Contract No. 68-01-3163, Task No. 4
Final Report No. IITRI-C6333C04-3

TECHNOLOGICAL PROBLEMS OF BURNING LOW-SULFUR WESTERN COAL

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December 31, 1975

FOREWORD

In Task No. 4 of EPA Contract No. 68-01-3163, we have examined some of the technological problems of burning low-sulfur coals in boilers. This report presents the data collected and evaluated with regard to this problem.

Respectfully submitted,
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TECHNOLOGICAL PROBLEMS OF BURNING LOW-SULFUR WESTERN COAL

1. INTRODUCTION

The burning of low-sulfur western coals in boilers designed for bituminous fuels can result in operational problems. Resolution of these problems requires modification of the existing systems. In examining five boiler types, cyclone, pulverized coal, spreader stoker, cross-feed, and under-feed boilers, the necessary conversion factors were identified. The costs associated with low-sulfur western coal utilization were estimated where sufficient information was available.

To understand the significance of operational problems in burning western coals, a background on coal characteristics and boiler design is presented. This information serves as a basis for discussion of the experiences in industrial and power-generating usage of western coals.

2. EXECUTIVE SUMMARY

Technological problems of boiler operation do occur when western coals are burned in those boilers designed to handle midwestern or other types of coal. These problems have been identified for the following five boiler types:

1. Cross-feed stoker
2. Under-feed stoker
3. Spreader stoker
4. Pulverized coal boiler
5. Cyclone boiler

These five boiler categories represent a wide range of boiler sizes and types. Under-feed boilers, which usually have capacities up to 20,000 pounds of steam per hour, are used primarily in small industrial applications. Cross-feed and spreader stokers are utilized in large and small industrial applications with boiler capacities up to 400,000 pounds of steam per hour. The cyclone and pulverized boiler systems are typically designed for power-generating stations and have greater than 200,000 pounds of steam per hour capacity. Because of the differences in design of these boilers, their flexibility in adapting to different coals also varies. Those coal characteristics which determine the acceptability of a new fuel are directly related to the boiler type and design.

The characteristics of coal which can be important in successful operation include Btu content, moisture content, grindability, ash fusion temperature, volatility, and ash content. These factors are interrelated and influence the boiler operation in many ways. High moisture coals will have low Btu content and thus a greater quantity must be burned to maintain boiler capacity. Moisture and volatility affect the combustion characteristics in the boiler. Ash content and ash fusion temperature are important indicators of the possibility of developing a slag layer for cyclones or of avoiding clinkers in other types of boilers.

To summarize the operating difficulties and methods of resolution for various boiler types, Table 1 was prepared. For each of the five types discussed, the coal characteristic which is primarily responsible is identified. There may be other contributing or related factors in addition to the ones listed; however, the attributes of western coal which appear to be significant are moisture or Btu content, ash characteristics, and ash fusion temperature. The major operating problems encountered were loss of boiler capacity, carbon carryover, maintaining proper combustion, and ash formation. The methods of resolving these problems involved equipment adjustments, increased maintenance costs, and equipment purchases. Thus, there are costs associated with these problems, but the technological problems can be resolved, or at least minimized, by applying these techniques.

Table 1

TECHNOLOGICAL PROBLEMS OF BOILER OPERATION

Boiler Type	Coal Type	Coal Characteristic	Technological Problems	Method of Resolution
Cyclone	Lignite	High moisture	Loss of boiler capacity and carbon carryover	1. Raise primary and secondary air to 750°F to dry coal 2. Two-stage conditioning to dry coal 3. Bypass moisture around furnace to increase heat value
Cyclone	Sub-bituminous	Low Btu content	Loss of boiler capacity	1. Raise primary air to 650°F to dry coal
		Low Btu content and high moisture	Carbon carryover	1. Adjust crushers to 97% particles pass through 200 mesh 2. Modify cyclone tubes to prevent carbon from leaking into boiler furnace
		Ash content and fusion temperature	Slag formation	1. Refractory coating applied to cyclone to increase temperature for combustion and slag formation 2. One slag tap utilized instead of two
Pulverized coal	Lignite	Low Btu content	Higher feed rate of coal needed to maintain boiler capacity	1. Larger motors in pulverizer 2. Increase feeder capacity

Table 1 (cont.)

Boiler Type	Coal Type	Coal Characteristic	Technological Problems	Method of Resolution
Pulverized coal (cont.)	Lignite	High moisture content	Proper ignition and loss of boiler capacity	1. Higher air temperatures during pulverization to dry coal
	Sub-bituminous	Low Btu content	Higher feed rate of coal needed to maintain boiler capacity	1. Larger mill capacity 2. Increase feeder capacity
		Ash content	Little buildup of ash on tube surfaces exposed to heat	1. Acid clean boilers every three years instead of five years
			Deposits on superheater pendant section	1. Increased soot blowing
Underfeed	Sub-bituminous	Low Btu content	Low fuel bed permeability and particle drifting	1. Control particle size of coal
		Low ash, low Btu content	High carbon loss	1. Change feed rate, rate of burning, and air flow
Crossfeed (traveling grate)	Lignite and sub-bituminous	High moisture content	Proper combustion and ignition	1. Use arches or overfire air to promote turbulence of volatile gases 2. Adjust feed rate, bed density, flame length, and excess air

Table 1 (cont.)

Boiler Type	Coal Type	Coal Characteristic	Technological Problems	Method of Resolution
Crossfeed (traveling grate) (cont.)	Lignite and sub-bituminous	Ash content, ash fusion temperature, and heat release rate	Clinkers	1. Control particle sizes and fuel bed depth for appropriate burning rates and temperature control
Spreader stoker	Lignite	High moisture content	Proper ignition and combustion	1. Preheat air to 405°F to dry coal 2. Proper sizing of fuel for combustion

3. COAL TYPES AND THEIR IMPORTANT ATTRIBUTES

Although coal may represent one of our greatest energy resources, the variety of constituents within coal have hampered its full utilization. Not only is the sulfur content an important factor, but also ash content, heat value, volatility, grindability, and moisture affect design considerations. Because our study is concerned with the usage of low-sulfur coal versus existing supplies with higher sulfur contents, it is important to note the differences between these sources. These differences affect boiler design and operation and must be considered in an evaluation of the feasibility of such a conversion. In the following sections, the pertinent coal types will be described and compared. Also, an analysis of the characteristics which impact design will be performed as the first step in determining conversion requirements.

3.1 Coal Types

Coal varies across the United States according to seam, county, and state. For our purposes, we shall consider those coals which have less than 1% sulfur and compare these to midwestern coals utilized by electric generating stations and industries in Region V. Low-sulfur coal can be categorized into four major types as shown in Table 2.

Although anthracite is a low-sulfur coal, none of that is appropriate for our analysis. Clearly, lignite and sub-bituminous coals are the primary sources of coal with less than 1% sulfur. Bituminous coal is also available in this category, but this coal is very difficult to obtain due to market competition. Therefore, the characteristics of sub-bituminous and lignitic coals will be compared to midwestern coals from Illinois and Indiana. Table 3 presents the basic characteristics of four midwestern coals in comparison to the average Rocky Mountain coals.

There are significant differences in average levels of moisture, heating value, sulfur, and grindability among these

Table 2

ESTIMATED SULFUR CONTENT DISTRIBUTION
BY COAL TYPE

Coal Type	Percent of Total Coal Reserves	Percent of Total Coal Reserves with Sulfur Content		
		S < 1%	S 1-2%	S > 2%
Bituminous	46.0	13.7	6.2	26.2
Sub-bituminous	24.7	24.6	0.1	-
Lignite	28.4	25.8	2.6	-
Anthracite	0.9	0.9	-	-

Source: L. Hoffman, et al.; Survey of Coal Availabilities by Sulfur Content, NTIS PB 211 505, May 1972.

Table 3

COMPARISON OF COAL CHARACTERISTICS

	Rocky Mountain Bituminous	Rocky Mountain Sub-bituminous	Rocky Mountain Lignite	Vermilion, Illinois (Bed II, Group 5)	Gallatin, Illinois (Harrisburg No. 5)	Perry, Illinois (Herrin No. 6)	Greene, Indiana (Bed VI)
Moisture Content (wt % dry)	7.7	19.6	36.8	12.2	4.5	10.2	13.1
Volatile Matter (wt % dry)	40.3	40.0	42.7	38.8	36.6	34.1	34.3
Fixed Carbon (wt % dry)	51.4	51.0	46.5	40.0	50.7	45.5	43.0
Ash (wt % dry)	8.0	8.4	10.5	9.0	8.2	10.2	9.6
Total Sulfur (wt % dry)	0.92	0.80	0.96	3.2	2.8	-	3.0
Pyritic Sulfur (wt % dry)	0.29	0.22	0.15	-	-	-	-
Organic Sulfur (wt % dry)	0.60	0.53	0.58	-	-	-	-
Grindability Index	50	51	48	-	-	-	-
Btu/lb	11,879	9,235	6,763	11,340	13,030	11,390	11,180

Source: L. Hoffman, et al.; Survey of Coal Availabilities by Sulfur Content, NTIS, May, 1972.

coals. Such attributes which create problems in operation are important, and are summarized in Section 2.2. Note that lignite is considerably different from the bituminous coals of the Midwest. The moisture content of Illinois coals varies from 10 to 12% while lignites average 36.8%. Heating values are considerably lower for Rocky Mountain coals, which means greater quantities must be burned to achieve the same Btu per hour generation.

Although columns 2, 3, and 4 present the average characteristics of the coals in this area, there is significant deviation within each category, especially moisture, ash, and grindability. The standard deviation for the values shown was approximately 15 to 30% of that reported.

The variation in coal characteristics within a state may also be significant, depending upon the types of coal available within that state. In Table 4, the average, minimum, and maximum values for coal analyses are presented as compiled from U.S. Bureau of Mines data. The average moisture content, Btu content, and ash softening temperature are quite different for Illinois and western coals from Montana. Since Montana presently represents the largest supply of western coals to the Midwest, it is important to compare the coals from these two states. The maximum moisture content in Illinois coals is 22%, while 25% is the Montana average. Allowing for variation, the boiler operating conditions would be quite different for these two coals. Ash softening temperature, which is important in determining the tendency to clinker, is 2,090°F for Illinois coals compared to 2,430°F for Montana coals. Thus, the operating conditions will be different for Illinois and western coals. The net result of coal quality variations and different averages is a change in the operating criteria when western coals are used. The importance of the needed modification in operating procedure varies with each boiler type and is discussed in conversion experiences.

