Technical Publication

Latest Equipment and Design for New Coal Fired Plants and Conversions to Increase Fuel Flexibility

by

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LATEST EQUIPMENT AND DESIGN FOR NEW COAL FIRED PLANTS AND CONVERSIONS TO INCREASE FUEL FLEXIBILITY

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INTRODUCTION

The following paper updates and includes the paper, "Latest Equipment and Design for New Coal Fired Plants and the Conversion of Existing Plants to Coal Firing" by Paul F. Seibold, Project Manager, Maintenance & Repairs Division and Robert D. Bessette, Sales Engineer, Midwest Regional Office, Riley Stoker Corporation, Worcester, Massachusetts, presented at the Industrial Fuel Conference at Purdue University, October, 1976. Our aim is to shed more light on the application of the equipment and the design parameters contained herein. We will demonstrate these parameters regarding today's insight into coal availability as it reflects the flexibility of operation and fuel usage within each plant environment.

The aforementioned paper can be used as a base or primer when considering coal as a primary industrial fuel for existing coal facilities or when converting from other fuels. The prices quoted herein are based on 1976 dollars and should be escalated to obtain current prices for budget purposes.

STOKER FIRING

Furnace designs should be based on the primary coal, but consideration should be given to slagging and fouling tendencies of the worst coal that may be used. It must be noted that it is not practical to design boilers to efficiently burn coals of extremely different characteristics such as high rank Eastern bituminous versus low rank Western lignite.

Due to the wide variations in coal, feeder capacity should be given primary consideration with regard to maximum feed requirements. This, in conjunction with coal feeder to width ratio, should be considered in selecting coal feeder arrangements.

PULVERIZERS

Boilers, for pulverizers, as for stokers, should be designed around the primary coal, but considerations for slagging and fouling as well as grindability and moisture of the worst coal have a greater effect on boiler design with regard to fuel flexibility. For greater flexibility of pulverizer operation, design should be based on 40 Hardgrove grindability even though the base coal has a higher grindability.

In concluding these introductory remarks, industry is taking a more active look at coal as a primary fuel. Industrial coal production is increasing to meet the demand. There must be more consideration of coal as it effects equipment design and of equipment as it effects fuel use flexibility. Needless to say these work hand in hand, however, boiler and fuel burning equipment design must be based on a primary coal analysis.

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INTRODUCTION

Thinking back on what has been said regarding energy, conservation, availability, and the number of new organizations that have been created for the purpose of improving our energy outlook, it is a foregone and almost worn out conclusion that coal will be the industrial fuel of the next thirty years. This is plainly evident when we look at Figure 1.[1]

