1. COMBUSTION - POWER GENERATION

The lignite deposits of the United States represent a huge potential source of fuel for power generation. It has been estimated that lignite constitutes about 24 percent of the remaining National reserves of solid fuel on a tonnage basis and about 15 percent of the reserves on a B.t.u. basis. (See sec. 3, part 1.) The major portion of these reserves is in North Dakota.

Lignite has been used locally for domestic heating since the first settlers burned it at forts and fur-trading posts as early as 1855. Some of the first studies of the use of lignite in steam boilers were conducted by the Federal Bureau of Mines from 1910 to 1920 (15, 19).[1/] However, the commercial utilization of lignite as fuel for producing power developed slowly. Not until about 1925 was any really successful lignite industrial fuel-burning equipment developed. Since then the commercial use of lignite as a fuel for producing power has been increasing steadily.

Because of its high moisture content, low heating value, and lack of preferential transportation rates, lignite has a more restricted area of competition than is generally true of higher rank coals. The approximate extent of the lignite-consuming area is shown in figure 36 (see sec. 6, part 1) and analyses and characteristics of North Dakota lignites are discussed in sec. 3, part 1.

When used with properly designed fuel-burning equipment, lignite has proved to be a satisfactory fuel for power generation. With the equipment now being used, the disadvantage of high moisture content in lignite is largely overcome, as regards firing and heat-release conditions in the furnace, although, obviously, greater amounts of fuel and ash must be handled per unit quantity of power generated than with higher rank coals.

It is interesting to note the important role that coal is playing in the rapidly expanding electric utilities industry in the Nation. Utility power-generating capacity is growing at the fastest rate in history. In 1950 approximately 50 percent (21) of the total energy output of electric utilities was generated with coal. Trends indicate a continued expansion of electric utilities with greatly increased consumption of coal in the near future. The utilization of North Dakota lignite in electric utilities plants has increased quite rapidly in the last few years also. For example, in 1944 the annual production of lignite in North Dakota was 2,516,000 tons, of which 54 percent (1) was used domestically and 46 percent was used industrially. By 1951 the output had expanded to 3,281,000 tons, with an increase in industrial use to 66 percent (14) and a decrease in domestic use to 34 percent. The increased use of fuel oil for domestic heating has caused the rapid reduction in the domestic coal market.

Methods of Firing

Lignite has been successfully burned in power boilers by each of the following methods: Underfeed stoker, traveling-grate stoker, spreader stoker, pulverized firing, and the cyclone burner. The underfeed stoker was never very popular for use with

1/ Underlined numbers in parentheses refer to citations in the bibliography at the end of this section.

lignite, and it is now considered obsolete. The first real progress in the utilization of lignite for power plants was brought about by the successful development of forced-draft traveling-grate stokers. This method of firing lignite was used extensively for a number of years. However, it now has been largely replaced by the more versatile spreader stoker. Most of the power plants constructed in the last few years are fired with spreader stokers used in conjunction with a traveling grate. However, the boiler-size limitation inherent in this method of firing, which will be discussed elsewhere in this section, is such that for large installations the unit-pulverizer method has been chosen. The use of pulverized-lignite firing for large central power stations will, no doubt, be further expanded in the future. The recently developed cyclone burner has been found, in one plant test, to give satisfactory operation with lignite.

The various methods of firing lignite in power boilers are discussed in further detail below:

Underfeed Stokers

In an underfeed stoker coal is introduced through a retort beneath the fuel bed. The volatile gases are distilled off and burned as the coal moves up through the incandescent fuel bed. Air for combustion is introduced through tuyères that form the sides of the retort. The fuel bed for underfeed stokers is usually quite thick and requires considerable agitation to move the fuel. Since lignite is a free-burning coal, which does not hold together, and when underfed burns in a very thin layer, it tends to drift or avalanche as a result of the air pressure and bed agitation. For this reason underfeed stokers have not been used extensively with lignite. Other disadvantages common to this method of firing are high maintenance costs and lack of flexibility in operation. Although there have been some reasonably satisfactory installations with underfeed stokers (5, 18) fired with lignite, at present this type of unit is not being used in any power-generating station in the North Dakota lignite-burning region.

Chain- and Traveling-Grate Stokers

There is a distinction between chain-grate and traveling-grate stokers, based on the link attachment and drive mechanism; but operation of both is essentially the same, and for the purposes of this discussion they will not be considered separately. In either instance, cast-iron links are assembled to form an endless grate, which is driven around a supporting structure by suitable chains and sprockets. Its operation is similar to that of a conveyor belt. Fuel is fed by gravity from the hopper and forms a level, uniform bed on the moving grate surface. The fuel is ignited by the radiated heat from the ignition arch and by hot gases forced over the bed by the rear arch. Forced draft is supplied to compartments between the strands of the grate. Each compartment has a damper for zoning and controlling the air to the various sections of the grate. As the grate moves the coal toward the rear of the furnace, the combustion process is completed, and the ash is automatically discharged into the ash hopper.

Since the fuel bed is not agitated with this type of stoker it is well-adapted for use with free-burning coals, such as lignite. During the period from 1921 to 1948 a number of forced-draft, traveling-grate stokers were installed in lignite-burning power plants in the United States and Canada. The early units were designed for preheated air temperatures (18) of about 300° F. It has since been found desirable to increase air temperature to 400° F. or more to improve the speed and stability of ignition. By increasing the preheated-air temperatures, it has been possible to obtain combustion rates considerably higher than those for which the unit was originally designed. Various types of ignition arches were tried with traveling-grate stokers. The most successful design (5) has been a low, long, water-cooled rear arch. The rear-arch design is used to force hot combustion gases across the bed top to increase both ignition and burning rates. Overfire air jets have been successfully used to create turbulence and mix the furnace gases, improving combustion.

Proper size consist and distribution of the lignite feed on the grate are important factors in obtaining good operating results with this method of firing. If the fuel bed is not uniform, owing to improper sizing of the coal, blowholes may occur and air distribution will not be uniform over the fuel bed. The coal size used with this method of firing ranges from 1- to 1-1/2-inch maximum size, with the permissible percentage of fines depending upon the draft used.

The largest boilers in the North Dakota lignite-burning region using traveling-grate stokers are the units at the Kidder station of the Otter Tail Power Co. at Wahpeton, N. Dak. This plant has two boilers of 100,000-pound-steam-per-hour capacity fired by this method. These units have maximum efficiencies of about 80 percent. A number of smaller furnaces (2, 12) in this region successfully use this type of stoker, and it has been estimated that a unit as large as 200,000-pound-steam per hour could be successfully fired with a traveling-grate stoker burning lignite. Figure 1 (12) shows a typical lignite-fired traveling-grate installation. This unit was installed at the Devils Lake station of the Otter Tail Power Co. in 1947. Operating-performance data (12) for this boiler are shown in figure 2.

Because of the characteristic of traveling grates to respond slowly to load changes owing to the relatively large quantity of fuel on the grate at one time and because of difficulty in burning coal with a high percentage of fines efficiently, the trend is toward the use of other types of stokers in the new installations.

Spreader Stoker

With spreader stokers, coal is thrown into the furnace and uniformly distributed over the grate either mechanically, as with a rotor, or pneumatically. Dumping or traveling grates may be used. The latter has proved to be more desirable for large boilers (7) because it offers the following advantages: A cleaner boiler room, no fuel-bed agitation, no loss in rating during ash discharge, and a lower combustible content in the ash. The traveling grate normally moves toward the front of the boiler. Primary air is introduced below the grates, and overfire air is supplied above the fuel bed. Fine portions of the fuel are dried and burned in suspension when thrown into the highly heated furnace cavity. The larger particles, which also are partly dried in suspension, fall to the grate and are burned there. Other things being equal, the percentage of fuel burned in suspension is a function of the size distribution of the fuel fed to the unit. Because of high moisture content, lignite shatters easily when exposed to the furnace atmosphere. Consequently, the portion burned in suspension and the amount of fly ash produced are greater when lignite is burned than when higher rank coals are fired by this method.

In early installations boiler passes plugged owing to the long flame and large quantity of fly ash having a low fusion temperature. To correct this condition, furnace heights were increased, slag screens were added, and water-wall construction was used to reduce furnace outlet temperatures (13). As a result of the large percentage of fuel burned in suspension, the fuel bed is thin, and high-resistance grates are used with spreader stokers to control undergrate air distribution and flow. Preheated air temperatures as high as 400° F. are used with spreader stokers. Most installations utilize overfire air to prevent stratification of furnace gases, create turbulence in the furnace cavity, reduce fly ash carryover, and sometimes to control superheat.

Less superheater surface per pound of fuel burned is required when lignite is burned than with other coals because of the greater volume of gases resulting from evaporation of the moisture in the lignite.

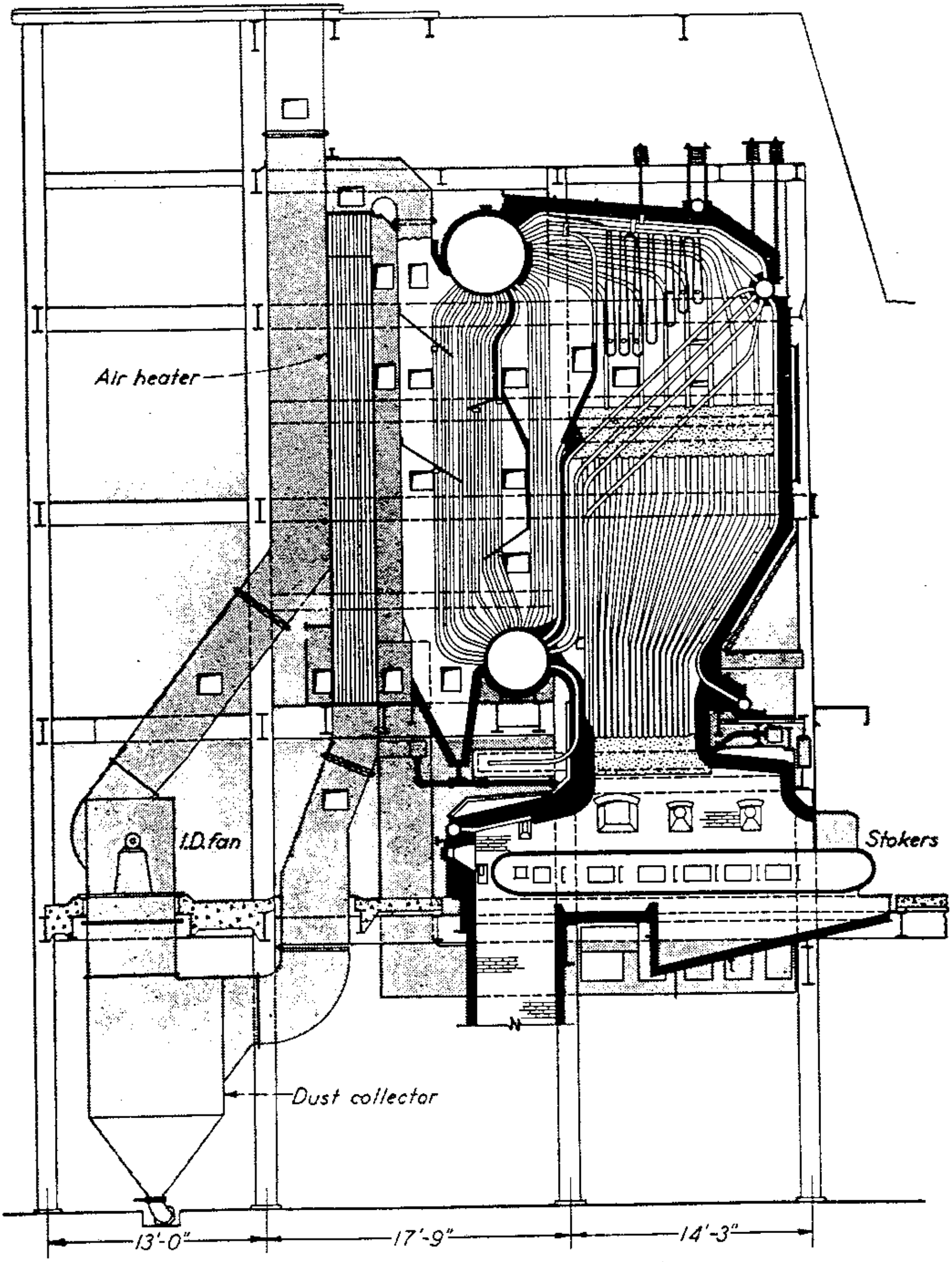

Figure 1. - Traveling-grate-fired steam generating unit of 75,000-pound-steam-per-hour capacity at Devils Lake station of the Otter Tail Power Co., Devils Lake, N. Dak. See reference (12) in section 1.