Table 4

RANGE OF COAL CHARACTERISTICS

State		Characteristic as a Percent of Total Coal Composition										Ash Softening Temperature, °F
		Moisture	Volatile Matter	Fixed Carbon	Ash	S	H	C	N	O	Btu, °F/lb coal	
Alabama	Min.	2.9	29.7	51.9	2.5	0.6	--	--	--	--	12,160	2,130
	Ave.	4.7	37.7	55.9	6.1	1.2	4.9	76.9	1.8	8.7	13,280	2,320
	Max.	12.5	42.0	62.7	14.6	2.0	--	--	--	--	14,150	2,680
Arizona	Ave.	11.7	44.4	47.1	8.5	0.4	5.1	70.3	1.1	14.6	10,900	--
Colorado	Min.	4.6	37.2	46.6	5.1	0.3	--	--	--	--	10,730	2,260
	Ave.	12.9	39.6	51.8	8.6	0.6	--	--	--	--	11,050	--
	Max.	22.5	43.3	56.1	14.6	1.1	--	--	--	--	11,270	2,910
Illinois	Min.	4.8	35.3	44.5	6.1	1.5	--	--	--	--	10,000	2,000
	Ave.	10.5	41.0	49.9	9.1	2.8	--	--	--	--	11,780	2,090
	Max.	21.9	47.4	55.7	11.5	4.3	--	--	--	--	12,810	2,180
Indiana	Min.	8.0	38.1	44.4	7.7	1.1	--	--	--	--	10,670	2,000
	Ave.	11.4	42.7	47.5	9.8	3.2	--	--	--	--	11,540	2,330
	Max.	19.0	45.3	52.4	11.6	4.5	--	--	--	--	12,370	2,700
Iowa	Min.	9.6	38.1	32.3	13.1	2.5	4.0	52.6	0.9	4.3	8,350	1,910
	Ave.	15.6	40.9	41.0	18.1	4.5	4.5	62.0	1.3	6.6	9,580	2,060
	Max.	19.2	48.1	46.6	29.6	10.0	4.9	68.7	1.6	8.9	10,970	2,200
Kansas	Min.	3.6	36.6	48.3	8.5	2.3	4.9	72.0	--	3.1	8,350	1,980
	Ave.	4.6	38.5	50.5	11.0	3.8	5.0	72.6	1.2	3.7	9,580	2,020
	Max.	5.8	40.6	53.0	11.3	4.8	5.1	73.3	--	4.3	10,970	2,070
Kentucky	Min.	2.0	33.6	48.2	3.6	0.6	5.3	--	--	--	11,210	2,130
	Ave.	6.1	39.2	54.3	7.8	2.2	5.4	79.5	1.6	7.2	12,800	2,410
	Max.	14.9	45.1	60.7	17.7	3.9	5.5	--	--	--	14,150	2,800
Missouri	Min.	11.1	43.7	46.7	8.9	--	--	--	--	--	11,390	2,020
	Ave.	12.1	44.0	47.1	8.9	4.1	--	--	--	--	11,530	2,030
	Max.	13.2	44.3	47.4	9.0	--	--	--	--	--	11,680	2,050
Montana	Min.	8.0	33.0	44.0	7.0	0.4	--	--	--	--	7,290	2,380
	Ave.	25.4	38.2	51.1	10.7	1.0	4.5	68.1	1.0	14.7	8,680	2,430
	Max.	43.0	42.0	58.0	16.0	2.3	--	--	--	--	11.030	2,490
New Mexico	Min.	11.7	44.1	46.6	7.1	--	--	--	--	--	--	2,080
	Ave.	12.7	44.2	47.6	8.2	0.7	5.2	70.9	1.3	12.6	10,790	--
	Max.	13.7	44.3	48.6	9.3	--	--	--	--	--	--	2,910
North Dakota	Min.	33.3	40.1	46.8	7.9	0.4	--	--	--	--	--	1,990
	Ave.	35.1	41.9	48.3	9.8	0.7	--	--	--	--	6,700	2,240
	Max.	38.6	44.2	49.2	13.1	1.0	--	--	--	--	--	2,520
Ohio	Min.	3.2	39.1	45.3	6.1	2.1	--	--	--	--	11,340	--
	Ave.	5.9	41.8	49.7	9.4	2.7	5.1	74.5	1.5	6.2	12,560	--
	Max.	8.2	45.2	54.1	13.6	3.2	--	--	--	--	13,440	--
Oklahoma	Min.	1.0	39.4	47.9	7.1	--	--	--	--	--	12,730	--
	Ave.	3.5	42.2	48.7	9.0	3.5	1.5	76.8	1.5	5.6	13,070	--
	Max.	5.0	45.0	49.6	11.0	--	--	--	--	--	13,420	--
Pennsylvania	Min.	1.0	16.0	46.3	5.8	0.7	4.9	73.7	1.1	4.8	10,750	2,020
	Ave.	3.7	33.4	57.0	9.6	2.3	5.1	76.7	1.4	5.6	13,020	2,410
	Max.	12.0	41.4	77.0	21.0	8.1	5.4	79.5	1.5	6.9	14,420	2,910
Tennessee	Min.	1.8	29.0	51.8	10.0	0.6	--	--	--	--	12,370	2,080
	Ave.	3.0	31.0	57.3	11.7	1.0	4.9	73.5	1.8	7.2	12,870	2,460
	Max.	3.8	36.8	61.0	14.6	1.2	--	--	--	--	13,350	2,910
Utah	Min.	2.8	40.5	44.4	5.7	0.3	--	--	--	--	11,370	2,110
	Ave.	5.3	45.2	50.1	7.3	0.5	--	--	--	--	11,430	2,250
	Max.	8.7	47.0	53.5	13.6	0.8	--	--	--	--	12,850	2,420
Washington	Min.	4.8	36.0	46.0	15.6	0.3	--	--	--	--	11,630	2,590
	Ave.	5.0	38.0	46.2	15.8	0.3	--	--	--	--	11,670	--
	Max.	5.2	38.0	46.4	16.0	0.4	--	--	--	--	11,720	2,910
West Virginia	Min.	1.5	29.1	53.0	2.8	0.6	4.3	73.1	1.2	1.9	11,930	2,070
	Ave.	3.6	36.4	56.7	7.9	1.0	5.1	80.0	1.5	5.3	13,130	2,540
	Max.	8.5	40.4	65.6	16.5	1.6	7.0	86.6	1.8	7.9	14,390	2,910
Wyoming	Min.	15.5	41.7	47.1	3.5	0.5	--	--	--	--	9,540	--
	Ave.	20.1	43.4	50.8	5.7	0.8	5.0	72.1	1.6	14.1	10,140	2,450
	Max.	23.0	46.4	54.2	7.9	1.0	--	--	--	--	10,700	--

Source. Monsanto Research Corp., Evaluation of Low-Sulfur Western Coal Characteristics, Utilization and Combustion Experience, 1975.

3.2 Attributes of Coal Important to Boiler Design

There are several major coal characteristics which influence boiler design and operation. These factors determine the rank of coal and thus its range of usefulness. It is important to be familiar with the definition of the tests and phrases which describe various coals. Table 5 summarizes the most useful of these attributes which are often referred to in later sections of the report. A general indication of the effect of these coal characteristics is presented for two major boiler categories, the stoker and the pulverized coal systems. Table 6 lists eight characteristics and the impact on design that these variables have. The pulverized and stoker fuel system designs are especially affected by variations in coal ash, moisture, and volatility. Low-sulfur western coals have significantly different characteristics in these respects and thus affect operation of the boiler system. Any modification of the coal characteristics from design may substantially alter operations, depending upon the type. Because there are many types of boilers within each category, a breakdown and discussion of these is provided in the next section.

4. GENERAL DESCRIPTION OF BOILER TYPES

A boiler system is comprised of several components, such as the type of fuel system, coal injection system, and ash handling facilities. Depending upon the boiler size and the coal which is to be burned, a combination of these systems is selected for use. Table 7 summarizes the general categories and limitations of these systems.

The two types of boiler systems specifically reviewed during this segment of the project were cyclone boilers and traveling grate stokers. Clearly, the traveling grate is a crossfeed system which is generally used for boilers of 6,000 to 200,000 pounds per hour steam. The fuel range is designated at bituminous, and it is not considered a system which can accept a wide variety of coal. The cyclone boiler

Table 5

DEFINITION OF COAL CHARACTERISTICS

Coal Characteristic	Definition
Moisture	Natural moisture lies in pores and is a true part of the coal, being retained when air dried. Surface moisture depends on climatic conditions. High moisture content in effect reduces the heat value of the coal.
Ash	Ash is impurities which form the incombustible matter left behind after burning.
Volatile Matter	This is the portion of coal driven off in gaseous form when a standardized temperature test is performed. This affects firing mechanics, and thus furnace volume.
Fixed Carbon	The combustible residue which is retained after the volatile matter is flashed off is the fixed carbon.
Sulfur	Three forms of sulfur are found in coal; pyritic (combined with iron), organic, and sulfate
Ash-Fusibility Temperature	In a reducing atmosphere, cones of ash are heated and the temperature at which the cone fuses down is the "softening temperature". This indicates clinkering and slagging tendencies under furnace conditions. Two other stages in the fusibility test are IT (initial deformation) and FT (fluid temperature).
Grindability	This measures the ease of pulverizing coal for a given amount of grinding energy. The higher the index, the more easily it is pulverized.
Caking / Freeburning	Measured by free-swelling index, caking or non-caking refers to the tendency of coal to agglomerate during burning

Table 6

COAL CHARACTERISTICS AFFECTING BOILER DESIGN

Coal Characteristic	Boiler Type	
	Pulverized	Stoker
Sulfur	Affects slagging and air heater exit temperatures	Affects clinkering and slag. Also limits economizer exit temperatures.
Ash	Reduces handling and burning capacity. Retards combustion	Reduces handling and burning capacity.
Ash Fusibility	Influences choice of furnace bottom, depending on fusion temperature.	Indicates clinkering or fusing characteristics.
Volatility	Low volatile coal ignites less readily which affects furnace size and amount of cooled surface	Affects flame length and thus minimizes grate settling height and furnace volume.
Moisture	Reduces burning and handling capacity Affects ignition and increases flame length.	Reduces burning and handling capacity
Coal Size	Pulverizer capacity changed by sizing needs.	Caking property and particle size determine the density and uniformity of fuel bed which changes air needs.
Grindability	Affects mill capacity, cost, and maintenance.	-

Table 7

CATEGORIZATION OF BOILERS

Type of Fuel System	Coal Injection System	Boiler Capacity (#/hr)
Fuel Bed	1) Spreader or Overfeed	5,000-400,000
	a) Traveling Grate	100,000-400,000
	b) Stationary	5,000- 30,000
	c) Reciprocating	5,000- 75,000
	d) Vibrating	-
	e) Oscillating	Up to 150,000
	f) Dumping	5,000- 60,000
	2) Mass-Burning or Crossfeed	
	a) Chain	6,000-200,000
	b) Traveling	6,000-200,000
	c) Vibrating	6,000-200,000
	3) Underfeed (Single Retort)	
	a) Reciprocating Ram	-
	b) Stationary	Up to 20,000
	c) Undulating	Up to 25,000
Suspension	1) Pulverization	Greater than 200,000
	a) Direct Firing	
	b) Direct Firing - Circulating	
	c)	
	2) Cyclone	Greater than 200,000

Sources: 1.) "Burn Coal in Fuel Beds in Small Industrial Boilers", Power, March 1974.