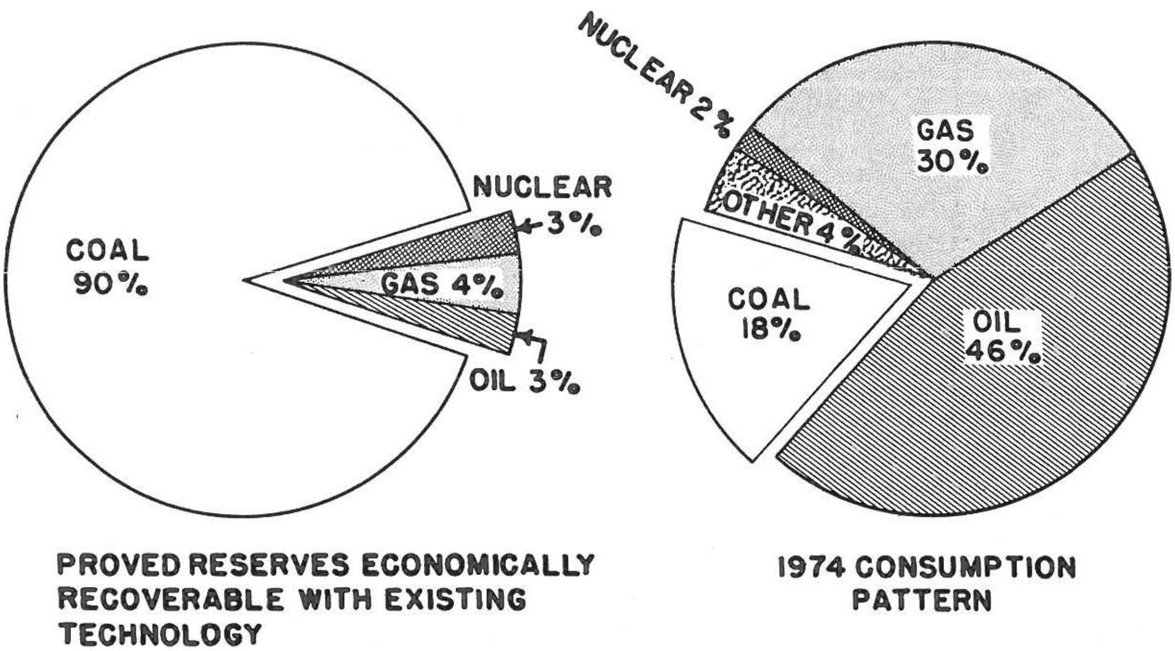

Figure 1 Proved Reserves vs. Consumption Pattern

When available supplies are used in such a disproportionate way, there is poor energy and economic management, and hence the administrations, commissions, and regulations aimed at the effective and efficient use of world resources.

[1] National Executive Energy Summary Outlook 1976 by Federal Energy Administration U.S. Govt. Printing Office 1976 0-204-986

To improve our energy situation with regard to national priorities and the future, the proportionate use of available fuels must be adjusted considering current technology and national priorities. Looking at Figure 2 and realizing current technology, the alternate use of coal as a fuel for household, commercial, and transportation applications would have minimum impact on the overall proportionate use of fuels. Thus, the adjustment of economic management to solve fuel problems must begin with industrial users. The result is, then, that coal will be the most probable industrial fuel of our near future.

Keeping the above in mind and considering the ease with which industrial plants have operated with easily burned, clean, and available low-cost fuels, coal burning has been "on the back burner" of the old wood stove left for the old timers. A young engineer and engineers operating gas and oil fired powerhouses today have had little contact with coal burning and would have limited knowledge of the requirements. Where would he look and what would he ask to gain this knowledge?

This paper is written in an attempt to touch on the design, engineering, and economic considerations an engineer would have to make in considering coal as a fuel for new or existing industrial boilers. Through this paper, we will provide brief descriptions and references for stokers, pulverized coal firing, and air pollution control equipment. This will give the engineer direction in evaluation and selection of equipment, systems, or modifications, best suited to the individual application.