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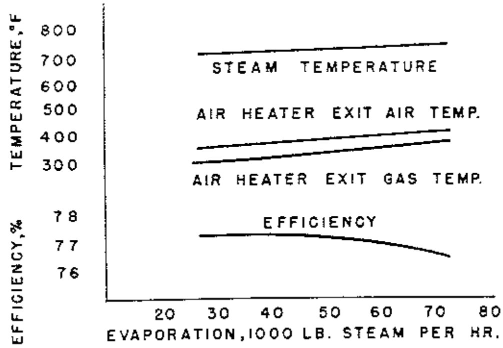
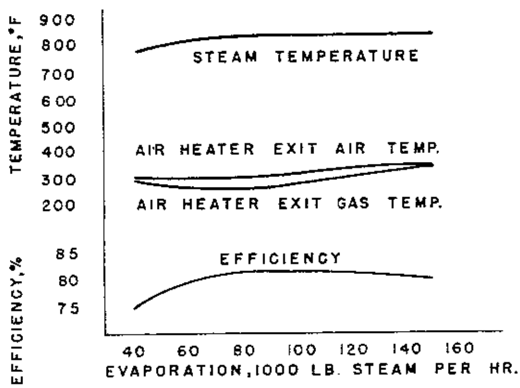
TRAVELING GRATE STOKER:
PERFORMANCE RECORD OF STEAM GENERATOR AT DEVILS LAKE STATION. SEE FIG.39 FOR BOILER DESIGN.



SPREADER STOKER:
PERFORMANCE RECORD OF STEAM GENERATOR AT MINNKOTA STATION.



UNIT PULVERIZER:
PERFORMANCE RECORD OF STEAM GENERATOR AT CROOKSTON STATION. SEE FIG. 45 FOR BOILER DESIGN.

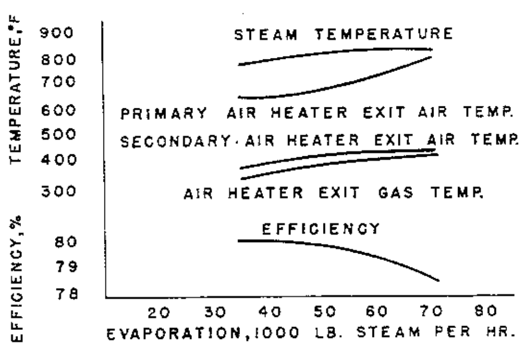


Figure 2. - Performance of three steam generators fired by traveling grate stoker, spreader stoker, and unit pulverizer.

Dust collectors usually are installed with spreader stokers. Some plants reinject cinders, but the large quantity of fly ash and the low combustible content of the ash do not make this practice as desirable with lignite as with other coals. If ash is reinjected, it usually consists of that caught from the boiler pass and air heater, although sometimes dust from the dust collectors is reinjected also (13).

The commercial sizes of coal most commonly used are 2- by 0-inch or 1-1/2- by 0-inch screenings with a considerable percentage of fines (under 1/2 inch). One of the most important operating factors for the spreader stoker; and one to which the stoker is most sensitive, is the size distribution of the feed. Almost any kind of coal can be burned successfully with the spreader stoker, provided the sizing is correct. For this reason, the spreader stoker often is chosen for plants having more than one type of coal available. Some of the other advantages of spreader stokers are (4, 7) low investment cost, low power requirements, low maintenance costs, rapid response to load changes, rapid starting, and ability to respond quickly from a condition of live bank.

Boiler capacity with spreader firing is limited by the distance the coal can be thrown with proper distribution. In present practice this distance is 18 to 19 feet. As a result, the maximum economic boiler capacity is considered to be approximately 250,000 pounds of steam per hour (13).

The largest spreader-stoker installation burning North Dakota lignite is the Ortonville plant of the Otter Tail Power Co., which has a capacity of 160,000 pounds of steam per hour.

Some disadvantages of this method of firing are: The possibility of considerable fly-ash carryover, frequent renewal of the fuel bed necessitated when operating with dump grates, and rapid burning out of the fire if the coal feed stops, owing to the small amount of coal on the grates.

A good example of a large modern spreader-stoker installation for burning lignite is the newest boiler at the Minnkota station, Grand Forks, N. Dak. This unit was added to the station in 1950. It is rated at 135,000-pound-steam-per-hour continuous capacity and has a maximum 4-hour capacity rating of 150,000 pounds of steam per hour. Steam is generated at 615 p.s.i.g. and 825° F. The boiler is of the bent-tube type, with complete water-wall construction. It is fired by two spreader-type stokers with chain-grate ash removal. Each stoker has an active grate width of approximately 12 feet and 170 square feet of grate area exposed to the furnace. Six overthrow-type coal feeders driven from a common line shaft supply fuel to the boiler. The superheater is constructed in two sections and is of the center interbank vertical pendant type. A return-bend loop-header-type economizer received the gases from the boiler outlet. The tubular-type air pre-heater is constructed in two sections. The larger section receives gases from the economizer, and the smaller section is installed on the discharge side of the dust collector. The furnace is designed to reinject the cinders from the last pass hopper. Additional overfire air is supplied by a separate fan.

Performance tests were run on this furnace in May 1950. The principal operating data from this test are plotted in figure 2. Overall boiler efficiencies exceeding 80 percent were maintained from about 45 to 115 percent of the rated load. Preheater-air temperatures range from 300° to 350° F. Ash samples were collected from the last-pass hopper and dust-collector hopper during part of the test to determine the reduction in combustible content by cinder reinjection. Less than 1 percent difference in combustible content of the ash was found for the two samples. Figure 3 shows graphically how the combustible content in the dust-collector hopper refuse increased with boiler capacity, whereas that of the ash pit refuse decreased.

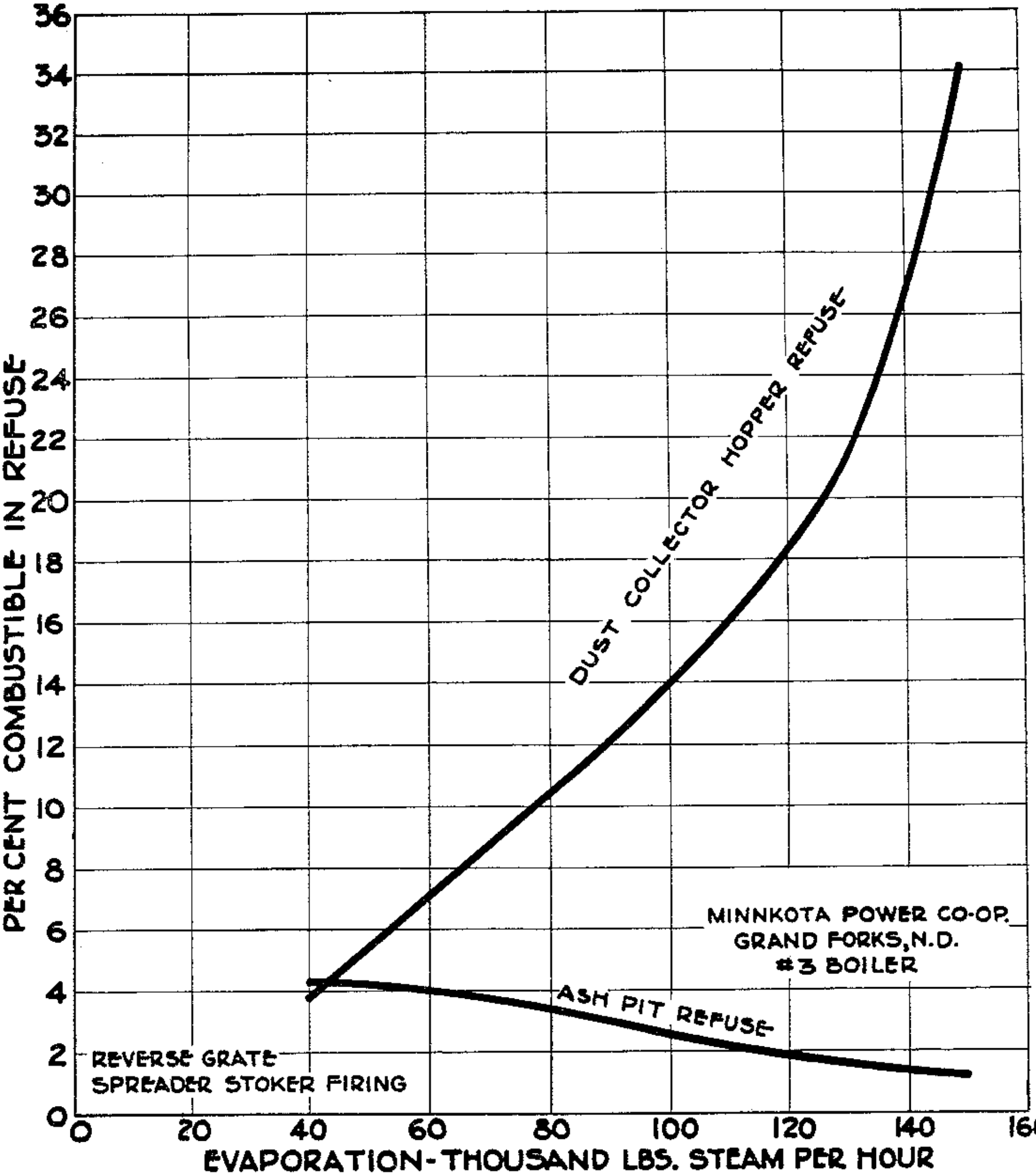


Figure 3. - Percentage combustible in the refuse as a function of boiler load during performance test on 135,000-pound-steam-per-hour boiler at the Minnkota station, Grand Forks, N. Dak. See reference (18) in section 1.

(By permission of Am. Soc. Mech. Eng.)

Operating data, taken from the plant reports for 1952 for the entire Minnkota station on a monthly and yearly basis, are given in table 1. As would be expected, the average boiler efficiencies are lower than those shown in the charts for performance tests.

TABLE 1. - Summary of operating data, 1952, Minnkota station, Minnkota Power Cooperative, Inc., Grand forks, N. Dak.

(Data supplied by Minnkota Power Cooperative, Inc.)

Fuel costs......................cents per million B.t.u.	31
Boiler efficiency...............................percent	77
Station heat rate.................B.t.u. per net kw.-hr.	15,582
Station consumption.....percent of gross power generated	6.17
Plant factor 1/.................................percent	70
Running plant capacity factor 2/.....................do.	85
Fuel cost.......................mills per net kw.-hr.	4.61
Operating labor......................................do.	0.63
Maintenance including material.......................do.	0.23
Miscellaneous..do.	0.11
Total production expense.............................do.	5.58
Station heat rate, best month.....B.t.u. per net kw.-hr.	15,076
Boiler efficiency, best month...................percent	77.4
Station consumption, best month.........................percent of gross power generated	5.05

1/ Plant factor = $\frac{\text{gross kw.-hr. generated per yr.}}{\text{(hr. per yr.) (Installed capacity in kw.)}}$

High plant factor is maintained at Minnkota station by using the diesel plant for peak loads. Diesel plant capacity is 15,000 kw.