2.) Roberson, J., "Selection and Sizing of Coal Burning Equipment", Power Engineering, October 1974.

system can be considered a sub-category of pulverized systems even though the coal is only crushed, not pulverized. Its usage is primarily large utility and industrial boilers with great flexibility in fuels burned. These two systems are discussed in detail in the following section.

5. CYCLONE BOILER

The cyclone boiler is a design adaptation for utilities which burn lower rank coals, such as those found in Illinois. Primarily utilized in the Midwest and in the states of North Dakota and Montana, the cyclone furnace has gained acceptance and over 700 were in use by 1970.

Before discussing the problems associated with the conversion from Illinois coals to low-sulfur western coals, it is important to understand the basic operation of the cyclone furnace. Therefore, a brief description of the important operating parameters and design characteristics related to fuel utilization are presented.

5.1 Cyclone Boiler Operation

In order to circumvent firing and ash-handling problems associated with lower rank bituminous coals, the cyclone furnace was developed. The basic principle of operation is to introduce crushed coal and combustion air tangentially to impart a whirling motion in the cylindrical horizontal furnace. Figure 1 depicts the coal and secondary air inlets used to maintain the centrifugal action. Combustion occurs at temperatures over 3,000°F, which results in a molten ash layer on the walls of the cylinder. Those gases generated during combustion exit from the cylinder into the boiler furnace while molten slag drains out through the slag tap opening. As coal particles are fed into the system, the centrifugal force throws the particles onto the walls where they are held

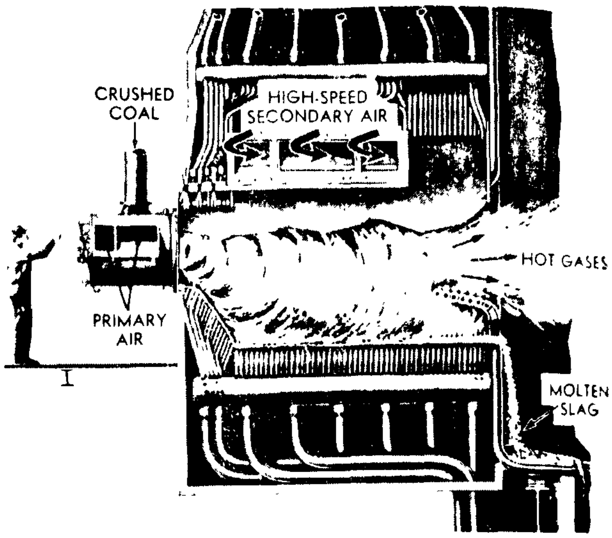

Figure 1

CYCLONE FURNACE OPERATION

Source: Babcock and Wilcox, Steam and Its Generation, 1972.

in the slag, burned, and then the ash becomes a molten slag. It is important for successful operation to maintain air flow, the furnace temperature, and the slag coating.

There are several auxiliary systems to the cyclone which will be included in this discussion because of their contribution to the overall performance of the cyclone. Coal is usually crushed in a preparation plant and then fired or stored in coal silos. As the coal is fed to the boiler, it is usually transferred by a conveyor belt to a gravity system controlled mechanically to insure a uniform feed rate. From this system the coal enters, burns, and exits as a molten slag to a holding tank where it is quenched. In Figure 2, these systems are shown in a typical cyclone furnace configuration.

According to the Babcock and Wilcox Company (1), there are several important fuel characteristics which affect the design and operation of the cyclone. Volatile matter higher than 15% is needed to sustain the combustion rate. An ash content between 6 and 15% on a dry basis is required to assure a proper slag coating can be obtained. Other important fuel criteria are the sulfur content and ratio of iron to calcium and magnesium in the coal. The tendency to form iron and iron sulfide must be sufficiently low for proper boiler operation.

Maintaining a slag layer is of the utmost importance in sustaining proper boiler operation. At a viscosity of 250 poises, the slag will run horizontally out of the furnace into the slag tap. The temperature at which this viscosity is attained depends upon the chemical constituents in the ash. Each coal has its own fusion temperature, and, thus, the furnace must be controlled to maintain this temperature. With lower Btu coal, a greater feed rate of combustion rate is needed to reach the same furnace temperature, and thus the control of the furnace may be very difficult.

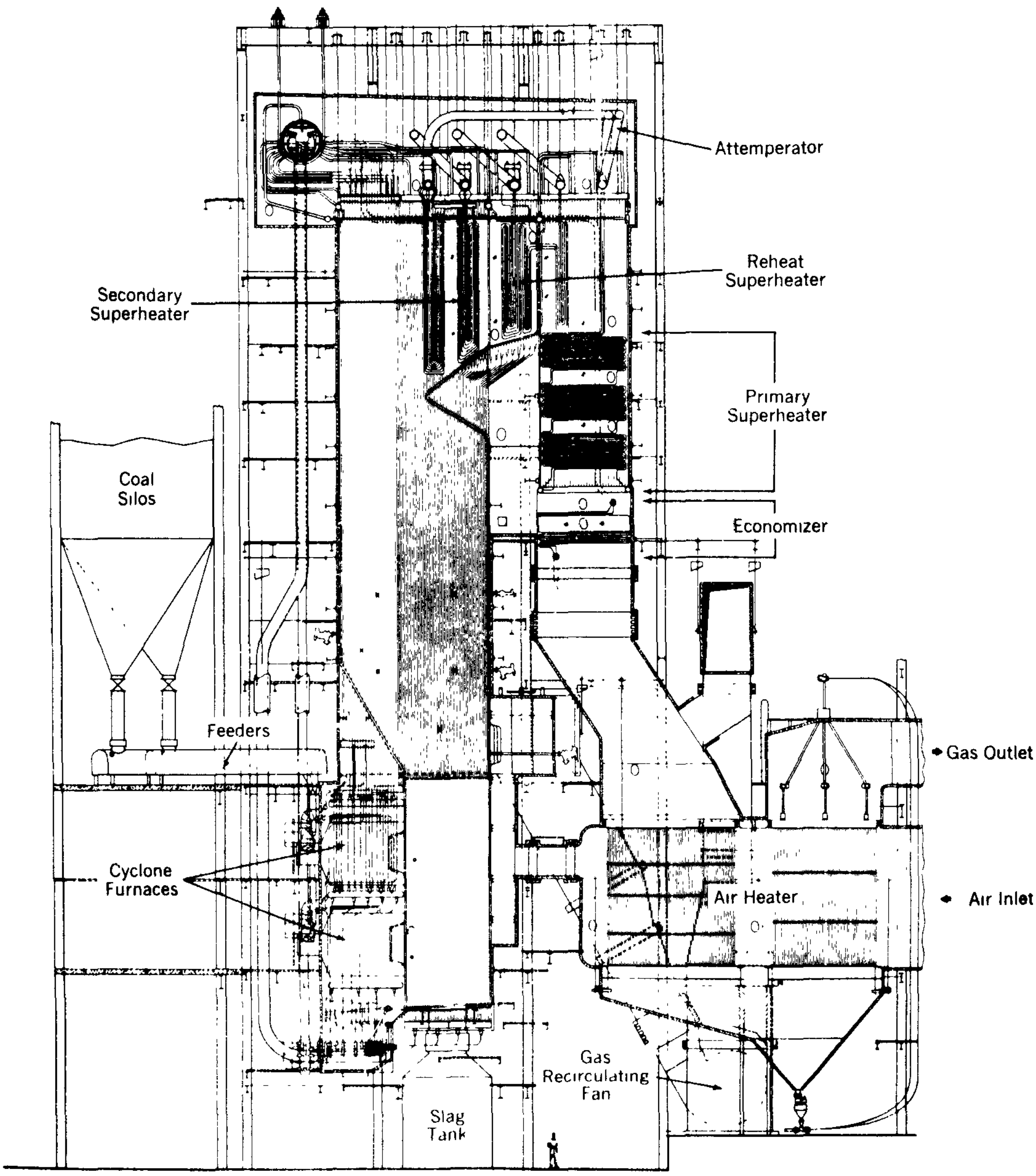

Figure 2

CYCLONE BOILER SYSTEM DESIGN

Source: Babcock and Wilcox, Steam and Its Generation, 1972.

The moisture of the coal can vary over a wide range, depending upon the plant's facilities for pre-drying, fuel preparation, and secondary air temperature. Moisture levels affect ignition stability and combustion temperature, and therefore, should be controlled for adequate cyclone performances. All of these coal characteristics are considered in the design and operation of the cyclone furnace.

5.2 Usage of Low-Sulfur Western Coals in Cyclone Boilers

The use of low-sulfur western coals in cyclone boilers has been considered not only as a converison from other fuels, but also as a design criterion. There are several examples in the literature of cyclones designed for lignite and sub-bituminous coals; however, the number of cyclones which have been converted from bituminous to lower rank coals is limited to two midwestern utilities, Northern States Power and Commonwealth Edison. In the following sections, a discussion of the design and operating parameters which have affected boiler performance are presented. Methods for improving performance which have been attempted or considered are listed, as well as the costs of implementation.

5.2.1 Boiler Design for Western Coals

Cyclone boilers, which were designed for lignite and sub-bituminous coals, differ from those in which midwestern coals were burned. The first commercial lignite-fired cyclone was located at the Black Hills Power and Light Company in South Dakota, and its design was similar to the standard one. By 1970, several features were added to the cyclone furnace as exemplified by the design of the Milton Young Station, Minnkota Power Cooperative, Inc. in North Dakota (2). This station, which was designed to burn lignite up to 40% moisture, utilized the following modifications:

1. Primary and secondary air at 750°F.
2. Two-stage conditioning system to dry fuel before combusiton.

3. Auxiliary fuel for startup or during burning of low heat value fuel.

4. Some moisture from coal is bypassed around furnace.

Cyclones designed for burning lignites at the Leland Olds Station and Big Stone Plant, owned by Basin Electric Power and Ottertail Power Company, respectively, included several features to aid in operation (2). The upper furnace was expanded in depth to reduce gas velocities and heat absorption rates in order to minimize and control slagging. Also incorporated was gas tempering to control gas temperatures to a low level entering the superheater. This modification allows reheating without accumulating high-temperature ash deposits.

Boilers burning sub-bituminous coals with moisture contents of 30% in the coal do not require as many adaptations. In the design of a 600-MW cyclone furnace, Babcock and Wilcox used the following modifications (2):

1. Primary air at 650°F.

2. Air-lift crusher for each furnace.

3. Convection pass design similar to lignites.

4. All moisture enters furnace.

Thus, it appears that cyclone furnaces which burn sub-bituminous or lignite coals require modifications from the standard design in order to operate efficiently. The range of coals which can be burned within an existing system depends upon the difference between the original design fuel and the low-sulfur western coal alternative. In the following section, the results of such an operating conversion are examined.

