 cents per ton.

Operating Costs: Aero Pulverizer Company (Unit System)

The Aero Pulverizer Company have estimated that the operating costs with their unit system of pulverizing and delivering the air and undried coal to the furnace are as follows:—

Operation	Cost per ton
Unloading	$ ·04
Pulverizing and conveying Air for control Air for combustion	·22
Upkeep and repairs	·04
Labour	$ ·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 upon the design and size of the equipment. Other variables affecting the cost are the cost of power and labour.

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 with properly designed equipment, plants of a reasonably large size may supply and prepare pulverized coal for less than $1 per ton.

CHAPTER VIII

DANGER FROM USE OF POWDERED COAL

Introductory

Although fatal accidents have occurred by explosions and fires in powdered coal plants, their causes 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 cared for 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 dryer, 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 dryer, or by leaving coal in the dryer 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 due to an explosion wave traveling along a low pressure air transport pipe used to convey coal.

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 by 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, which could not resist the force of the explosion and burst. This explosion occurred soon after starting the system, 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 coal in suspension distribution 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 operates 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 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 Company'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. (See Iron Trade Review, February 19, 1920, page 552.)

Pulverizer Explosions

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

Mr. L. D. Tracy, of the United States Bureau of Mines, investigated this explosion and found that many fires had occurred previously at this plant in the distribution line near the furnaces and in the storage bins. The particular disastrous explosion referred to occurred at a time when the temperature of the gases leaving the dryers 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 dryer used was a Bonnot dryer in which the coal leaving the dryer comes into contact with the gases leaving dryer furnace. The makers of this dryer 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 where they may overheat the coal.

Unconfined Dust Clouds

Dust clouds in a mill or boiler room are always a source of danger, and they should not be allowed to form. One dust cloud explosion occurred in a pulverizing house by opening a compressed air tank which contained a deposit of powdered coal, before being assured that the tank was at atmospheric pressure. The compressed air blew out coal dust, which mixed with air and ignited at a nearby 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 and 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 the regular attendants.

The dryer and dryer 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 entrusted with the direct operation of a dryer. 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 dryer, and recording pyrometers should be installed to enable the officials of the plant to check the operation of the dryer.

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

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

Fine coal at a temperature over 150° Fahrenheit 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 smouldering 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 enclosed 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.

Enclose 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.

Non-sparking 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 connexions 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 regenators 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 dryers 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

By Henry Kreisinger, Milwaukee, Wis., and
John Blizard, Pittsburgh, Pa.

1. 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 and Light Company, Milwaukee, Wis. The tests were made by the Fuel Section of the U.S. Bureau of Mines in co-operation with the Research Department of the Combustion Engineering Corporation. The powdered coal equipment was designed and installed by the Locomotive Pulverized Fuel Company. The coal burned in these tests came from the Illinois coal field. The object of the tests was to determine what overall 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.

2. 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.

3. Tests Nos. 28 to 30, inclusive, were made with the usual preparation of coal as it is burned in the plant under ordinary operating conditions. Test No. 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 Nos. 32 to 35, inclusive, were made with the same furnace arrangement as test No. 31, but with the coal pulverized to a lesser degree of fineness. Tests Nos. 36 to 38, inclusive, were made with the same furnace arrangement as in the previous four tests, but with undried coal.