2/ Running plant capacity factor = $\frac{\text{Gross kw.-hr. generated per yr.}}{\text{(Hr. operated per yr.) (installed capacity in kw.)}}$

In figure 4 ash-collection data are presented for one of the two 72,000-pound-steam-per-hour boilers at the Minnkota plant. The boiler design is shown in figure 5. These units are similar in design to the large boiler. Shown on the graph are typical percentages of total ash collected in the stoker ash hopper, in boiler and air-heater soot hoppers, in economizer soot hoppers, and dust collectors. The percentages of combustible material at each of the points of collection also are shown in figure 4. Principal operating data from performance tests for this boiler are given in figure 6.

Pulverized Fuel

A pulverized-fuel system consists basically of a pulverizer to convert the raw coal to powder, a fan to convey it into the furnace, and a burner to mix air and fuel in such a manner as to maintain stable ignition. Pulverized-fuel systems may be arranged as either unit or bin systems. In the bin system the pulverizers are operating independently and at full capacity. Pulverized coal is discharged to a storage hopper, from which it is removed as required. In the unit system one or more machines pulverize and deliver the fuel directly to the burners. Most recent installations are of the unit system, which is simpler, requires less space, creates less fire hazard, and has a lower initial cost than the bin type.

Burners for pulverized fuel may be mounted either horizontally or vertically. The horizontal burners sometimes are made adjustable so that the rate of evaporation in the

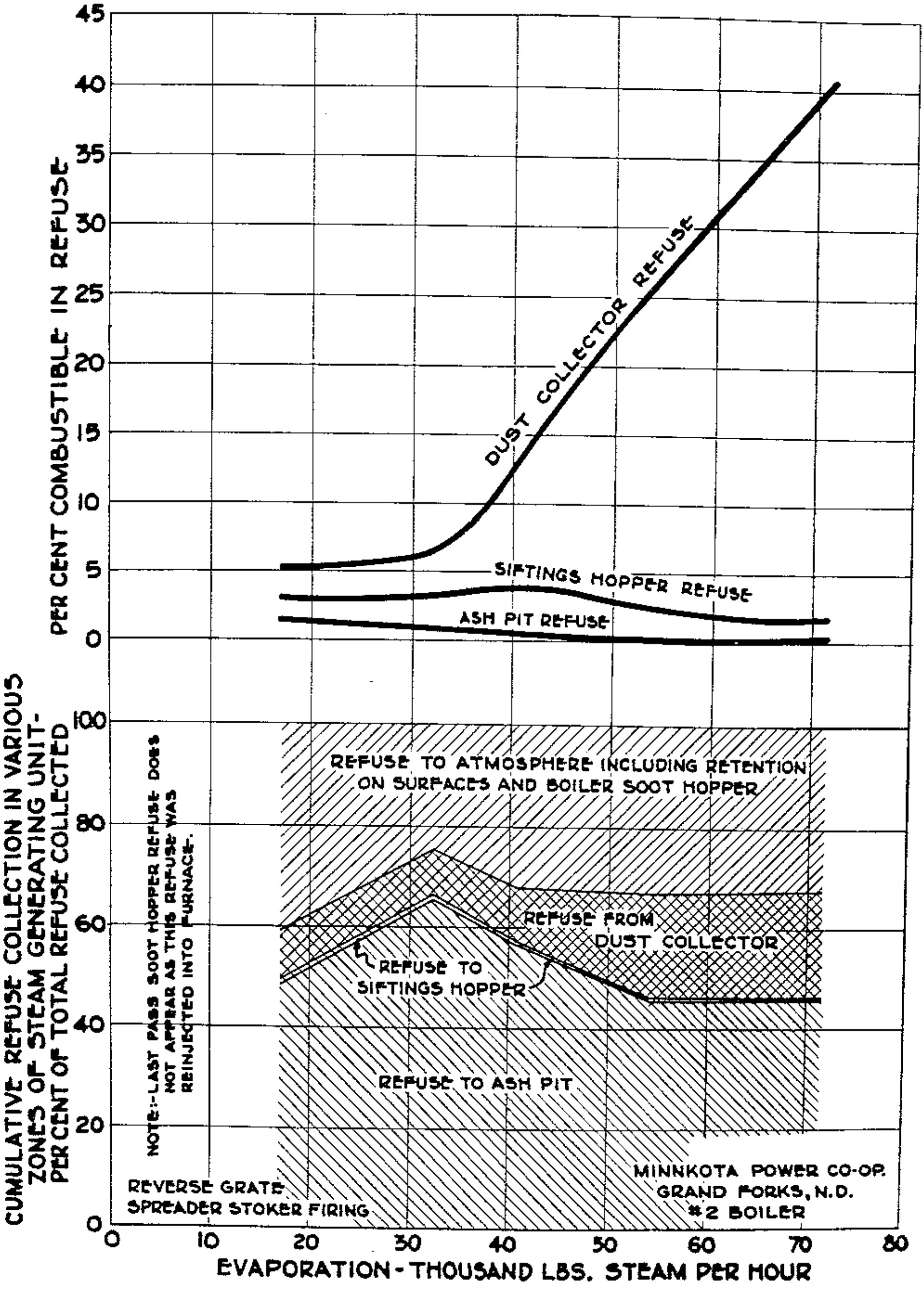


Figure 4. - Percentage distribution of lignite refuse by weight and of combustible in refuse during tests on 72,000-pound-steam-per-hour boiler at the Minnkota station, Grand Forks, N. Dak. See reference (18) in section 1.

(By permission of Am. Soc. Mech. Eng.)

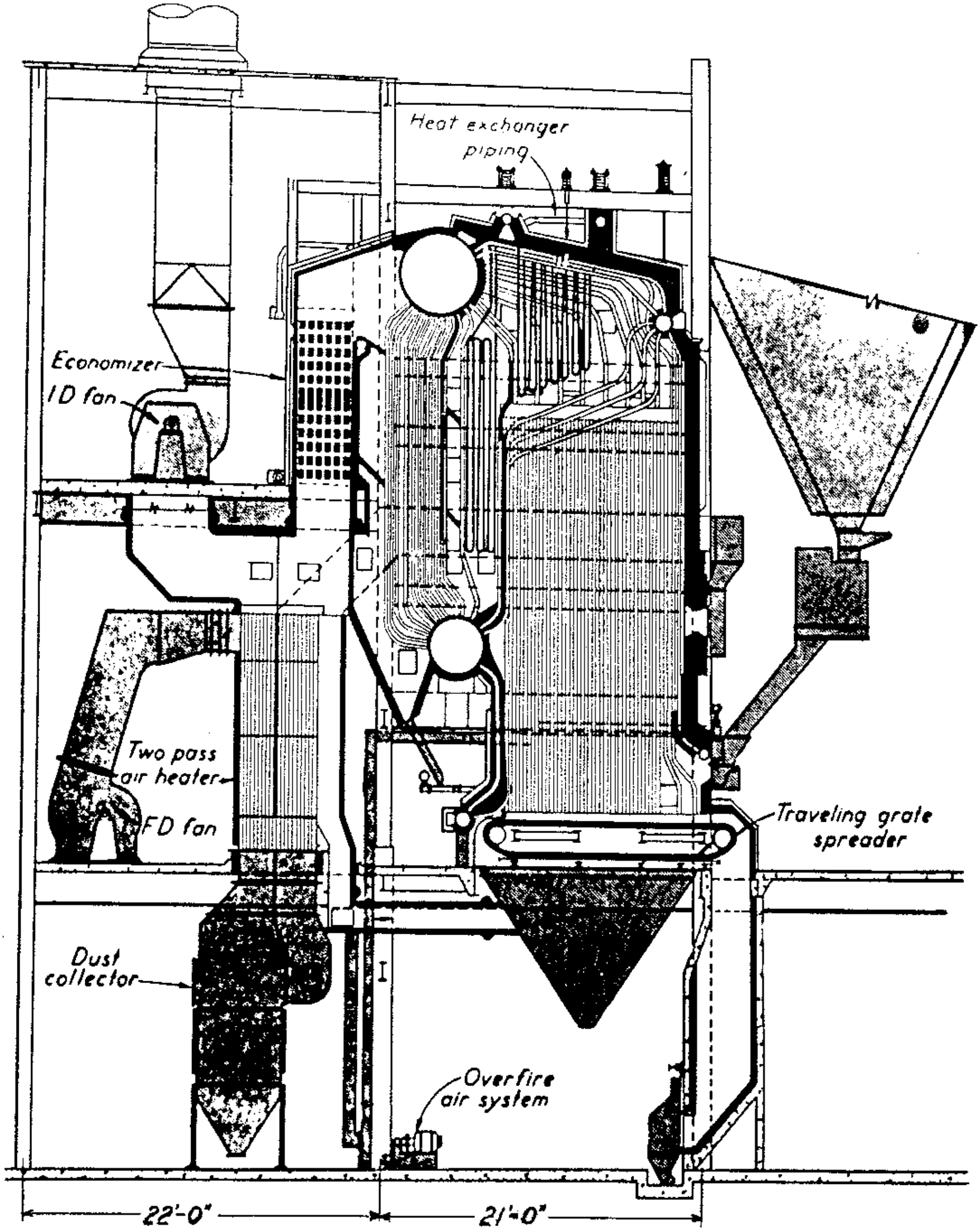


Figure 5. - Spreader stoker-fired steam-generating unit of 72,000-pound-steam-per-hour capacity at the Minnkota station of Minnkota Power Cooperative, Inc., Grand Forks, N. Dak. See reference (12) in section 1.

(By permission of Industry and Power magazine)

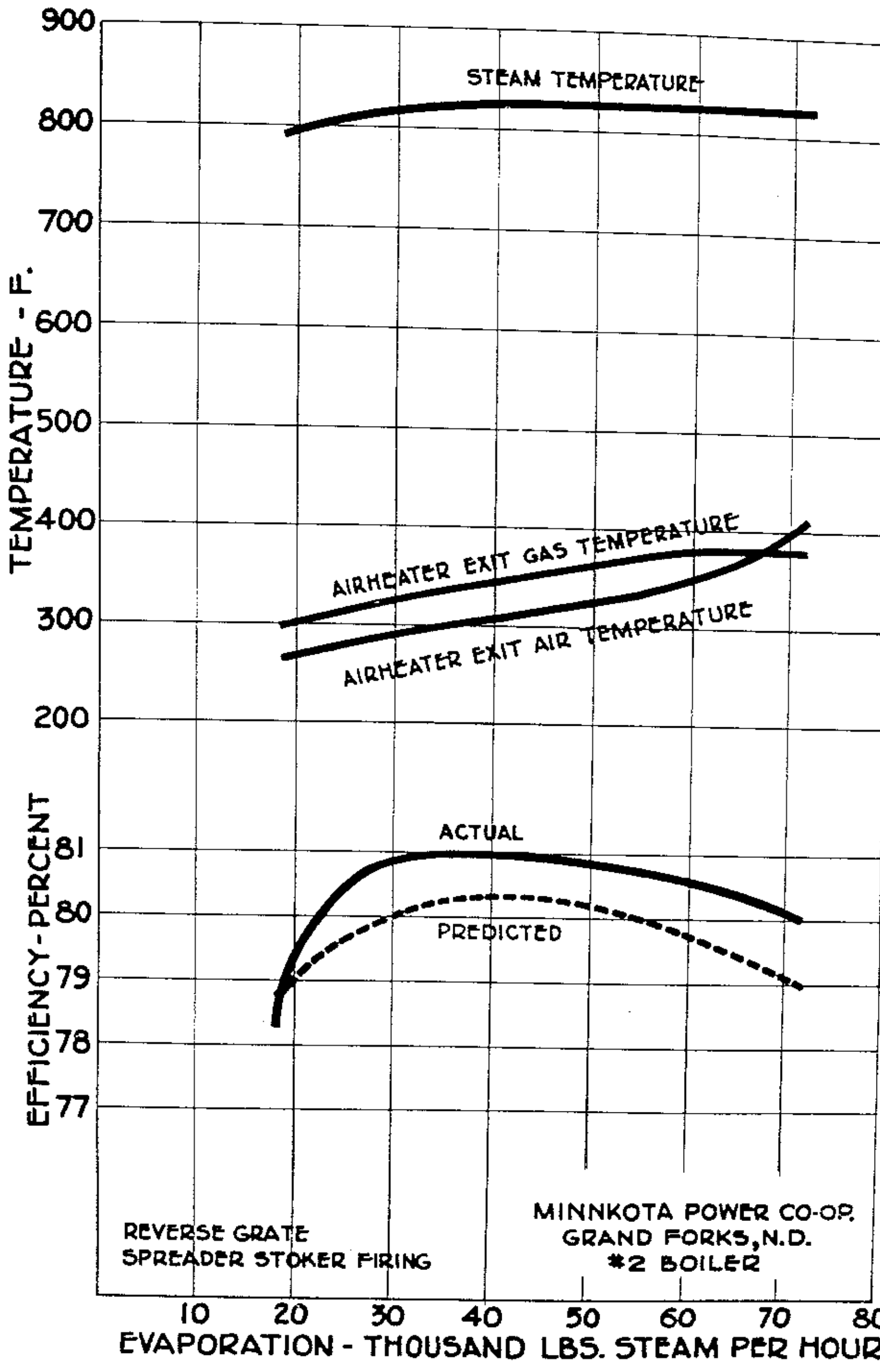


Figure 6. - Operating record for 72,000-pound-steam-per-hour capacity boiler at the Minnkota station, Grand Forks, N. Dak. See reference (12) in section 1. *(By permission of Industry and Power magazine)*