5.2.2 Fuel Conversion Experience

Deviation in fuels from the design coal can result in operating problems within the boiler. Two pilot tests in which a range of coals was examined and two full scale operations which converted to western coal provide information regarding boiler performance. Each of these studies and their results are summarized briefly.

1. Black Hills Power and Light Company (3) (Ben French Station)

   Three coals were tested in the cyclone boiler to ascertain the flexibility in coal characteristics which could be tolerated. These three coals are described in Table 8 and varied in heat value from 6,500 to 8,100 Btu's per pound. Cyclone performance was satisfactory for the design coal and the Baukol-Noonan coal; however, the Glenharold coal, which represented the highest moisture, required 5% supplementary fuel to insure ignition. Without the gas, lighter slag deposits and unburned fuel accumulated at the bottom, front end of the cyclone furnace. These deposits resulted in carbon carry-over into the boiler primary furnace.

2. Babcock and Wilcox - Barbarton Works (3) - Test Program

   Babcock and Wilcox, who is a major designer of cyclone furnaces, conducted a series of tests using the high moisture Glenharold coal. Without modifying their existing boiler, Babcock and Wilcox could not achieve the desired boiler performance without adding supplemental gas fuel. Therefore, modifications of their boiler system were required to successfully burn a high-moisture low-Btu coal. By bypassing some moisture from the cyclone and installing a pre-drying system for the coal boiler, operation improved. Also, using combustion air at 700-750°F and lower levels of excess air (raises furnace temperature) aided combustion.

3. Commonwealth Edison (4)

   At the 1973 ASME Winter Meeting and in a recent meeting with IITRI personnel, Commonwealth Edison representatives discussed their long-term operating experiences in utilizing low-sulfur, western coals. The problems encountered related to carbon carry-over, slag layer formation, and boiler derating. The moisture, ash, and chemical constituents of western coal all affected boiler operation. In Table 9, there is a comparison of three coals which could be utilized by Commonwealth Edison. Colstrip coal resulted in explosions in the exhaust ducting

Table 8

BLACK HILLS POWER & LIGHT COMPANY TESTS—TYPICAL ANALYSES

Date		June and July 1966	
Mine	Glenharold	Baukol-Noonan	Wyodak
County	Mercer	Burke	Campbell
State	N. Dak.	N. Dak.	Wyoming
Equilibrium Moisture	36.7	33.3	30.6
Ultimate Analysis, as fired			
Moisture	33.4	35.4	30.5
Carbon	36.4	42.2	48 3
Hydrogen	2.7	2.9	3.3
Nitrogen	0.5	0.7	0.7
Sulfur	0.4	0.3	0.4
Ash	7 5	6.9	5.4
Oxygen	12.1	11.6	11.4
HHV, Btu/lb	6500	7180	8100
Ash Fusibility, F			
IDT reducing	1920	1960	2130
ST h = w	2090	2030	2150
ST h = w/2	2100	2080	2170
FT h = 1/16 in.	2300	2180	2340
IDT oxidizing	2090	2230	2150
ST	2120	2270	2170
ST	2140	2290	2200
FT	2380	2330	2290
Ash Analysis			
SiO_2	36.0	30.0	26.0
Al_2O_3	14 0	11.0	15.0
TiO_2	0 5	0.6	1.0
Fe_2O_3	7.2	6.6	7 4
CaO	18 0	21.0	22.0
MgO	4.8	4.7	6.4
Na_2O	5.40	11.00	1.30
K_2O	1.30	0.64	0.27
Temperature for 250 poises, F	2100	2120	2210

Source: Rusanowsky, N., "Lignite Firing in Cyclone Furnaces", Proceedings of American Power Conference, 1967

Table 9

CHARACTERIZATION OF THREE COALS

Coal Characteristic		Mine No. 10 Christian County Illinois	Colstrip Rosebud County Montana	Glenrock Wyoming
Moisture Content (%)		12	21	22
Volatile Matter (%)		39.7	39.9	45.4
Ash (%)		16.5	9.7	10.0
Sulfur (%)		5.0	0.8	0.8
Heating Value (Btu/lb)		11,540	11,620	11,110
Ash Fusibility	IT (°F)	1,905	2,190	2,120
	ST (°F)	1,945	2,220	2,155
	FT (°F)	1,985	2,250	2,190
SiO_2 (% of ash)		43.7	35.4	30.5
Fe_2O_3 (% of ash)		21.3	5.6	6.6
TiO_2 (% of ash)		0.5	0.8	0.6
P_2Os (% of ash)		0.3	0.3	0.4
CaO (% of ash)		7.0	17.8	25.5
MgO (% of ash)		1.0	4.4	3.7
Na_2O (% of ash)		1.5	0.3	0.3
K_2O (% of ash)		1.4	0.1	0.5
SO_3 (% of ash)		6.1	16.3	16.4
Al_2O_3 (% of ash)		17.0	19.0	15.7

Source: Bureau of Mines Circular No. 8471, Technology and Use of Lignite.

caused by excessive carbon carryover and was totally inadequate, while Arch-Mineral coals, which are similar to the Wyoming coal, have been satisfactorily burned. Clearly, the differences which appear small significantly impact boiler operation. High moisture impedes ignition and lowers the furnace temperature. Due to chemical constituents and ash characteristics, a satisfactory slag layer may be difficult to maintain.

To alleviate the carbon loss, Commonwealth Edison attempted pre-drying of the coal and crushing to 97% through a 1/4 in. sieve. In their test runs, no significant improvement in carbon loss was achieved. Carbon carryover can result in fires in the duct work, air heaters, or precipitators, which is a signficant maintenance cost and loss of boiler capacity.

No major modifications have been made to existing cyclone systems, such as Waukegan, Will County, or Stateline, where western coals are currently being burned. The costs associated with this operation are boiler capacity derating of up to 20% and extraordinary replacement of equipment.

Some of the modifications employed by Commonwealth Edison to improve operations are the following:

a) Cyclone tube modification -- The cyclone re-entrant throat openings were closed to prevent carbon from leaking into the boiler furnace.

b) Adjustment of crushers -- To maintain better control of particle size distribution which should enhance combustion.

c) Secondary air temperature was raised from 600°F to 700°F to dry coal and improve combustion.

d) Alteration of secondary dampers -- Damper closest to furnace was closed to prevent carbon entering.

e) Refractory coating was applied to increase the cyclone temperature.

f) Other changes suggested were an increase in the pressure drop across the cyclone, excess air at 7%, and a reduction in primary and tertiary air settings.

4. Northern States Power (5)

Presently, Northern States Power is burning low-sulfur western coal in their power plants in Minneapolis. No modifications were made to their existing systems, although Babcock and Wilcox recommended either supplementary fuel (gas) or better particle size control in their crushing to alleviate operating problems.

5.3 Cost of Utilizing Western Coals

Certain modifications may be required to satisfactorily burn low-sulfur western coal in a cyclone boiler. Commonwealth Edison listed several actions which they had taken to improve operations with low-sulfur coal. These alternations included crusher adjustment, cyclone tube modification, an increase in secondary air temperature, and an increase in pressure drop across the cyclone. The costs associated with these modifications are difficult to estimate because of the importance of plant configuration. However, the cost of additional crusher capacity and the cost of lost boiler capacity due to derating may be presented as potential costs incurred in converting to low-sulfur western coal. The additional maintenance and equipment replacement costs cannot be readily included in the calculations presented, but should also be considered.

5.3.1 Boiler Derating

Conversion to low-sulfur, western coal has reduced the effective capacity of the cyclone boiler due to the lower heating value of the western coal and constraints upon feeding rates. According to Commonwealth Edison (4), in 1973, a 3.6% or 400 mw system reduction for cyclone and pulverized coal systems was realized because of the use of low-sulfur western coal. Mill capacity limitations of pulverized coal systems were responsible for a large portion of this loss (4). The actual cost associated with a boiler derating varies according to the operating characteristics of the individual generating station.

5.3.2 Crushing Equipment

As suggested by Babcock and Wilcox representatives and the literature, better control of the particle sizing would improve boiler performance. Rather than requiring 90% of the particles through 1/4" mesh, 99% must pass through this screen. To achieve a higher level of particle size uniformity, additional crusher capacity would be required.

To estimate the cost of using such additional equipment, a feed rate of 400 tons per hour was assumed. At least 5% additional crushing capacity or 10 tons per hour was required to maintain the proper feed rate to the boilers. This modification can be obtained at a cost of $172,000 per unit*, based on values from Popper's Modern Cost Engineering (6).

5.3.3 Conclusions on Conversion

Presently, the usage of low-sulfur western coal in cyclone boilers is occurring without any modifications to the system. To alleviate costly repairs and operation, the variability in coal quality must be reduced or the cyclone furnace must be adapted. Changes in coal attributes and their impact on operation must be thoroughly investigated to understand the operating difficulties associated with this fuel conversion. To improve operation, it is possible to modify a cyclone furnace, coal preparation equipment, or supporting systems, such as ash handling.

6. TRAVELING GRATE STOKER

The traveling grate stoker is a member of the fuel-bed-fired devices and is generally used in industrial applications. This stoker was very popular in the 1940's, but its use has waned since that time. The basic operation of this stoker is much simpler than the cyclone and will be discussed in the following sections.

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* Updated to January 1975 dollars.

Utilization of western coal in this particular device can only be described in general terms because of the lack of information. Although direct examples of conversion to low-sulfur coal were not located, references to successful operation were obtained and are discussed. The modifications which would insure boiler operation are listed, and their associated costs are discussed in the ensuing section.

6.1 Traveling Grate Operation

The operation of a traveling grate stoker is primarily one of dropping coal on a moving grate through a high temperature region within a furnace. Typically air flows upward through the grate and is used to burn the coal and volatile gases emitted. Figure 3 shows the general structure of a chain grate stoker which is very similar in design. As the coal burns, it is not disturbed in the bed, and it finally is reduced to ash which is collected in a hopper on the far side of the furnace as the belt rotates.