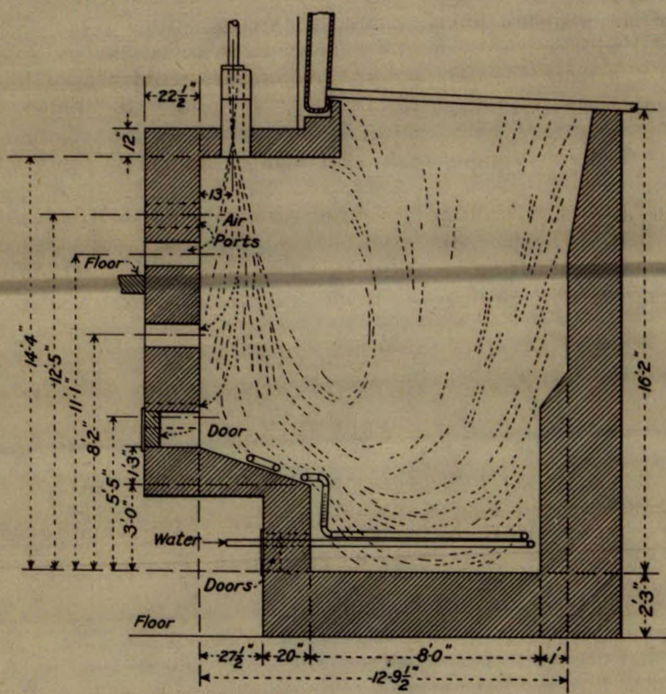

FIG. 38. Section through furnace, showing arrangement of burner and cooling coil over hearth and near bottom of furnace.

4. Fig. 38 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.

5. Fig. 39 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 connexions 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 commenced and closed with the feeder bins empty.

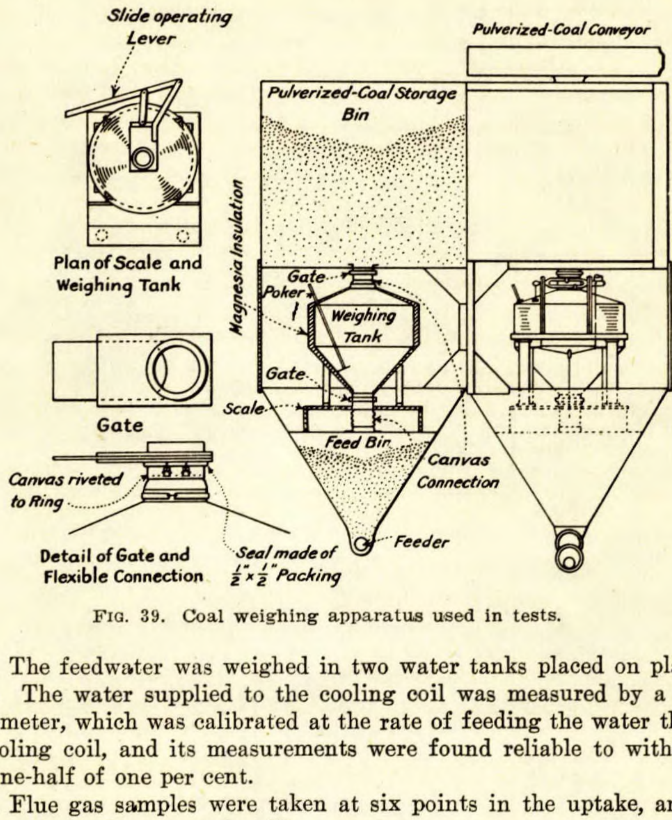

FIG. 39. Coal weighing apparatus used in tests.

6. The feedwater 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 one per cent.

7. 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 Table 1 is the average of the measurements with the six couples.

SUMMARY OF RESULTS OF 11 STEAMING LISTS ON AN EDGEMOOR BOILER BURNING POWDERED COAL AT ONEIDA STREET POWER STATION, MILWAUKEE, WIS.

TABLE I

Heating Surface:
Boiler.........................4680
Superheater.................. 594
Furnace coil.................. 48

Total heating surface......5322 sq. ft.

Draft—Natural.
Burner—Lopulco vertical.
Coal feed—Screw and air blast.

Rating of boiler............................ 468 hp.
Volume of furnace..........................1600 cu. ft.
Greatest height of furnace..................16·7 ft.
Greatest width of furnace.................... 9·3 ft.
Greatest length of furnace...................13·3 ft.