water walls and the superheat temperature can be controlled by tilting the burners and thereby changing the position of the main flame in the furnace.

Pulverizers are classified as either impact or attrition mills, depending on the method of fuel reduction. The 2 methods may be combined in 1 mill, and lignite can be pulverized successfully by either. It is necessary to reduce the moisture content of the lignite enough to prevent packing and sticking in the mill. With unit pulverizers this is accomplished by introducing high-temperature primary air (600°-800° F.) into the mills (13, 18). The temperature of the fuel-air mixture from the mill usually is maintained at 130° to 200° F. (13); this discharge from the mill contains water vapor, often near the saturation point, so it is necessary to insulate the duct to the furnace to prevent condensation. This method of pulverizing reduces the total moisture content of the fuel approximately one-third.

Pulverized lignite ignites easily and burns with a stable, relatively short flame. The high percentage of volatile matter and low fixed-carbon content promote rapid ignition, therefore the fineness of pulverization is not as critical with lignite as with other coals. Secondary air for combustion is introduced around the periphery of the burner. Dry-bottom furnaces are used with pulverized lignite firing.

The first successful pulverized-lignite installations in the United States were made in Texas in 1926 (11). In that year 4 boilers, each rated at 185,000 pounds steam per hour, were installed at the Trinidad station of the Texas Power & Light Co. The boilers were of the three-pass, crossdrum design, with interdeck superheaters. At that time mill drying had not been developed. Lignite was predried in steam-heated grid driers before being fed to the mills. Moisture content was reduced from 30 to 33 percent as mined to 25 to 28 percent at the mill. The dried and pulverized fuel was then stored in bins before being fed to the burners. Burners were mounted for vertical firing, and dry-bottom furnaces were used. These units operated at an efficiency of 75.5 percent at full load, with a heat release of 14,600 B.t.u. per cubic foot per hour. Two other similar units were added to the station in 1931. These boilers each had a capacity of 325,000 pounds steam per hour and showed a full-load efficiency of about 76 percent (11), with a furnace heat-release rate of 23,200 B.t.u. per cubic foot per hour.

Other equally successful pulverized-lignite units were operated for a number of years at the Comal station of the San Antonio Public Service Commission (5). These boilers had a rated capacity of 232,000 pounds of steam per hour and were designed for an efficiency of 79.5 percent with a furnace-heat release of 18,400 B.t.u. per cubic foot per hour.

The power stations mentioned above have since been converted to firing other fuels. However, the use of Texas lignite for large steam generators has shown renewed promise recently with installation of the large Texas Power & Light Co. plant at Rockdale, Tex. (16).

The first modern pulverized-fuel installation for North Dakota lignite was installed at the Crookston station (12) of the Otter Tail Power Co. in 1945. (See fig. 7.) The rated capacity of this unit is 75,000 pounds of steam per hour at 425 p.s.i.g. and 825° F. Two unit pulverizers are used to supply fuel to four horizontal burners. The air heater is divided into primary and secondary sections. The total combustion air passes through the secondary heater, after which the steam is divided, about 80 percent being supplied to the burner plenum boxes as secondary air at about 400° F. The other 20 percent is passed through the primary air heater, where the temperature is raised to about 650° F. before it is sent to the pulverizers. The principal operating data (12) for this boiler are shown in figure 2. The satisfactory operation of this plant definitely established that North Dakota lignite was suitable for use in pulverized-fuel installations.

A series of boiler-performance tests was conducted in 1949 at the Crookston station by the Bureau of Mines, in cooperation with the University of North Dakota and the Otter Tail Power Co. The purpose of the tests was to obtain information on the behavior of steam-dried lignite, as compared with the burning characteristics and efficiency of raw lignite. These comparative tests were run with a boiler load of about 50 percent of rated capacity.

A summary of the test data showed the following difference in operation when burning raw and dried lignite:

1. Boiler efficiency was increased from 76.4 to 81.5 percent when dried lignite was burned (17.8 percent moisture) compared to raw lignite (33 percent moisture).

2. The temperature at the burner outlet, as determined by an optional pyrometer, was approximately 360° F. higher when dried lignite was burned, using an equal percentage of excess air.

3. Steam temperature leaving the superheater was 18° F. lower when the boiler was operated on dried lignite. Less air preheat was used. Although less heat was removed in the superheater and air heater, stack gas temperature was 78° F. lower when dried lignite was burned, indicating that more heat was transmitted by radiation in the main part of the furnace.

The superior combustion characteristics of dried lignite are indicated by these test results. However, such improvements must be balanced against the increased cost of drying when the economics of this type of operation is considered. At present no power plants are using steam-dried lignite.

In general, it has been found that the operating efficiency of pulverized-fuel units is about 2 percent higher than spreader-stoker installations with the same exit-gas temperature (18). Some other advantages of pulverized-fuel firing are: Quick response to load changes, wide range of kinds and quality of coal that may be burned, absence of moving parts in high-temperature inaccessible locations, and the ease with which the boiler can be converted to gas or oil firing. Units of virtually any capacity over 75,000 pounds steam per hour can be fired with pulverized fuel.

The main disadvantage of pulverized-fuel firing, especially with lignite, is the high auxiliary power required for pulverizing. Both the first cost and maintenance are considered to be higher for pulverized-fuel installations than for other methods of firing. For a given capacity boiler, larger pulverizers are required for lignite because of its low heating value. The fibrous nature of lignite also increases grinding difficulty and power required.

The W. J. Neal station (figs. 8 and 9 (6)) of the Central Power Electric Cooperative, Inc., Voltaire, N. Dak., is a good example of modern pulverized-lignite installation. This plant was built in 1951 to meet increasing power demands in western North Dakota and to serve as standby power for Missouri River hydroelectric developments. This plant is only a short distance from several producing lignite mines.

Guaranteed continuous capacity of each of the 2 boilers is 230,000 pounds steam per hour at 865 p.s.i. and 905° F. The maximum 2-hour capacity is 260,000 pounds steam per hour. The plant was designed to burn lignite of the following analysis: Moisture 39.0 percent, ash 6.6 percent, heating value 6,600 B.t.u. per pound (as mined). The boilers are designed for 80-percent efficiency with a heat release of 18,000 B.t.u. per cubic foot per hour. The furnace is of the dry-bottom type and fully