The burning mechanism in the fuel bed is very important in determining the furnace's performance. In Figure 4, a simplified version of the combustion zones in the bed is depicted. These zones vary in location and shape, depending upon the feed mechanism and grate construction. As the coal is ignited, the volatile matter is emitted (distillation zone). When all oxygen is consumed as the coal burns to carbon dioxide (oxidation zone), then carbon monoxide is formed (reduction zone). At the end of the burning process, only ash is left in the fuel bed. Secondary air is usually added to aid in achieving complete burning. The fuel bed temperature depends upon the firing rate of coals, and if the ash fusion temperature is exceeded in the bed, clinkers may form. In the chain grate, clinkers are broken as the chain goes over the drum with a scissor-like action; however, there is no such motion in the traveling grate, and thus, clinkers may be problem in operation. The rate at which fuel is

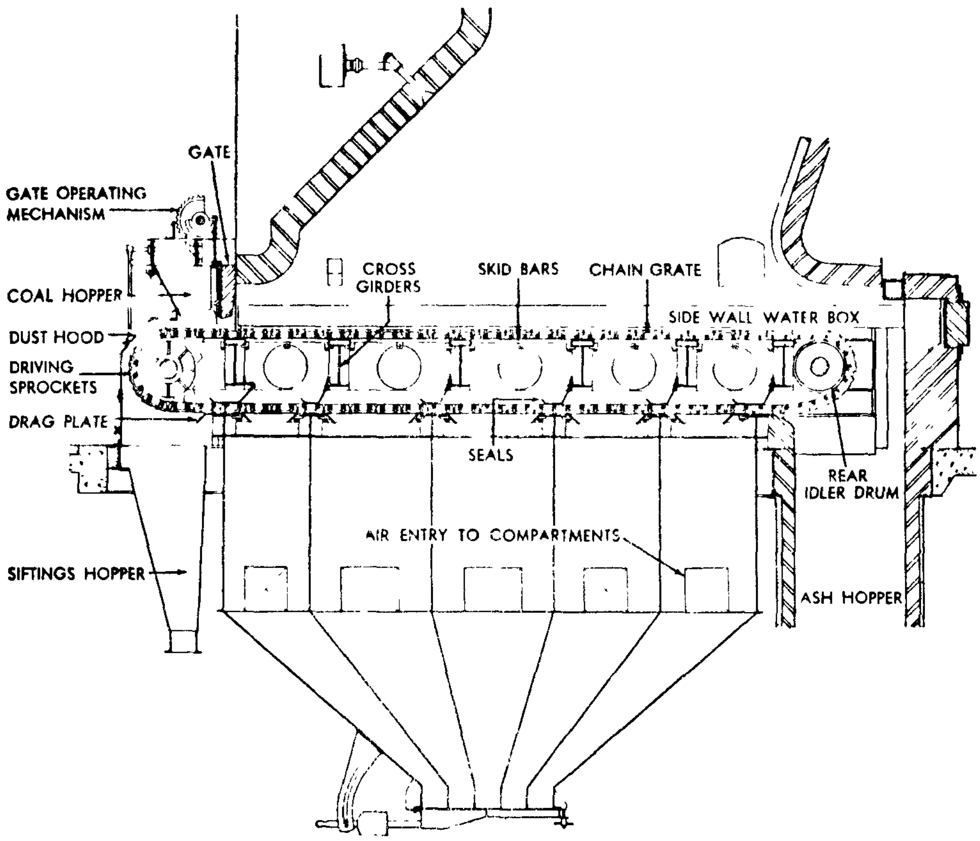


Figure 3

CHAIN GRATE STOKER CONFIGURATION

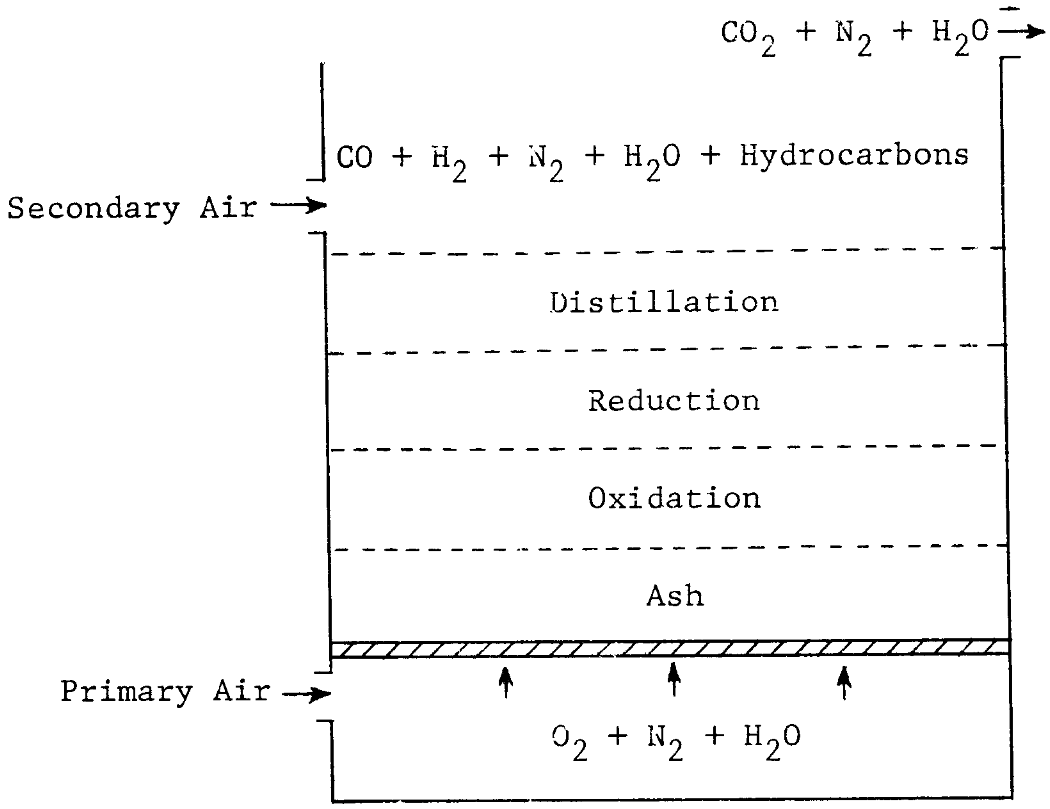


Figure 4

SIMPLIFIED FUEL BED DIAGRAM

burned depends upon the heating value, bed thickness, and grate speed. Control of these variables allows the stoker to adapt to a variety of loads and fuels.

The amount of ash within a coal may also affect operation in that coals with less than 7% ash do not sufficiently protect the grates from overheating and cannot be used. Higher ash coals may tax the capacity of the ash handling system and lead to an expansion problem.

Another variable which is important is the control of air. Air pressure may vary from section to section on the grate to control combustion and heat release. If preheated, the temperature must be regulated to prevent clinkers.

6.2 Usage of Western Coals in Traveling Grate Stokers

According to Babcock and Wilcox (1), the traveling grate stoker represents a versatile process which can handle a variety of fuels from wood to bituminous coal. Other reports also indicate that traveling grates can burn western coals without difficulty. Modifications of these systems, in order to burn western coals, have not been discussed in the available literature.

As early as 1951, there were reports of traveling grates burning lignite without difficulty. Stokers in North Dakota, Wyoming, Minnesota, Canadian Alberta, and Saskatchewan were more conservatively designed for lignite coals than other midwestern fuels (8). Another report (9) on traveling grate operation in 1951 also indicated successful performance without additional coal preparation. Designs for these fuels differ from the standard stoker which does indicate that some operating problems may be incurred by switching fuels.

A design consideration in using western coals is the use of arches or overfire air to maintain ignition and combustion (9,10). This is especially useful for the high moisture lignite fuels. The ash fusion temperature is different for western and midwestern fuels as shown in Table 8. This difference requires that the heat release rate, coal feed rate, excess air, and flame travel all be adjusted. Figure 5 depicts these design criteria for various coal types. Maintaining proper fuel bed thickness is also important in controlling the rate of combustion and preventing clinker formation. If the heat release rate is too high, the ash may form clinkers because it was not sufficiently cooled.

Coal sizing for a traveling grate varies, depending upon the rank of coal. Therefore, according to ASTM Classification, an Illinois bituminous of Rank II-4 or II-5 and sub-bituminous coals of III-1, III-2, and III-3 should have 50% through a 1/4 in. screen. The grindability index for the Illinois and sub-bituminous coals does differ, and adjustments in the crushing equipment would have to be made to obtain the correct particle size and decrease the number of fines. This would also reduce the clinker problem.

To reduce clinkers, which is one of the major problems with western coals, requires changes in operating parameters, such as bed density, flame length, and air requirements. Expenses involved in such adjustments are difficult to estimate because the corrections are basically in-process and no data regarding such changes is available.

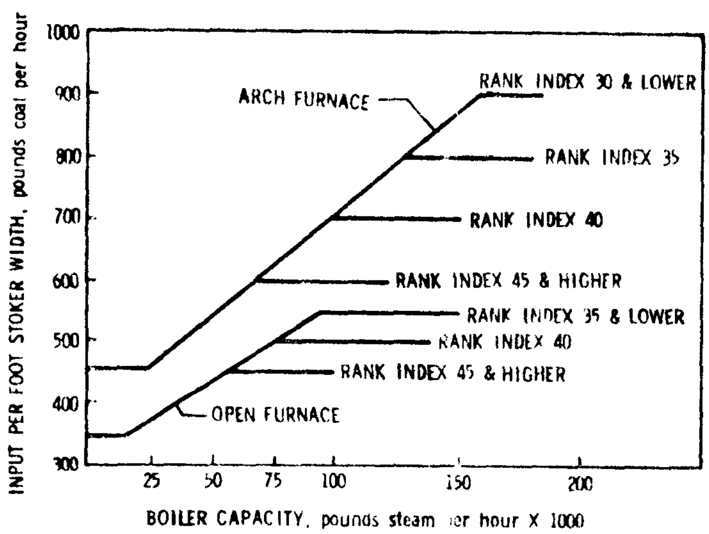
7. <u>UNDERFEED STOKER</u>

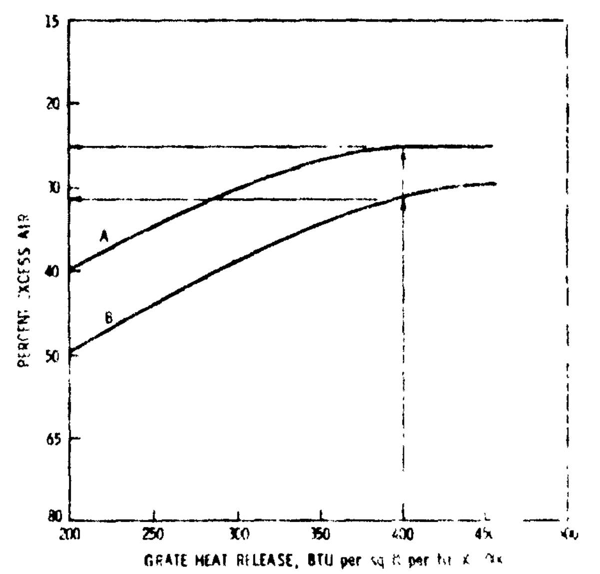
The underfeed boiler is primarily utilized for heating and in small industrial facilities. Approximately 70% of the boilers designed for 10,000 to 16,000 pounds per hour of steam are underfeed boilers (10). Since primary emphasis of the project is large utility and industrial boiler types, only a brief description is provided of this operation and expected problems.