1	Test number	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, per cent	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, per cent	48·16	46·63	46·08	48·07	48·43	49·01	46·39	48·87	45·74	46·39	44·67
7	Ash, per cent	13.80	13.79	13.72	12.80	11.21	11.63	12.84	11.39	10.75	10.96	12.40
8	Sulphur, per cent	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.Th.U	11956	11860	11875	12085	12172	12178	11889	12188	11565	11508	11245
10	Total fuel fired, lb	40214	39862	52746	46613	43947	45469	47459	41250	43729	41640	36315
11	Coal fired per hour, lb	1756	1681	2903	1973	1862	2024	1882	1753	1866	1785	2171
12	Coal fired per hour per cu. ft. 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 2d and 3d 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, per cent	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, per cent of coal fired	0.50	0.54	0.62	0.36	0.87	0.61	0.67	0.30	0.24	0.22	0.26
17	Softening temperature of coal ash, deg. fahr	....	2050	2210	2120	2120	2110	2060	....	....	....	....
	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 2d and 3d 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	0.00	10.80	19.20	23.40
	Air											
22	Temperature, air at furnace, deg. fahr	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, per cent by volume	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, per cent by volume	0	0	0.26	0	0	0.10	0.10	0	0	0	0
28	Pounds of dry flue gas per pound of coal	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, deg. fahr	517	492	610	483	457	472	470	486	484	466	514

Draft											
30 At uptake, inches of water	0.12	0.10	0.27	0.09	0.06	0.08	0.05	0.09	0.10	0.05	0.15
31 Top of furnace, inches of water	0.00	0.02	0.00	0.00	0.01	0.00	0.01	0.02	0.02	0.03	0.03
Steam and Water											
32 Steam pressure, lb. absolute	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 feedwater, deg. fahr	108	99	99	101	101	100	100	103	98	100	99
35 Temperature of water to coil, deg. fahr	No coil	No. coil	No coil	54	53	52	50	48	46	46	46
36 Temperature of water from coil, deg. fahr	No coil	No coil	No coil	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	480.8	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)	No coil	No coil	No coil	49.7	55.0	59.7	45.9	7.5[1]	32.0	29.1	26.8
41 Total horsepower developed	514	502	812	589	549	601	545	528	527	487	586
B.Th.U. Absorbed per Sq. Ft. of Heating Surface per Hour											
42 By water in boiler	3567	3482	5575	3743	3437	3758	3466	3508	3413	3207	3798
43 By steam in superheater	892	861	1856	920	772	845	869	1155	1039	934	1573
44 By water in furnace coil	No coil	No coil	No coil	33900	37600	40770	31270	33190	21920	20160	18440
Heat Absorbed per Pound of Coal as Fired, B.Th.U.											
45 By water in boiler	9500	9690	8990	8870	8630	8710	8625	9360	8650	8405	8190
46 By steam in superheater	301	304	380	277	246	249	274	391	330	311	430
47 By water in coil	No coil	No coil	No coil	843	995	988	815	335	575	554	414
48 Total absorbed	9801	9994	9370	9990	9871	9947	9714	10086	9465	9270	9034
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	No coil	No coil	No coil	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 gases	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	0.1	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.8	0.9	0.9
56 By steam entering with air	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
57 By carbon monoxide	0.0	0.0	1.0	0.1	0.1	0.2	0.4	0.0	0.0	0.0	0.0
58 By carbon in ash and flue dust	0.6	0.6	0.7	0.4	1.0	0.7	0.8	0.4	0.3	0.3	0.3
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	0.6	1.4	3.1	2.2
61 Total	100.0	100.0	1.000	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1]Cooling coil in operation during first $8\frac{1}{3}$ hours of test only.

RESULTS OF THE TESTS

8. The results of the tests are given in Table 1. 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 on 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.Th.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.Th.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

9. 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. Table 2 gives the results of complete sizing tests of the coal burned in Tests Nos. 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.

10. 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

11. 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 Nos. 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.

TABLE 2

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.

12. 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.

CAPACITY OF BOILER THAT CAN BE DEVELOPED WITH PULVERIZED COAL

13. The capacity of boiler 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 pound per cubic foot of combustion space per hour. Good results can be obtained when the coal is burned at rates varying from ½ to 2 pounds per cubic foot of combustion space per hour, which gives a considerable working range. In Table 1 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 burners and the admission of air are very important 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.