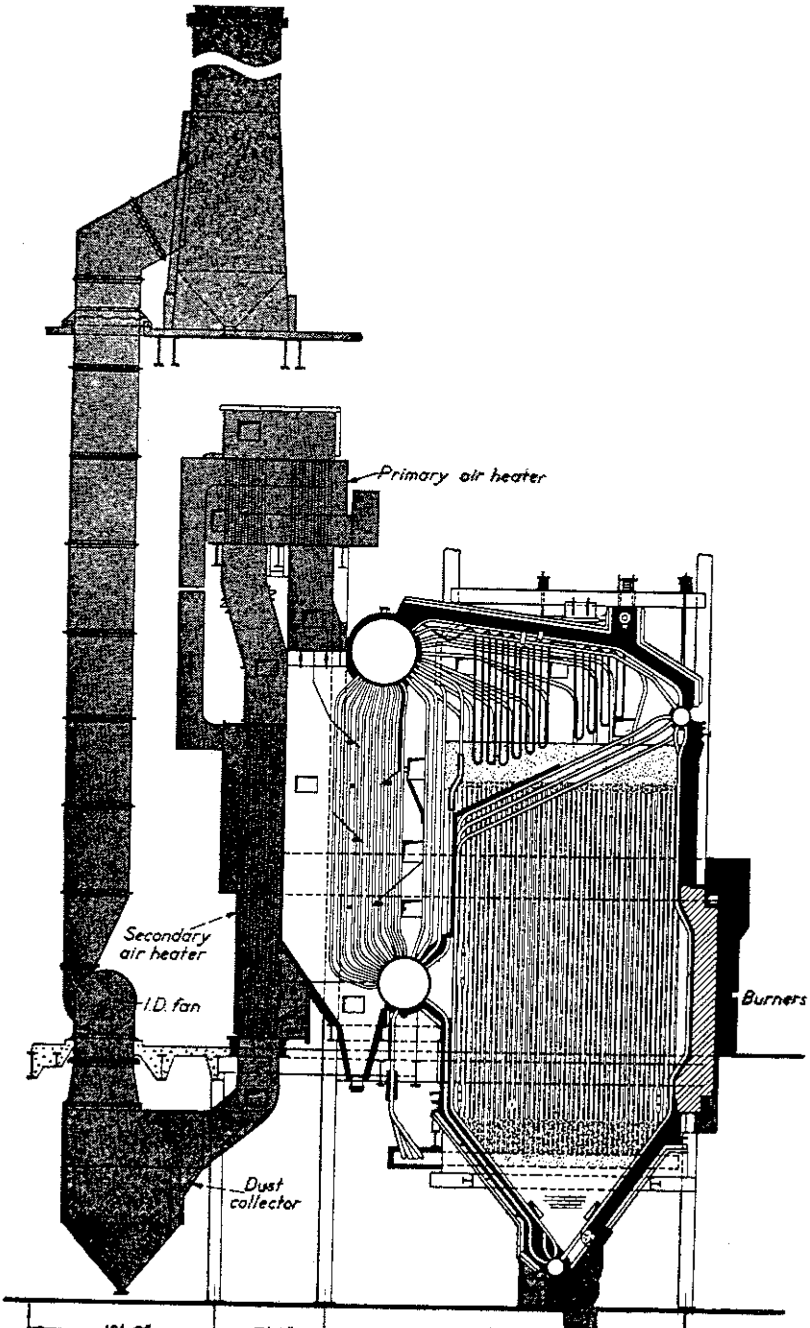


Figure 7. - Pulverized-fuel steam generating unit of 75,000-pound-steam-per-hour capacity at the Crookston station of the Otter Tail Power Co., Crookston, Minn. See reference (12) in section 1.
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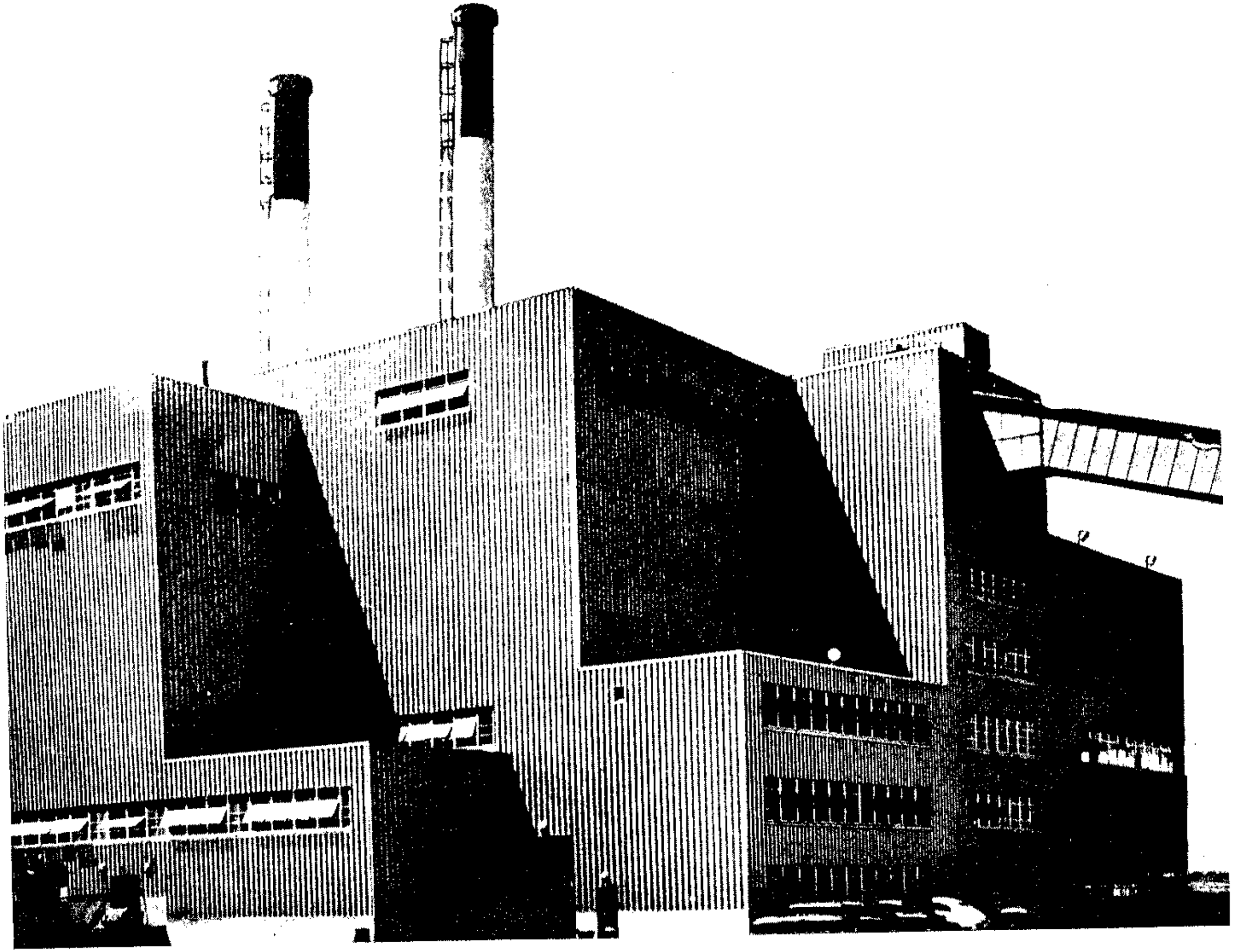

Figure 8. - W. J. Neal station, Voltaire, N. Dak. See reference (6) in section 1. *(By permission of Power magazine)*

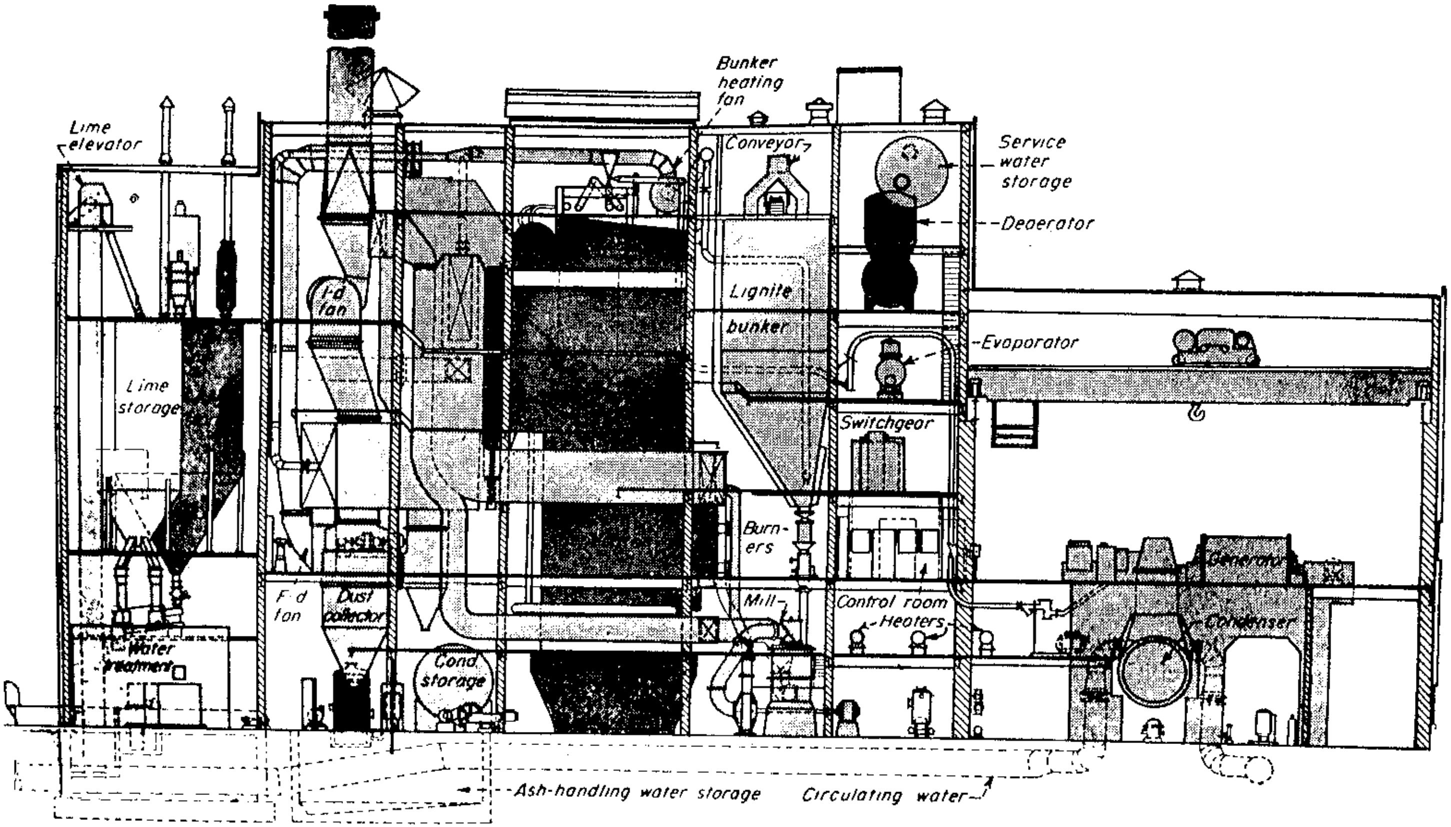

Figure 9. - Cross section of pulverized-fuel installation of 230,000-pound-steam-per-hour capacity at the W. J. Neal station of the Central Power Electric Cooperative, Inc., Voltaire, N. Dak. See reference (6) in section I.

(By permission of Power magazine)

water cooled. Each boiler has 6 horizontal turbulent-type burners supplied with fuel from 3 bowl-type unit pulverizers. An air preheater supplies air at about 685° F., part of which is used for mill drying in the pulverizers. The fuel-air mixture leaves the pulverizers at about 130° F. Flue gas leaves the furnace at 400° F.

The plant has been operating on a low capacity factor for over a year, and during that time the pulverizers and boilers have given satisfactory performance. Results of a recent test by the boiler manufacturer show that these boilers can be operated with pulverized lignite and satisfactory ignition maintained at less than one tenth of rated capacity.

Operating data for the Neal station for 1952 are listed in table 2. These data are taken from a summary sheet of operating data from selected cooperatives compiled by the United States Department of Agriculture.

TABLE 2. - Summary of operating data, 1952, W. J. Neal station, Central Power Electric Cooperative, Voltaire, N. Dak.

Fuel cost........................cents per million B.t.u.	17
Boiler efficiency..............................percent	76
Station heat rate................B.t.u. per net kw.-hr.	14,500
Station consumption.....percent of gross power generated	11.7
Plant factor...................................percent	34
Running plant capacity factor.......................do.	63
Fuel cost........................mills per net kw.-hr.	2.54
Operating labor cost................................do.	1.04
Maintenance cost....................................do.	0.26
Miscellaneous cost..................................do.	0.36
Total production cost...............................do.	4.20
Station heat rate, best month.....B.t.u. per net kw.-hr.	14,058
Boiler efficiency, best month..................percent	80

Cyclone Burners

Cyclone burners are the most recent development in coal-burning equipment. They are essentially water-cooled, cylindrical, combustion chambers, the inside of which is lined with a plastic chrome refractory. Crushed coal and primary air are introduced tangentially at one end of the burner. Fuel and air are thus given a whirling motion, which is further increased by tangential introduction of secondary air. Tertiary air is admitted tangentially at the outer end of the burner, causing the mixture to move in an increasing helix toward the main furnace. Combustion of the fuel is completed as it moves through the burner, leaving most of the molten ash adhering to the cylinder wall, from where it flows to the slag tank. The nature of this burning tends to reduce substantially the amount of ash carried in suspension, hence fly-ash emission is low. The axis of the burner is tilted downward at the furnace end to facilitate discharge of the molten ash. Combustion gases pass into the main furnace through a reentrant water-cooled throat at the discharge end of the burner and then pass over the heat-absorbing surfaces in the boiler. After a molten-slag coating has been established on the burner wall, the larger particles of the incoming fuel are forced against the sticky surface by centrifugal force and thereafter move with the slag at a slower rate than the air, causing a violent scrubbing action between the coal and air. This action accelerates the rate of combustion. Burning rates as high as 400,000 B.t.u. per cubic foot per hour and temperatures over 3,000° F. (9) are developed in the cyclone burner. Preparation of coal for use in a cyclone burner consists of crushing to a size of about 1/4-inch. This represents a substantial reduction of auxiliary power over that required for pulverized firing. However, the forced-draft-fan power requirements are large with cyclone firing because air is supplied to the burner at a pressure of about 35 inches H_2O. This pressure is required to obtain satisfactory velocities in the burner. The cyclone burner has been successfully used with a large number of coals, as well as with oil and gas.

Cyclone firing was developed to obtain a better method for burning coals with high ash content and low ash-fusion temperature. Pilot-plant models were constructed and tested before 1940 (10). A developmental installation was made at the Calumet station (fig. 10) of the Commonwealth Edison Co. in 1944. Since then this method of firing has been installed in a number of large midwestern (20) power plants.

In May 1949 tests were conducted at the Calumet station of the Commonwealth Edison Co., Chicago, Ill., using North Dakota lignite in an 8-foot-diameter nearly horizontal cyclone burner. The rated capacity of the boiler was 180,000 pounds steam per hour at 350 p.s.i. and 650° F. steam. The following information is taken from a description by Hoffman and Drabelle (13) of the test conditions and results.