Figure 5

STOKER DESIGN CRITERIA

Ash softening temperature (reducing atmosphere) °F	1900	2200 & above
Grate heat release rate - Btu input/hour/sq ft grate area	300-425,000	450-500,000
Grate coal feed rate - pounds/hour/foot stoker width	See diagram A	
Furnace heat liberation - Btu input/hour/cu ft furnace vol.	35-40,000	30-35,000
Flame travel - (distance from grates to furnace exit) feet	Approx 12	30-40
Excess air leaving furnace - percent	See diagram B	
Undergrate air temperature - °F		
Free swelling index - up thru 7 1/2	80	300
- above 7 1/2	80	80





Source: Table 40, Monsanto Research Corp., Evaluation of Low-Sulfur Western Coal Characteristics, Utilization, and Combustion, 1975.

7.1 Underfeed Stoker Operation

The basic design of the underfeed stoker is to feed coal into the fuel bed from below. Coal in a feed trough overflows onto the bed because of the pressure of fresh coal feed behind it, and then the coal is combusted on the fuel bed as shown in Figure 6. The rate of burning depends upon the type of coal utilized and its ash softening temperature as well as the air distribution system (10). Usually the main air chamber is directly below the retort and air is forced through holes in the grate bars.

7.2 Usage of Lcw-Sulfur Western Coals

To operate an underfeed stoker with low-sulfur western coal requires strict regulation of coal particle size. By limiting coal to the following three sizes, particle drifting and low fuel bed permeability caused by fines can be prevented:

- 1-1/4 in. x 3/4 in. -- nut
- 3/4 in. x 5/16 in. -- pea
- 50% passes 1/4 in. hole -- slack

High carbon losses which reduce boiler capacity can also be expected for low ash, low heating coals, such as the western type. The primary modification to correct these two operating problems is closer scrutiny or higher quality control of coal size specification (1). Additional changes which are practicable have not been located in the literature for these small boiler types.

8. SPREADER STOKERS

One of the more popular industrial boiler designs is that of the spreader stoker. Fifty percent of the boiler capacity rated at 101,000 to 250,000 pounds per hour steam is designed as spreader stokers as well as 30% of the industrial boiler capacity for those between 251,000 and 500,000 pounds per hour steam (10). The popularity of this boiler type is attributed

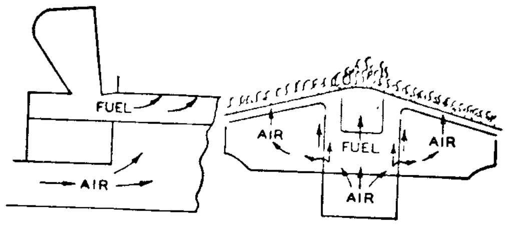


Figure 6

UNDERFEED STOKER

Source: Combustion Engineering, Combustion Engineering, 1969.

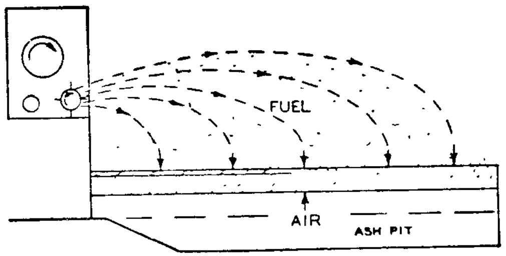
to its ability to adapt to rapid load swings and fuel types. There are approximately six grate variations in this design which include traveling grate, chain grate, oscillating, vibrating, reciprocating, and dumping grate. The operation of the spreader stoker is basically the same regardless of the grate mechanism and is briefly described in the following section.

8.1 Spreader Stoker Operation

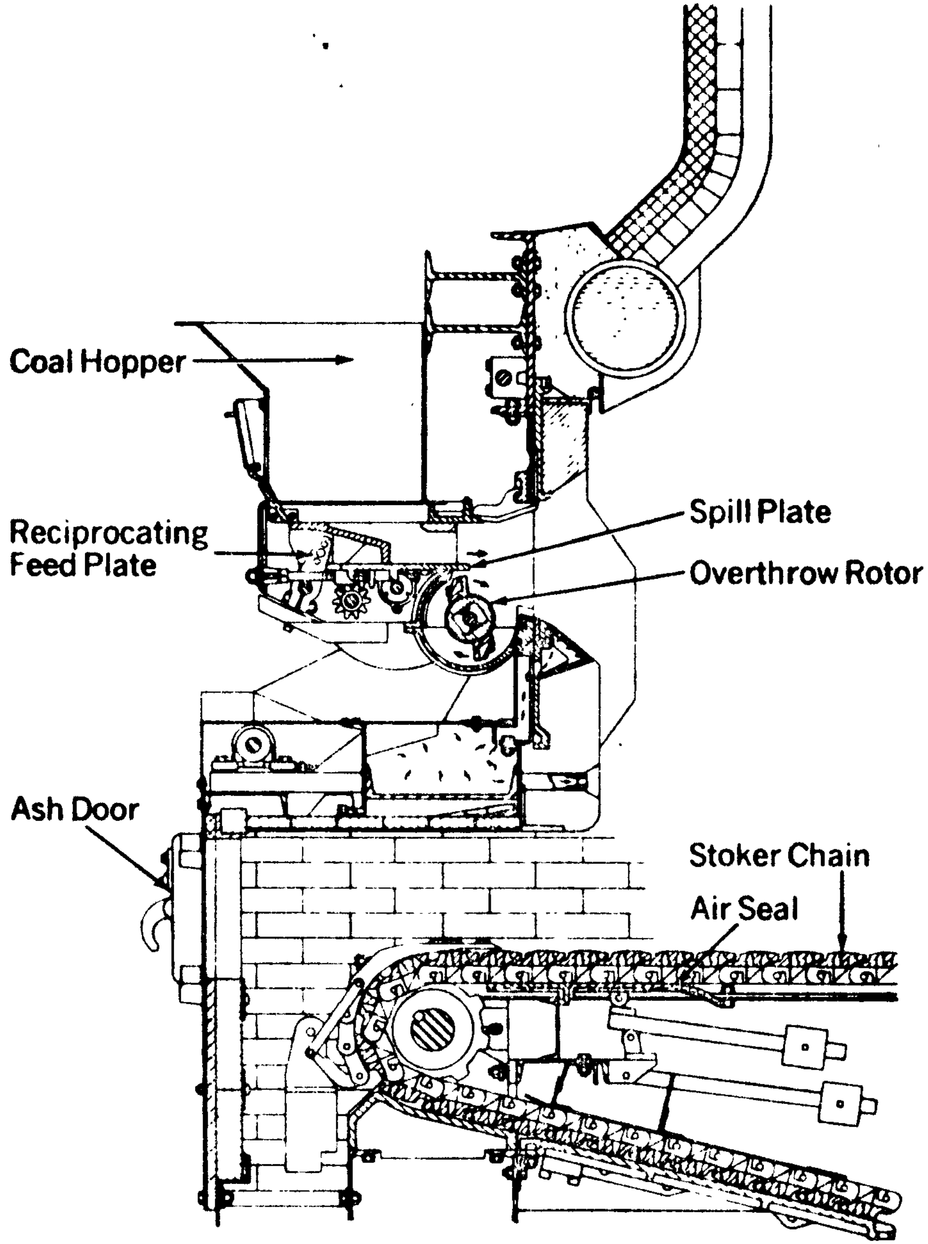
A spreader stoker consists of three basic units, a coal injection system, stoker grate, and ash handling system. Usually coal is fed from the fuel hopper into a bladed rotor which spreads the fuel in the furnace as shown in Figure 7A. The coal particles are distributed in the furnace according to size as the overthrow rotor ejects them into the furnace. The fines burn in suspension while larger particles fall onto a grate and are combusted there. As the grate, which can vary in design from a traveling grate to an oscillating one, moves toward the ash hopper, the fuel bed burns to ash. Air flow between the openings in the grate and the ash layer protect the metal parts from reaching high temperatures. The air must be carefully controlled to prevent disruption of the fuel bed layers and maintain combustion. Additional air (overfire air) enters over the bed to maintain the volatile gas turbulence for proper mixing and combustion. Shown in Figure 7C is the location of overfire air ports, which are important for enhancing combustion efficiency.

Several types of grates may be utilized with the spreader stoker, depending upon the plant operation (11). Small stationary grates are the minimal cost design and require manual cleaning of ashes. However, these are not commonly specified today because of air pollution restrictions. Continuous cleaning grates such as the reciprocating, oscillating, and traveling grate are currently much more popular.

The reciprocating grate, which has a synchronized movement of fuel, air supply, and ash, can supposedly burn



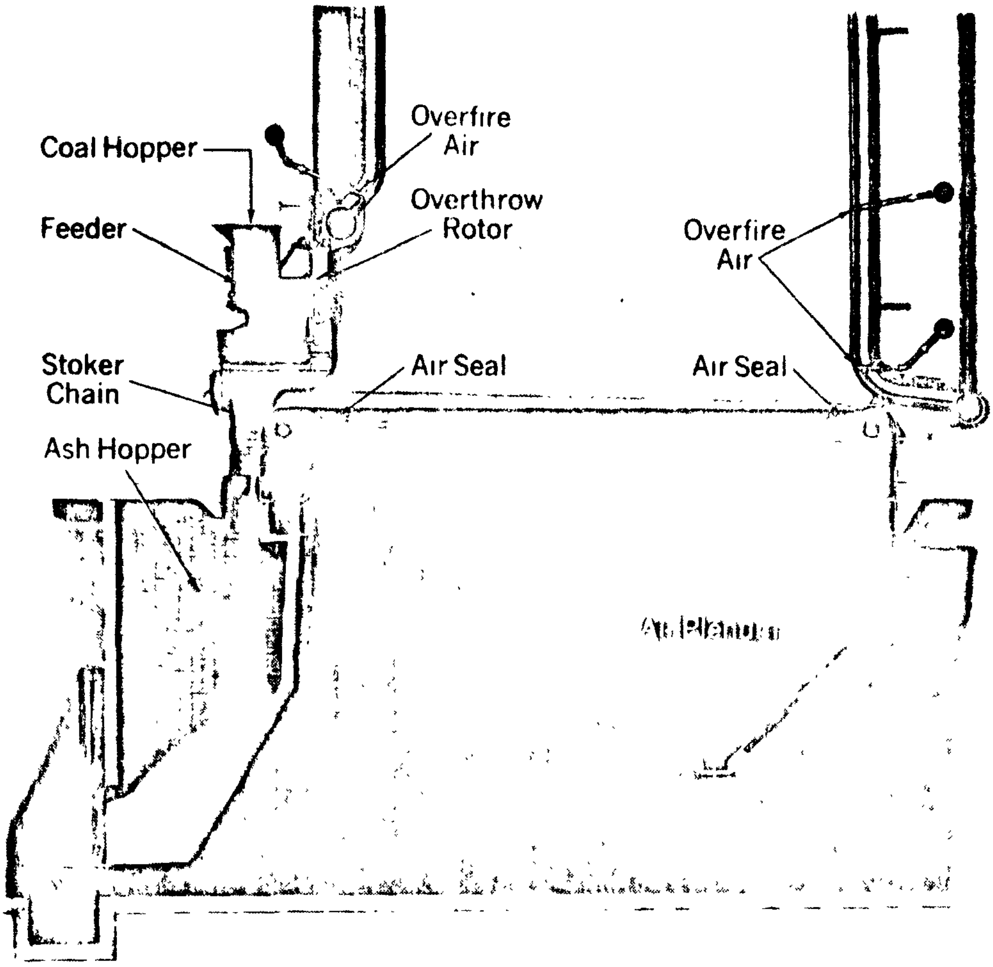
A. General Operation



B. Stoker Equipment

Figure 7

SPREADER STOKER DESIGN



C. Air Source Location

Figure 7 (cont.)