> The high moisture content caused some ignition difficulties in the early part of the tests, but these were overcome by burning natural gas in the primary air line to the crusher, thereby raising the air temperature to the crusher from approximately 425° F. to 650° F.
>
> Rates up to 170,000 pounds of steam per hour were carried with satisfactory operating conditions. Excess air leaving the cyclone was varied from approximately 5 to 30 percent to study the effect on combustion and slag tapping. During periods of operation with low excess air, only fine sparklers, similar to those which might have occurred from burning paper, were observed in the primary furnace, and slag from the tap was quite fluid. There was no smoke at any time firing this fuel. During periods of operation with high excess air, the slag in the primary furnace was somewhat more viscous, and occasional large flakes of lignite could be seen on the primary furnace floor. In general the slag behavior was similar to that of the normally-burned Illinois No. 6 bed coal, but perhaps slightly more viscous.
>
> The test results can be summarized as follows:
>
> 1. This lignite can be successfully burned in the cyclone furnace.
>
> 2. Primary air temperature of around 650° F. is required to provide the necessary drying to give good ignition.
>
> 3. Slag behavior is similar to that of Illinois No. 6 bed coal, although the slag may be a little more viscous.
>
> 4. The crushing characteristics are somewhat different from those of other coals burned, the crushed product being coarser and more flaky.
>
> 5. There is no smoke discharge from the stack regardless of excess air.
>
> 6. To eliminate the need for pre-drying equipment, a cyclone-furnace-fired unit designed for burning this lignite should be arranged for direct firing to permit drying in the crusher.

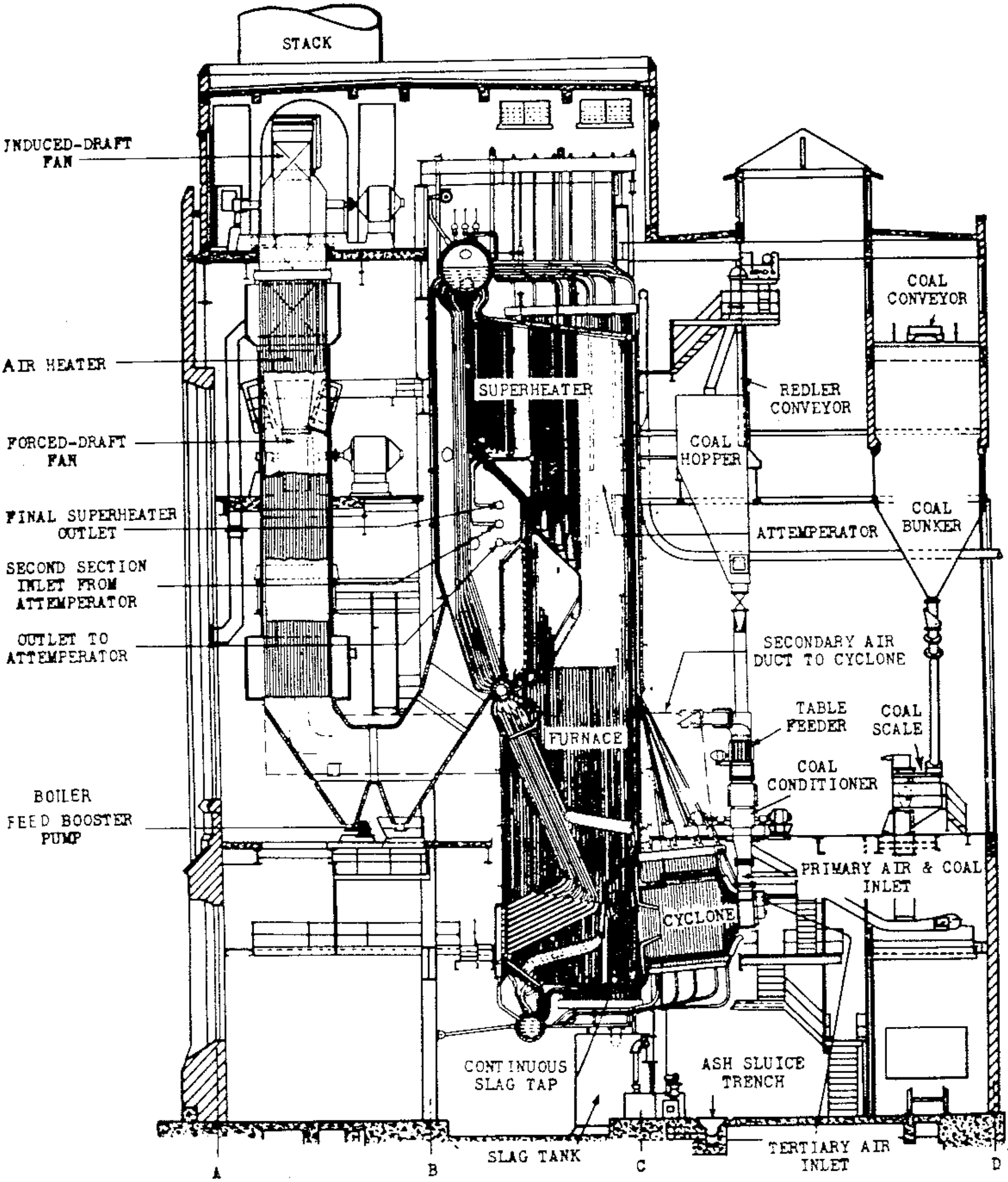

Figure 10. - Cyclone burner-fired steam-generating unit of 180,000-pound-steam-per-hour capacity at the Calumet station of the Commonwealth Edison Co., Chicago, Ill. See reference (13) in section 1. *(By permission of Am. Soc. Mech. Eng.)*

7. Although dust loading tests were not conclusive, indications were that ash discharge from the stack was somewhat lower than when burning Illinois No. 6 bed coal.

Cyclone-furnace-fired boilers have shown high efficiencies owing to the low excess air and the low combustible loss in the ash. Only about 10 percent of the total ash content of the fuel enters the main furnace. This can be compared with an average figure of 50 percent for a wet-bottom pulverized-fired furnace and 80 percent for a dry-bottom furnace. Results of cyclone-burner tests using Illinois coal (20) have shown no reduction in equipment, or labor for cleaning the heat-absorbing surfaces, however, because the dust that is carried over is of such a composition that it sticks to the surfaces. Much smaller dust collectors are required for this method of firing. The combined slag- and ash-handling system is, however, more complicated for cyclone-burner firing than for pulverized-fuel firing.

According to Schroeder and Stasser (20), a cyclone-fired boiler requires approximately 10 percent less floor space and 25 percent less volume than a comparable pulverized-fuel installation. Some other advantages are low cost of preparing the fuel and low maintenance cost on burner because of the lack of moving parts. In some installations the induced draft fan has also been eliminated. The cyclone burner has been used successfully with units as small as 180,000 pounds of steam per hour, and it appears to be applicable to virtually any larger size installation.

Comparative Survey of Steam Power Plants Burning North Dakota Lignite

Table 3 lists the lignite-burning steam power plants in North Dakota, South Dakota, and Minnesota (2, 12).

It should be noted from table 3 that lignite-fired boilers have followed the industry-wide trend of using increasingly higher operating temperatures and pressures. It is also significant to note the large number of boilers that have been installed since 1947.

Boiler, furnace, and stoker data (2, 12) for 15 of the larger lignite-burning boilers are listed in table 4. The data listed are design or specification information in all instances and not test or operating data. The boilers listed range in capacity from 60,000 to 230,000 pounds of steam per hour, and all except the Fargo unit have been installed since 1947. Open-type complete water-wall construction is used for all the recent installations, except the Bison unit, which uses a refractory front wall. Air heaters are used in all the installations listed except Fargo, but economizers are used with only 5 of the 15 boilers listed. Twelve of the boilers listed are fired with spreader stokers, 2 with unit pulverizers, and 1 with a chain-grate stoker. The popularity of spreader stokers is quite obvious. However, the Ortonville plant approaches the maximum size unit now considered adaptable for use with them. The unit pulverizer method was chosen for the larger W. J. Neal station, and future boilers over 250,000 pounds steam per hour will probably be fired with unit pulverizers or cyclone burners. Heat release for the units listed varies from 18,000 B.t.u. per cubic foot per hour for the W. J. Neal boiler to 35,600 B.t.u. per cubic foot per hour for the chain-grate-fired Kidder station. Preheated air temperatures ranging from 350° F. to 450° F. are used with the spreader stokers and 675° to 700° F. with the unit pulverizers. The boiler efficiencies listed, which range from 73 to 80 percent, compare favorably with efficiencies for similar boilers fired with other coals after adjusting for higher flue-gas loss due to evaporation of the moisture content of the fuel.

Comparative data on heat releases for boilers burning bituminous coal and lignite are presented in table 5 (2, 12).

TABLE 3. —Lignite-burning power plants in North Dakota, South Dakota, and Minnesota

No. boilers alike	Year built	Plant	Name of company	Steam generating capacity, lb./hr.	Steam pressure, psi.	Steam temperature, °F.
2	1951	Wm. J. Neal, Voltaire, N.D.	Central Power Cooperative	230,000	865	905
	1951	Minnkota, Grand Forks, N.D.	Minnkota Power Cooperative, Inc.	135,000	615	825
	1950	Ortonville, Minn.	Ottertail Power Co.	160,000	865	900
	1950	Grand Forks, N.D.	Northern States Power Co.	75,000	425	750
	1950	Minnkota, Grand Forks, N.D.	Minnkota Power Cooperative, Inc.	72,000	615	825
	1950	Valley City, N.D.	Municipal Utility	50,000	425	750
2	1950	Mobridge, S.D.	Montana-Dakota Utilities Co.	50,000	415	750
	1949	Kidder, Wahpeton, N.D.	Otter Tail Power Co.	100,000	600	825
	1949	Devils Lake, N.D.	Otter Tail Power Co.	100,000	400	750
	1949	Fargo, N.D.	Northern States Power Co.	75,000	425	750
	1949	Bison, Minot, N.D.	Northern States Power Co.	75,000	420	750
	1949	Crookston, Minn.	Otter Tail Power Co.	75,000	400	825
	1949	Minnkota, Grand Forks, N.D.	Minnkota Power Cooperative, Inc.	72,000	615	825
2	1949	Beulah, N.D.	Montana-Dakota Utilities Co.	50,000	400	750
	1949	Moorhead, Minn.	Public Service Dept.	45,000	400	750
	1948	Jamestown, N.D.	Otter Tail Power Co.	100,000	600	825
	1948	Hoot Lake, Fergus Falls, Minn.	Otter Tail Power Co.	95,000	400	825
	1948	Grand Forks, N.D.	Northern States Power Co.	75,000	425	750
	1948	Crookston, Minn.	Otter Tail Power Co.	75,000	400	825
	1948	Bismarck, N.D.	Montana-Dakota Utilities Co.	60,000	450	750
	1948	Kincaid, N.D.	Montana-Dakota Utilities Co.	60,000	250	545
	1947	Devils Lake, N.D.	Otter Tail Power Co.	75,000	400	750
	1946	Moorhead, Minn.	Public Service Dept.	45,000	400	750
2	1945	Aberdeen, S.D.	Northwestern Public Service Co.	45,000	625	850
	1945	Washburn, N.D.	Otter Tail Power Co.	40,000	250	610
2	1940	Valley City, N.D.	Municipal Utility	40,000	425	625
	1939	Fargo, N.D.	Northern States Power Co.	100,000	425	750
	1938	Fargo, N.D.	Northern States Power Co.	50,000	225	525
2	1938	Bismarck, N.D.	Montana-Dakota Utilities Co.	30,000	450	750
	1937	Kidder, Wahpeton, N.D.	Otter Tail Power Co.	100,000	800	825
	1937	Grand Forks, N.D.	Northern States Power Co.	65,000	200	525
	1937	Beulah, N.D.	Montana-Dakota Utilities Co.	50,000	265	600
	1936	Minot, N.D.	Northern States Power Co.	54,000	200	505
	1936	Valley City, N.D.	Municipal Utility	35,000	275	500
	1936	Moorhead, Minn.	Public Service Dept.	17,500	400	750
2	1932	Grand Forks, N.D.	Northern States Power Co.	45,000	200	525
2	1932	Kincaid, N.D.	Montana-Dakota Utilities Co.	25,000	250	530
	1930	Minot, N.D.	Northern States Power Co.	32,000	200	505
	1929	Fargo, N.D.	Northern States Power Co.	110,000	225	525
	1929	Washburn, N.D.	Otter Tail Power Co.	40,000	250	610
2	1929	Harvey, N.D.	Otter Tail Power Co.	23,000	230	610
	1928	Beulah, N.D.	Montana-Dakota Utilities Co.	50,000	285	600
	1928	Grand Forks, N.D.	Northern States Power Co.	45,000	200	523
2	1928	Jamestown, N.D.	Otter Tail Power Co.	30,000	200	500
	1927	Fargo, N.D.	Northern States Power Co.	110,000	225	525
	1927	Kidder, Wahpeton, N.D.	Otter Tail Power Co.	70,000	300	625
	1927	Beulah, N.D.	Montana-Dakota Utilities Co.	50,000	265	600
	1927	Bismarck, N.D.	Montana-Dakota Utilities Co.	40,000	180	460
2	1926	Washburn, N.D.	Otter Tail Power Co.	40,000	250	610
	1923	Fargo, N.D.	Northern States Power Co.	32,000	225	525
	1920	Aberdeen, S.D.	Northwestern Public Service Co.	60,000	250	600
	1920	Aberdeen, S.D.	Northwestern Public Service Co.	35,000	250	600
2	1915	Minot, N.D.	Northern States Power Co.	20,000	165	525
2	1910	Minot, N.D.	Northern States Power Co.	20,000	165	525
	1910 1/	Harvey, N.D.	Otter Tail Power Co.	45,000	230	550

1/ Rebuilt in 1942.