Source: Monsanto Research Corp., Evaluation of Low-Sulfur Western Coal Characteristics, Utilization and Combustion, 1975.

bituminous through lignite coals without preparation other than sizing changes. The traveling grate is utilized in larger boiler designs and also can handle a variety of coals.

Because the coal is injected into the furnace, the flyash carryover is high and a reinjection system (pneumatic or gravity) may be used. For steam capacity above 70,000 pounds per hour, the gravity type, which directs ash from a hopper onto the grate, is used (12) to increase boiler capacity 2 to 3%. A pneumatic system which blows the suspended flyash into the furnace is also frequently used in boiler systems.

The most important parameters for maintaining satisfactory stoker performance are coal sizing and moisture content (10). It is important to have a range in particle size in order to develop a uniform fuel bed. The more fines which are introduced, the greater is carbon carryover. Large coal particles cause uneven fuel bed burning and result in clinker formation. If the coal has high surface moisture, it sticks to the feeder surface and causes uneven distribution of coal particles. Moisture which is natural to the coal, such as lignites, does not cause this problem.

8.2 <u>Usage of Low-Sulfur Western Coals in Spreader Stokers</u>

The use of low-sulfur western coals in spreader stokers has been investigated for a comparison of operation efficiencies. A discussion of the design and operating parameters which were affected are presented in the following section, and methods for improving performance have been listed.

8.2.1 <u>Stoker Design for Western Coals</u>

The spreader stoker is recognized for its ability to burn a wide variety of fuels; however, in converting from midwestern to low-sulfur coal, several problems should be considered. The following three changes or modifications may be necessary to satisfactorily burn these coals:

1. Higher inlet air temperatures

2. Crushing equipment adapted or increased

3. Adjustment of flame length

In utilizing lignite coals, the high moisture content required a higher inlet air temperature for improved handling and combustion of the coal. Although lignites have more moisture than sub-bituminous coals, this modification may still be important for these coals. Obtaining a distribution of coal particle sizes is important in obtaining a uniform fuel bed. If too many particles fall in the same grate portion, then burning is uneven and clinkers form. The grindability of western coals is lower than that of midwestern fuels, and therefore, adjustments in crusher operation are needed. Reduced capacity of crushes will probably occur because of the more stringent sizing requirements and additional units may be required (10). The flame length, which was the third adjustment utilized, was deemed necessary to distribute heat absorption uniformly.

Not many experiences with spreader stokers have been documented in the literature but one which is particularly detailed is described in the following paragraph.

1. Minnkota Power Cooperative (Grand Forks, North Dakota) (9)

In 1951, the first attempt to burn lignite in spreader stokers was documented. Using a completely open furnace in an installation of 72,000 pounds per hour of steam, boiler efficiency of 80% was attained. The design included economizers and air preheaters because of the high moisture (~40%) of the coal. Maintaining preheated air at 405°F was considered critical to achieve optimum operation. A recommendation was made to lengthen the flame mass in some cases to uniformly distribute heat absorption. The spreader stoker is sensitive to poor fuel sizing which affects operation by causing fluctuations in operating conditions.

8.2.2 Cost of Utilizing Western Coals

The cost of converting a spreader stoker for burning low-sulfur western coal is difficult to estimate. Adjustments in the flame length, air flow rate, air inlet temperature, and grate speed are basically in-process changes on which no cost data are available. Other modifications may also be required depending upon the ash handling system, grate design, and other specific design criteria.

9. PULVERIZED COAL FURNACES

Although the first industrial application of pulverized coal occurred in 1895, in the cement industry, usage of pulverized coal in central power stations did not substantially increase until after World War I. Primarily utilized in the electric generating industry, pulverized coal furnaces generally have a capacity greater than 200,000 pounds per hour stream. The popularity of this design is attributed to its ability to handle a wide range of loads and different fuel types. Operation of these units with a variety of fuels has been described in various reports and will be summarized herein. It is important, however, to understand the basic operation of a pulverized unit and the possible variations in design. In the following section these configurations are delineated and compared.

9.1 Pulverized Furnace Operation

The operation of a pulverized coal furnace relies upon the suspension burning of extremely fine coal particles, which makes it quite different from a stoker operation. Basically fine particles, which are injected into the furnace, are heated and the volatile matter distilled off. Primary air mixes with the particles to sustain combustion of the volatiles which heats the remaining carbon to complete combustion (2). To operate this system requires a pulverizer to reduce coal to fine particles, a coal feeder, burners, and an air system as shown in Figure 8.

There are in general three types of pulverizing or grinding mills, three burning arrangements, and four types of burners. The three types of mechanisms used to reduce particle size in mills are impact, attrition, and crushing. The four most commonly used are the ball, ring roll, ball race, and impact

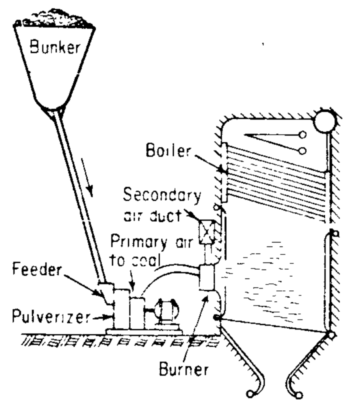


Figure 8

PULVERIZED COAL SYSTEM

Source: Elonka, A., <u>Standard Boiler Operator's Questions and Answers</u>, 1969.

attrition type. The members of the ball mill, ball-and-race, and roll-and-race pulverizers, are utilized in power generating stations and industrial applications. Coals which can be utilized in these pulverizers are identified in Table 10. Illinois coals which are generally bituminous high volatile "B" or "C" can be pulverized in all types except impact mills for "C" coals. Western coals are sub-bituminous or lignite coals and should be handled by ball-and-race and ring-and-roll mills. Sub-bituminous "A" and "B" can also be fined in ball or tube mills. Thus, there is a limitation in design as to the coals which can be handled. The most important parameters are grindability index and quantity of coal.

Burners are utilized to insure stable ignition, effective control of flame shape and travel, and complete mixing of air and fuel (2). Various types of burners can be required depending upon the fuel and furnace design. The arrangement of the burners may be long-flame, shelf system or tangential system firing. The difference in configuration is the relative placement of the primary and secondary air, as shown in Figure 9.

The coal characteristics which affect pulverizer capacity and combustion efficiency are the grindability index, surface moisture, and coal fineness required. When coals of lower heat value are burned, then the boiler capacity is reduced if the same pulverization rate is maintained. The grindability index indicates the ease of pulverization and higher indices result in greater mill capacity. Western coals have lower grindability and thus reduce mill capacity although it is not a directly proportional relationship. Particle fineness required depends upon the ignition and swelling characteristics. High volatile contents in coal, such as bituminous, require less fine particles than low volatiles (western coal). This fineness requirement also affects mill capacity. The relative effect of fineness and grindability on capacity is shown in Figure 10.

Table 10

TYPES OF PULVERIZING MILLS FOR VARIOUS MATERIALS

Type of Fuel	Appropriate Pulverizer Type			
	Ball or Tube	Impact or Attrition	Ball Race	Ring Roll
Low volatile anthracite	x	--	--	--
High volatile anthracite	x	--	x	x
Bituminous coal (L.V.)	x	x	x	x
Bituminous coal (M.V.)	x	x	x	x
Bituminous coal (H.V. "A")	x	x	x	x
Bituminous coal (H.V. "B")	x	x	x	x
Bituminous coal (H.V. "C")	x	--	x	x
Sub-bituminous coal "A" *	x	--	x	x
Sub-bituminous coal "B" *	x	--	x	x
Sub-bituminous coal "C" *	--	--	x	x
Lignite *	--	--	x	x
Brown coal	--	x	--	--

* These coals represent typical low-sulfur western coal types.

Source: Combustion Engineering, <u>Combustion Engineering</u>, 1969.

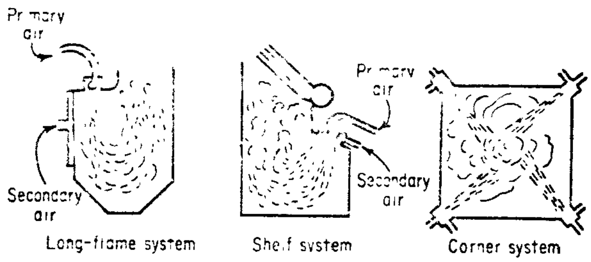


Figure 9

FIRING CONFIGURATIONS OF PULVERIZED COAL FURNACE

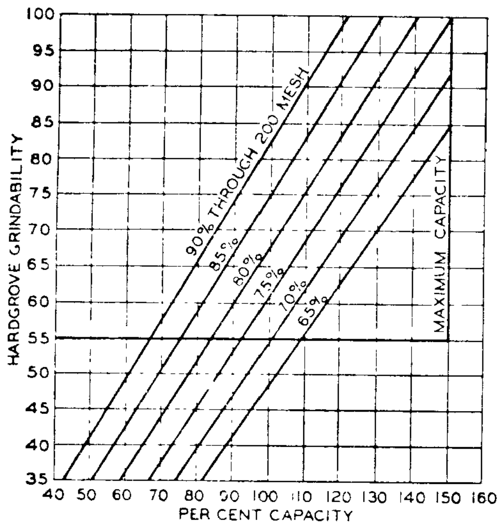


Figure 10

MILL CAPACITY VERSUS FINENESS AND GRINDABILITY

Source: Combustion Engineering, Combustion Engineering, 1969.

Moisture of coal can cause agglomeration of fines and only by using hot air in the system is this problem eliminated. Depending upon the total moisture content of the coal, different air inlet temperatures and flow rates are required. At a flow rate of 3 pounds of air per pound of coal, coal with total moisture of 10% required temperature of 300°F while a 26% moisture coal needed 570°F as an inlet air temperature. Thus, total moisture is important in ascertaining proper air temperature and mill capacity for grinding.