TABLE 4.–Boiler, furnace, and stoker data for the larger steam-generating plans firing lignite 1/

Plant	Capacity, lb. steam per hr.	Year built	Pressure, psi.	Tempera-ture, °F.	Chamber construction	Heating surfaces, sq.ft. Boiler	W.W.	S.H.	Econ.	A.H.	Furnace vol., cu. ft.	Grate area, sq. ft.	Lb. lignite per hour	Heat release (based on 6600 B.t.u./lb. lignite) B.t.u./cu.ft. per hour	B.t.u./sq.ft./hr.	Type stoker	Type grate	Type ash disposal	Primary air temp., °F.	Maximum effi-ciency,%
Wm. Neal, Voltaire, N.D.	230,000	1951	865	905	W.W.	13,610	9,615	6,600	None	58,400	17,200	None	47,000	18,000	-	Pulverized coal fired		P.	675	80
Ortonville, Minn.	160,000	1950	865	900	W.W.	16,250	4,230	4,780	6,100	17,200	12,250	446	37,200	20,000	550,000	Sp.	T.	P.	370	79
Minnkota, Grand Forks, N.D.	135,000	1950	615	825	W.W.	14,950	1,825	5,370	4,620	16,890	7,750	392	27,000	23,000	455,000	Sp.	T.	P.	360	80
Fargo, N.D.	110,000	1939	225	525	R.W.	11,510	-	-	None	None	-	284	19,900	-	463,000	Sp.	D.	P.	Room temp.	-
Kidder, Wahpeton, N.D.	100,000	1949	600	825	W.W.	9,500	2,200	-	2,400	13,000	4,100	316	22,100	35,600	462,000	C.G.	T.	H.	360	79
Devils Lake, N.D.	100,000	1948	400	750	W.W.	10,435	2,460	-	None	9,450	7,660	304	22,400	19,300	487,000	Sp.	T.	P.	375	75
Jamestown, N.D.	100,000	1948	600	825	W.W.	12,670	2,195	-	None	-	6,150	288	22,200	23,800	506,000	Sp.	T.	P.	350	77
Hoot Lake, Fergus Falls, Minn.	95,000	1948	400	825	W.W.	10,170	2,436	-	1,850	4,330	6,500	253	21,300	21,000	540,000	Sp.	T.	P.	375	77
Moorhead, Minn. 2/	90,000	1948	410	550	W.W.	16,950	2,673	-	None	8,600	6,840	235	24,000	23,100	673,000	Sp.	T.	P.	360	-
Crookston, Minn.	75,000	1948	400	825	W.W.	7,550	3,400	1,630	None	11,600	5,430	None	18,300	22,300	-	Pulverized coal fired		P.	706	78.5
Crookston, Minn.	75,000	1949	400	825	W.W.	9,250	2,025	-	None	6,300	4,800	195	16,800	23,200	570,000	Sp.	T.	P.	350	77.5
Grand Forks, N.D.	75,000	1950	425	750	W.W.	8,350	-	1,730	None	5,800	4,195	230	17,000	26,700	487,000	Sp.	T.	P.	350	74
Bison, Minot, N.D.	75,000	1948	420	750	W.W. except front	8,150	1,160	-	None	5,800	4,195	230	16,800	26,400	483,000	Sp.	T.	H.	350	73
Minnkota, Grand Forks, N.D.	72,000	1950	615	825	W.W.	7,650	-	2,510	2,125	8,590	4,000	168	15,300	25,200	602,000	Sp.	T.	P.	360	78
Kincaid, N.D.	60,000	1948	250	545	W.W.	6,999	1,051	-	None	-	3,250	163	13,500	27,400	546,000	Sp.	T.	P.	450	77

1/ Data in each case are for single boilers, and do not necessarily represent total plant capacity.
2/ American Crystal Sugar Plant.

Abbreviations:
- W.W. – Water wall
- Sp. – Spreader
- D. – Dump
- P. – Pneumatic
- R.W. – Refractory wall
- C.G. – Chain grate
- T. – Traveling
- H. – Hydraulic
- S.H. – Superheater
- A.H. – Airheater

TABLE 5. - Comparative heat-release rates for boilers burning lignite and bituminous coal

Fuel and firing equipment	No. of boilers	Capacity, pounds of steam/hr.	Firing rate, pounds/sq.ft. grate/hr.	Heat release	
				B.t.u./cu.ft./hr.	B.t.u./sq.ft. grate/hr.
Plants burning lignite:					
A. Traveling grate.....	6	36,700	62.1	35,100	416,833
B. Spreader stoker.....	21	73,000	76.9	27,029	562,333
C. Pulverizer..........	2	-	-	20,767	-
Plants burning bituminous coal:1/					
A. Traveling grate.....	2	85,000	35.9	35,956	450,000
B. Spreader stoker.....	25	63,000	36.5	26,248	465,000
C. Pulverizer..........	29	-	-	21,048	-

1/ Toby, T. S., Data from New Steam Generators in Pulp and Paper Industry: Utilization, No. 12, 1948, p. 17.
Information on bituminous firing was taken from this source to provide information on boilers of capacities similar to those of the lignite-burning units.

It will be noted that the performance of lignite-burning boilers is very similar to that of bituminous-burning boilers, with the exception of the pounds of coal per hour per square foot of grate area. This value is larger with lignite because of its lower heating value. On the basis of the data presented in table 5, the average heat release rate for the lignite-fired boilers about equals that of similar units burning bituminous coal. However, the respective boiler efficiencies are not considered in this listing. To obtain maximum efficiency, lignite furnaces are generally built higher and have somewhat greater volume per unit capacity than bituminous furnaces.

Selected operating data (2, 12) for 1950 of plants fired with North Dakota, lignite are shown in table 6. These plants were chosen for study because, unlike many of the other plants in table 3, they do not supply steam for heating purposes outside the plant.

It will be noted that the B.t.u. per kilowatt-hour net for the plants listed ranges from 14,800 for the new Minnkota plant to 38,613 for the older Harvey station. In general, the newer plants show better heat rates than the older units. However, the plant-capacity factor probably has more effect on the B.t.u. per kilowatt-hour than any other single factor. If boilers are operated on banked conditions or at low loads for a considerable part of the time the heat rate will be high. The average boiler efficiency and average plant efficiency are similarly affected by a low capacity factor. The percentage of generated output required for station power for the plants listed varies from about 5 to 12 percent. This ratio is, of course, higher for pulverized fuel installations and again the capacity factor has considerable influence.

A comparison of boiler efficiencies of lignite-fired power plants and modern bituminous-fired power plants operating with a high plant factor indicates that station heat rates as low as 11,500 B.t.u. per net kilowatt hour seem feasible with a lignite-burning installation operating with a comparable high plant factor.

TABLE 6. - Operating data for plants fired with lignite[1/]

Plant	Year first boiler installed	Electrical generating capacity in kw.	Net kw.-hr. generated in 1950	Average B.t.u. per net kw.-hr.	Type[2/] stoker	Station power ave., %	Average boiler efficiency, %	Average plant efficiency, %	Plant capacity factor, %
Beulah, N. Dak.	1919	13,500	64,587,596	23,537	CG+Sp.	8	72	14.5	54.6
Aberdeen, S. Dak.	1920	13,500	70,379,200	21,200	T.G.	9	78	17	59.5
Ortonville, Minn.	1950	15,000	7,073,000	15,500	Sp.	5	79	25 3/	12.8 3/
Kidder (low press.) Wahpeton, N. Dak.	1927	10,500	82,411,000	23,500	C.G.	9	57	15	45.8
Kidder (high press.)	1937	10,000		17,000	C.G.	3	79	20	
Moorhead, Minn.	1936	8,250	23,877,700	21,700	Sp.	7	80	16	33.0
Fargo, N. Dak. (high press.)	1939	10,000		18,459	Sp.	6	74	18.5	
Crookston, Minn.	1948	10,000	49,688,000	16,553	Sp.+P.	10	77	20.7	56.6
Minnkota, Grand Forks, N. Dak.	1950	10,000 4/	72,600,000	14,800	Sp.	7	78	21	82.8
Harvey, N. Dak.	1924	5,000	16,499,000	38,615	C.G.+Sp.	12	55	8.9	37.7
Kincaid, N. Dak.	1928	6,000	24,923,669	35,294	C.G.+Sp.	11	75	9.7	47.4
Washburn, N. Dak.	1926	8,000	54,289,000	24,999	C.G.	7	70	13.7	77.4

1/ Source, references (2)(12).

2/ Abbreviations:
P. —Pulverized coal fired
Sp. —Spreader
C.G.—Chain grate
T.G.—Traveling grate

3/ Plant new - in operation about 5 months.

4/ New 11,500 kw. generator added March 1951.

Construction and Electrical Production Costs for Lignite-Burning Power Plants

The construction and electrical production cost for some of the larger lignite-burning power plants in North Dakota and Minnesota are listed in table 7 (2, 12).

TABLE 7. - Selected lignite power plants, production and operating costs

Plant	Year built	Generating capacity in kw.	Construction cost per kw.	Production cost, mills/kw.-hr. Labor and Miscellaneous	Fuel	Total
Ortonville, Minn.	1950	15,000	219	1.16	5.80	6.96
Hoot Lake, Fergus Falls, Minn. ..	1948	7,500	232	2.14	5.44	7.58
Crookston, Minn..	1948-49	10,000	317	2.12	5.85	7.97
Minnkota, Grand Forks, N. Dak..	1944-51	21,500	194	1.57	4.60	6.17
Devils Lake, N. Dak.	1947-49	12,500	248	-	-	7.27
Bison, Minot, N. Dak.	1949	4,000	528	2.58	4.06	6.64
W. Neal,1/ Voltaire, N. Dak.	1950	45,000	189	1.66	2.54	4.20

1/ Data taken from a summary sheet of operating data from selected cooperatives compiled by the U. S. Department of Agriculture.

Construction costs for the Bison and Crookston plants are unusually high because in each instance building and other provisions were made for the future addition of units that could greatly expand the present installed capacity. Of interest is the decrease in construction cost per kilowatt as the plant capacity increases. The construction cost of $189 per kilowatt for the Neal station is indicative of the manner in which costs can be reduced with large central power stations.

In 1951 the Vern E. Alden Co. (3), Chicago engineering firm, prepared studies of the construction and operational cost for several proposed large power plants utilizing lignite. It estimated that a private company would require $120,000,000 capital to build a plant of 800,000 kilowatts capacity. This would be a unit cost of $150 per kilowatt. This plant would burn pulverized fuel. Alternate plans were worked out by Alden for plants of 800,000 and 240,000 kilowatts, respectively, using char from a low-temperature-carbonization process like that to be used at the Texas Power & Light Alcoa plant (16) in Milam County, Tex. The construction cost estimated for the smaller unit was about $200 per kilowatt because of increased investment required for the carbonization plant.

The cost of producing power is primarily a function of the fuel cost. Therefore, plants at the mine mouth can effect a substantial savings by eliminating freight costs. This is shown in table 7, listing production costs for selected plants burning lignite. The Ortonville, Hoot Lake, and Crookston plants are near the eastern boundary of the geographical area of economical use of lignite as a fuel (fig. 37, part 1), and as such their coal costs are high.

The Alden Co. estimated a production cost, including overhead and fixed charges, of 2.86 mills per kilowatt-hour for a 800,000-kw. station using raw lignite. This was based on a coal cost of 1.15 dollars per ton and a 95-percent load factor. Production costs were also worked out for plants using low-temperature carbonization for recovery of byproduct chemicals. However, the basis of this calculation was that North Dakota lignite would produce about 15 gallons of salable oil and tar per ton, which is too high. (See sec. 2.)

Detailed heat and material balances for a power plant using fluidized carbonization of lignite from Garrison damsite, N. Dak., as prepared by the Bureau of Mines, Denver, Colo., are presented in the following section.

Fluidized Processing of North Dakota Lignite for Power Production

Power requirements in the West are rapidly increasing, owing both to increasing population and substitution of electric power for other energy forms. Thermal power production will account for a large portion of this increase because of the limitations in potential hydroelectric development. Lignite, coal, natural gas, and residual fuel oils all compete for the thermal power market, and the selection of fuel will be determined by the cost of delivered energy and the costs incidental to their use.

The recent developments in utilization of Texas lignite for power production indicate that, in certain situations, processed lignite will be the most economical power-plant fuel. A plant is being erected in Texas using the process developed at the Denver laboratories of the Bureau of Mines. In this process, the raw lignite is crushed, dried in a stream of hot gases, and carbonized in a fluid-bed reactor to yield char, tar, and gas. The char will be used as power-plant fuel, a portion of the gas will supply the heat required to carbonize the coal, the remainder of the gas will supplement the char as boiler fuel, and the tar will be sold for chemical use.

The details of the pilot plants used to develop this process and the results of tests made are given in a recent publication of the Bureau (17). Lignite from Garrison Dam, N. Dak., was tested, and it was demonstrated that this lignite could be treated successfully in the pilot-plant units. The calculations in the present report are based on the use of Garrison lignite.

This report gives the results of study made to determine the probable heat and material flow rates for a 120,000-kw. thermal power plant operating on char obtained by the fluidized processing of Garrison damsite lignite. It deals only with the flow calculations required for the schematic design of the processing plant. Complete economic and engineering analyses of the application of processing must be made specifically for Garrison lignite and the power plant before further consideration of the plant.

Analysis of the proposed plant for the Texas installation indicated that the most economically sized processing unit would be one designed to serve units of 40,000-kw. generating capacity. It has been assumed in the present report that such units would also be most efficient for the Garrison application. On this basis, three integrated drying and carbonizing units would be required for a plant having 120,000-kw. generating capacity. Three units would permit operating the boiler on processed fuel over its entire operating range.

The annual fuel requirements of a 120,000-kw. plant operating at 90-percent plant factor on various fuels are shown in figure 11. This load would require 1,527,000 barrels of fuel oil a year or 9,461 million cubic feet of natural gas. If the plant were operated on char, 1,005,400 tons of lignite would have to be processed per year, producing 401,800 tons of char. In addition, processing this

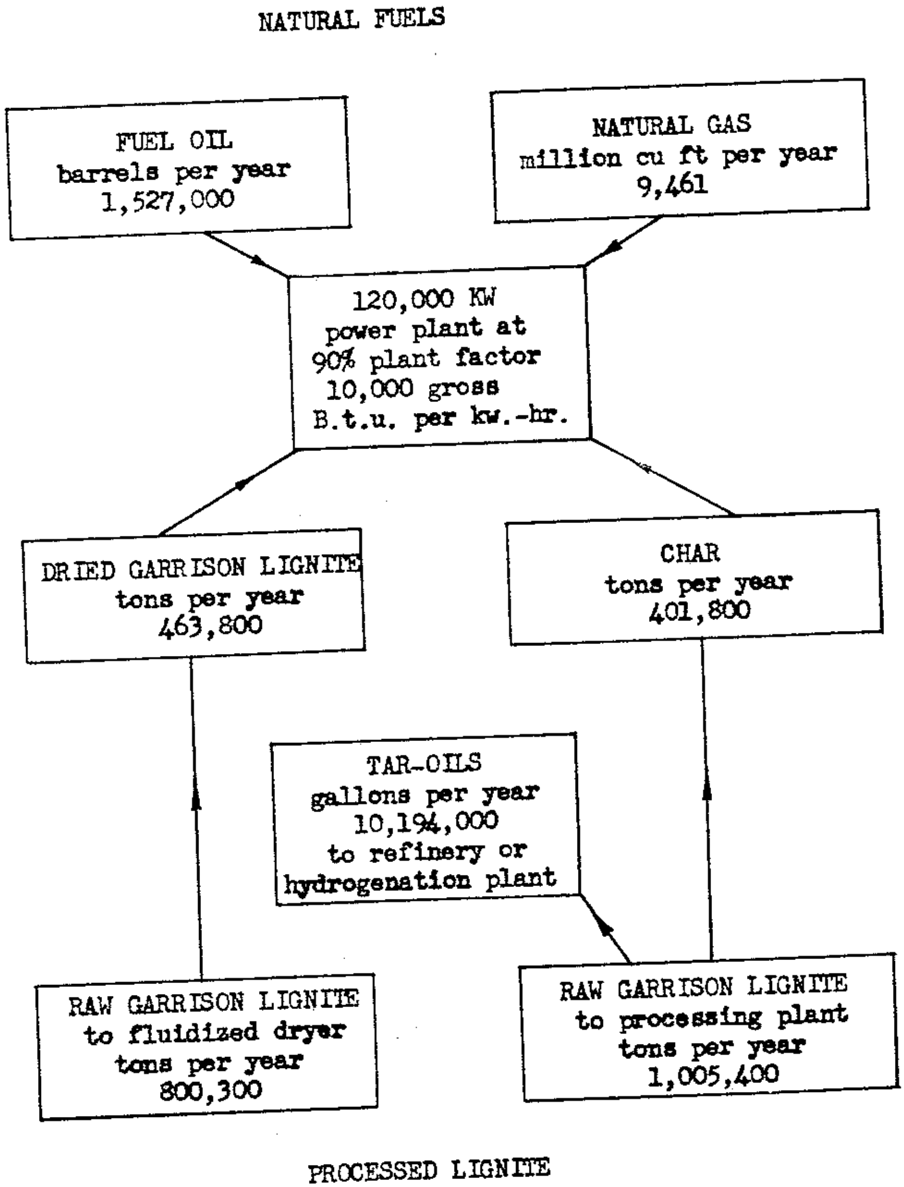

Figure 11. - Calculated fuel requirements for 120,000 kw. power plant.

quantity of coal would produce 10,194,000 gallons of tar oils a year. The power plant could be operated by the combustion of 462,800 tons of dried lignite per year, requiring the drying of 800,300 tons of raw lignite. The difference in the raw lignite requirements for the two latter cases is due principally to the potential heat of the tar.

The overall flow of materials through the entire plant on an hourly basis is shown in table 8. For 120,000 kw., 225,060 pounds of raw lignite per hour must be processed, producing 101,940 pounds of char, 1,014 gallons of tar, 279 gallons of light oil, 335,000 std. c. f. of gas, and 2,241 gallons of liquor. The total gas make will be 607,000 cu. ft. per hr., but a portion of it is required to heat the carbonizer.

TABLE 8. - Overall heat and material flow rates for a 120,000-kw. generating plant, using Garrison damsite, N. Dak., lignite

(Hourly rates)

	Volume	Pounds	Gross potential heat, million B.t.u.	Net potential heat, million B.t.u.
Input:				
Raw lignite......		225,060	1,644.0	1,473.9
Output:				
Char.............		101,940	1,200.0	1,170.9
Tar..............	1,014 gal.	8,910	151.2	143.1
Light oil........	279 gal.	1,890	35.1	33.6
Process gas......	335.1 M std.c.f.	27,600	36.3	32.7
Char in tar......		180	2.1	2.1
Liquor...........	2,241 gal.	18,660		
		159,180	1,424.7	1,382.4

Table 10 shows the analysis of the net operation of the carbonizer. Each 40,000 kw. of generating capacity will require combustion of 33,980 pounds of this char per hour, which is the basic figure used in designing this plant. About 3,600 pounds of tar, including light oil, will be produced per hour from each unit, equivalent to 1,293 gallons per hour from the 3-unit plant.

The analyses of the raw, dried, and carbonized Garrison lignite are shown in table 11. The raw lignite, based on available analyses, is expected to contain 39.3 percent moisture and 6.9 percent ash and have a gross heating value of 6,450 B.t.u. per pound. The dried lignite will contain 3.9 percent moisture, 10.9 percent ash, and have a heating value of 10,200 B.t.u. per pound. The ash content of the char will be 16.2 percent, and its heating value will be 11,770 B.t.u. per pound.

TABLE 9. - Overall drier heat and material balances for a combined drying and carbonizing unit operating on Garrison damsite, N. Dak., lignite and serving 40,000-kw. generating capacity1/

(Hourly basis)

	Temp., °F.	M std. c.f./hr.	Pounds	Net B.t.u. (thousands)
Input:				
Raw lignite	60		85,020	
Air	60	557.3	42,530	
Net heat liberated				42,300
		557.3	127,550	42,300
Output:				
Dried lignite	175		49,270	1,580
H_2O evaporated	275	656.6	31,290	36,170
Combustion gases	275	587.8	46,390	2,490
Ash out of furnace	1,600		330	150
Dust loss	175		270	10
Heat loss				1,900
		1,244.4	127,550	42,300

1/ 3 of these combined units are required for a 120,000-kw. generating plant.

TABLE 10. - Overall carbonizer heat and material balances for a combined drying and carbonizing unit operating on Garrison damsite, N. Dak., lignite and serving 40,000-kw. generating capacity1/

(Hourly basis)

	Temp., °F.	M std. c.f./hr.	Pounds	Net B.t.u. (thousands)
Input:				
Retort:				
Dried lignite	175		49,270	1,580
Air	700	147.8	11,280	1,780
Net heat liberated				14,690
Furnace:				
Air	1,200	106.8	8,150	2,350
Net heat liberated				8,880
		254.6	68,700	29,280
Output:				
Retort:				
Char	900		33,980	7,980
Tar	900	6.4	2,970	1,770
Light oil	900	2.2	630	370
Liquor	900	130.6	6,220	8,680
Process gas	900	111.7	9,200	2,140
Char in tar	900		60	20
Furnace:				
Stack gases	1,500	195.8	15,640	6,190
Heat loss				2,130
		446.7	68,700	29,280

1/ 3 of these combined units are required for a 120,000-kw. generating plant.

TABLE 11. - Proximate analyses of raw, dried, and carbonized Garrison lignite

	Raw lignite	Dried lignite	Lignite char
Moisture.................percent	39.3	3.9	0
Volatile matter..............do.	26.4	41.8	19.7
Fixed carbon.................do.	27.4	43.4	64.1
Ash..........................do.	6.9	10.9	16.2
Total........................	100.0	100.0	100.0
Gross B.t.u./lb.	6,450	10,200	11,770

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