9.2 Usage of Low-Sulfur Western Coals in Pulverized Coal Units

9.2.1 Pulverized Coal Boiler Design

The conversion to and design for western fuels in pulverized coal boilers has been performed by utilities in the Midwest. To accomplish such a feat required several modifications of existing systems. These can be summarized briefly to provide an indication of changes needed.

1. Larger motors in the pulverizers are required.
2. Higher air temperatures during pulverization.
3. Increase in feeder capacity.
4. Increased acid cleaning of boilers and maintenance to pulverizers.
5. Increased number of sootblowers.

These modifications were necessary due to the lower heat value, higher moisture content, grindability, and ash charac-terisitcs of western coals. Several experiences with lignite and sub-bituminous coals are presented in the following paragraphy to provide an understanding of the importance of these factors.

1. Crookston Station, Otter Tail Power Company (9)
   In 1945, the first pulverized coal unit to burn lignite was designed. At 75,000 pounds per hour steam, the capacity of this unit was smaller than today's designs. Their design included two air

preheaters to raise primary air temperature to 700°F. No auxiliary fuel was required for ignition and even at 20% of maximum load, no instability was noted. The auxiliary power requirements for grinding were 4.78% of gross power generated or 0.021 Kw per pound of coal processed.

2. Leland Olds Station, Basin Electric Power (13)

A pulverized coal unit which went into operation in 1966 had several design modifications to properly handle the lignite used as fuel. The 216-mw plant had six specific design features:

1. increased boiler size by 30%
2. increased pulverizer capacity
3. inclusion of air heaters in the primary air flow
4. wide separation of pendant boiler tubes to prevent bridging by ash
5. more thermoprobes than usual to monitor temperatures
6. 100% more sootblowers than same plant with bituminous coal

The tendency of the ash to build up in boiler gas passages was solved by wider separation of boiler tubes. Also, to reduce plugging between superheater tubes, additional soot blowers were added. Lignite caused slagging problems because the mills could not grind to the proper fineness at a sufficient rate. Thus, the low grindability of lignite caused a coarse grind which induced slagging and carbon carryover. This problem was solved by increasing the motor horsepower on mills by 50%.

3. Commonwealth Edison (4)

Commonwealth Edison has utilized sub-bituminous western coals in pulverized coal boilers which were designed for Illinois coals. The conversion has required several adaptations of equipment for successful operation The boiler capacity has been reduced by 5 to 10% because of mill capacity constraints and the lower heating value of western coals. Boiler tubes require acid-cleaning every three years rather than every five years. Sootblowers are increased in number and usage frequency. The advantages of western coals are that the boiler fire-exposed sections remain clean, clinker grinders can be eliminated, and less frequent removal of ash. There are problems in dewatering ash of western coals and removing it.

9.2.2 Conversion Costs of Pulverized Coal Boiler for Western Fuels

The costs of conversion can be estimated for various capital investment and operating expenses incurred, but the actual overall cost may be far greater depending upon the specific constraints and facility modification expenses which accompany such adaptations. Without additional detailed information, cost estimations would be inappropriate and misleading.

10. WESTERN COAL AVAILABILITY

The feasibility of burning western coals depends not only on the technological problems but also upon the supply available for use. In the early 1900's, coal supplied 88% of the energy requirements in the United States; however, that dropped to 17% by 1972. The increased interest in energy independence has stimulated the demand for coal. Because of the capital intensive aspects of this industry, however, it is not possible to respond to rapid changes in demand. Environmental legislation has also hampered the development of western coal reserves.

The western coal market is quite different from the established eastern and midwestern markets. Because of the large capital investment (approximately $21 and $61 million for a 1 and 3 million ton per year strip mine, respectively), long term contracts are needed in the development of western coal. The spot market is a viable organization in the Midwest and East; however, small operators and excess coal supplies which create this market in the East are not present in the West. Sixty percent of western coal production is attributed to 13 mines in 1973. The total number of western coal mines in 1972 was 64, and they produced 51 million tons of coal.

Thus, the supply response to increased demand for western coal has been rather slow. Manufacturers of mining equipment normally have a two-year lead time, depending upon market conditions.

Transportation equipment, such as barges and railroad cars, typically require 18 months (14) for the construction of new equipment. Therefore, the expansion of supply is a planned and projected affair.

Projected supplies of federal western coals which are 35% of the total coals by 1980, are shown in Table 11. According to this forecast, the only midwestern states receiving these western coals are Iowa, Illinois, Wisconsin, Michigan, and Minnesota. Another projection of total production for five western states is presented in Table 12. According to these predictions, the supply of western coal will double before 1980 (10). Another study by the Federal Energy Administration (14) (FEA) indicated the following ranges for 1977 and 1980 production:

	Millions Tons Per Year	
	Low Production Estimate	High Production Estimate
1977	81	117
1980	120	213

The FEA study considered possible constraints and is perhaps a realistic range of production. Most of the western coal presently supplied is on long-term contract to utilities. The economies of scale in surface mining have resulted in large mine facilities with high capital investment. Thus, an assured customer on contract is needed to develop these mines.

To place the supply projections in perspective relative to the needs of utilities in the Midwest, the present status of Commonwealth Edison is described. Table 13 depicts the coal usage of Commonwealth Edison plants in 1972. The total coal consumption was 11.2 million tons per year for the plants shown. In 1973, of the 20.5 million tons of coal under contract by Commonwealth Edison, 7.5 million tons were western coals. Table 12, which shows federal coal projections for 1980, indicates 6.9 million tons will come to Chicago, and this does not

Table 11

PROJECTED COAL PRODUCTION FROM FEDERAL SURFACE COAL MINES FOR STEAM ELECTRIC PLANT FUELS FOR 1980-1981

State	Location of Mine	Major Contracts Annual Tons	Location of Powerplant
Colorado	Oak Creek	800,000	Denver, Colorado
	Hayden	1,000,000	Hayden, Colorado
	Craig	600,000	Craig, Colorado
	Sub-total	2,400,000	
Montana	Colstrip	280,000	Billings, Montana
	Colstrip	800,000	Minneapolis, Minnesota
	Colstrip	1,600,000	Chicago, Illinois
	Colstrip	920,000	Wisconsin
	Colstrip	1,200,000	St. Paul, Minnesota
	Colstrip	1,200,000	Colstrip, Montana
	Colstrip	1,500,000	Cohasset, Minnesota
	Colstrip	2,200,000	Becker, Minnesota
	Savage	90,000	Sidney, Montana
	Decker	5,300,000	Chicago, Illinois
	Decker	6,500,000	St Clair, Michigan
	Decker	8,300,000	American Electric Power
	Sub-total	29,890,000	(Locations Unknown)
North Dakota	Beulah	200,000	Hoot Lake, Minnesota
	Beulah	160,000	Beulah, Mandan, N.D.
	Gascoyne	250,000	Ortonville, South Dakota
	Stanton	1,000,000	Stanton, North Dakota
	Center	400,000	Center, North Dakota
	Zap	500,000	Stanton, North Dakota
	Sub-total	2,510,000	
New Mexico	Fruitland	3,600,000	Fruitland, New Mexico
	Gallup	250,000	Joseph City, New Mexico
	Sub-total	3,850,000	
Utah	Alton	5,600,000	Las Vegas, Nevada St. George, Utah
	Sub-total	5,600,000	
Wyoming	Glen Rock	3,500,000	Glen Rock, Wyoming
	Hanna	100,000	Denver, Colorado
	Hanna	1,300,000	Sioux City, Iowa
	Hanna	1,200,000	Council Bluffs, Iowa
	Hanna	4,500,000	Nebraska
	Point Rocks	3,000,000	Point of Rocks, Wyoming
	Kemmerer	250,000	Kemmerer, Wyoming
	Gillette	520,000	Rapid City, South Dakota
	Gillette	1,400,000	Gillette, Wyoming
	Gillette	2,400,000	Pueblo, Colorado
	Gillette	3,500,000	Avinger, Texas
	Gillette	6,400,000	Topeka, Kansas
	Gillette	3,700,000	Muskogee, Oklahoma
	Gillette	1,800,000	Western Nebraska
	Gillette	1,000,000	Amarillo, Texas
	Gillette	1,700,000	Louisiana
	Gillette	5,000,000	Redfield, Arkansas
	Sub-total	41,270,000	
Grand Total		85,520,000	

Source: Monsanto Research Corp., Evaluation of Low-Sulfur Western Coal Characteristics, Utilization and Combustion Experience, 1975.

Table 12

ANNUAL COAL PRODUCTION (1969-1972) WITH ESTIMATES FOR 1973, 1975, 1980, AND 1985

State	Production in Millions of Tons							
	1969	1970	1971	1972	1973	1975	1980	1985
Arizona[a]	.0	0.1	1.1	1.1	2.9	10.0	13.0	13.0+
Montana[b]	1.0	3.4	7.1	8.2	9.9	19.8	41.0	74.0
New Mexico[c]	4.5	7.4	8.1	8.2	9.3	17.0	27.0	27.0+
North Dakota[b]	4.7	5.6	6.1	6.8	7.4	11.7	19.0	49.1
Wyoming[d]	4.6	7.2	8.1	10.9	13.6	22.9	87.0	140.0
Totals	14.8	23.7	30.5	35.2	43.1	81.4	187.0	303.0

[a]Forecast by Arizona Bureau of Mines, 1973

[b]Forecast by Northern Great Plains Resource Program (most probable), 1973

[c]Forecast by New Mexico State Bureau of Mines and Mineral Resources, 1973

[d]Forecast by Wyoming Geological Survey, March 1974

Source: Monsanto Research Corp., Evaluation of Low-Sulfur Western Coal Characteristics, Utilization and Combustion Experience, 1975.

Table 13

COMMONWEALTH EDISON
COAL FIRED GENERATING
STATIONS

Station	Estimated tons/year	Source of Coal
Fisk	720,000	Montana and Wyoming
Crawford	930,000	Montana and Wyoming
Waukegan No. 1	2,131,000	Illinois, Kentucky, Wyoming, and Wisconsin
Joliet	3,819,000	Illinois and Montana
Powerton	1,114,000	Illinois and Montana
Dixon	291,000	Illinois, Indiana, Kentucky, Wyoming, and Wisconsin
Stateline	2,192,000	Illinois, Indiana, Montana, and Wyoming
Total	11,197,000	

Source: Monsanto Research Corp., Evaluation of Low-Sulfur Western Coal Characteristics, Utilization and Combustion Experience, 1975.

include the 2.2 million tons per year of coal produced by Arch Mineral (4). The amount of western coal which may become available between 1975 and 1977 is difficult to project because of the financial, environmental, and equipment constraints discussed. Presently, demand exceeds the available supply of western coal. Expansion is anticipated, but the explicit commitments to western coal usage are needed at least two years in advance of obtaining any large supply of western coal.

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