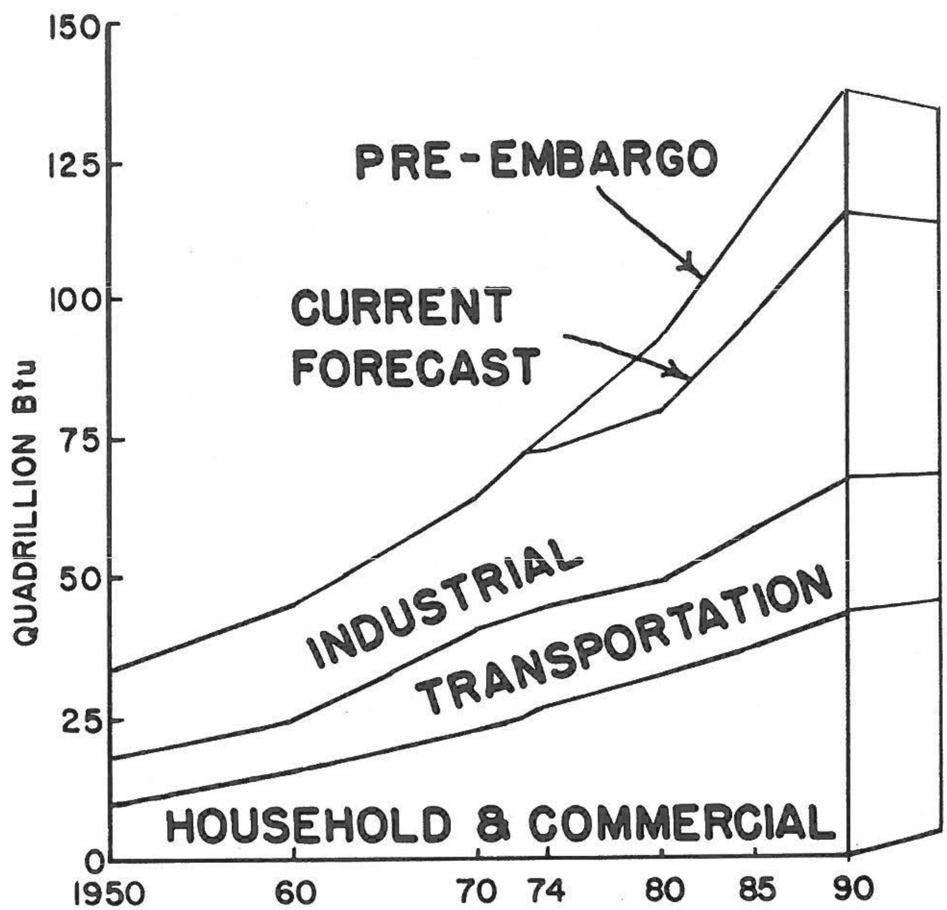

Figure 2 Consumption Trends

ASSUMPTIONS

1. Units considered 50,000 to 300,000 pph.
2. Natural gas not available except as pilot fuel.
3. Available coal is as received (50% less than 1/4" and not washed or screened more than once). Source and quality is the same for both pulverized coal and stoker firing.
4. There is no consideration of any proprietary difference in emission control equipment.
5. All costs or dollar evaluations are based on 1976 dollars.
6. Consideration is given only to the boiler proper and normally associated auxiliary equipment.
7. It will be assumed that control logic will be generated to suit the equipment selected. No attempt will be made to treat this subject.

PART I: STOKER FIRING EQUIPMENT

1930	1950	Today
75M pph*	150M pph*	300M pph*
Figure 3	Figure 4	Figure 5

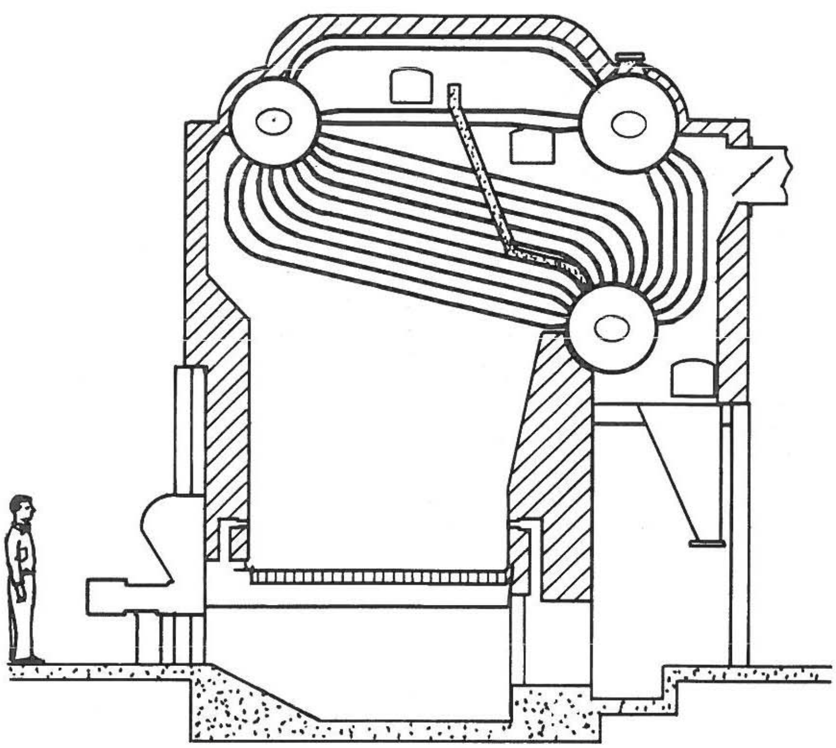

Figure 3 Typical Early 1930 Low Head Design, Boiler

*Approximate (see Part I).

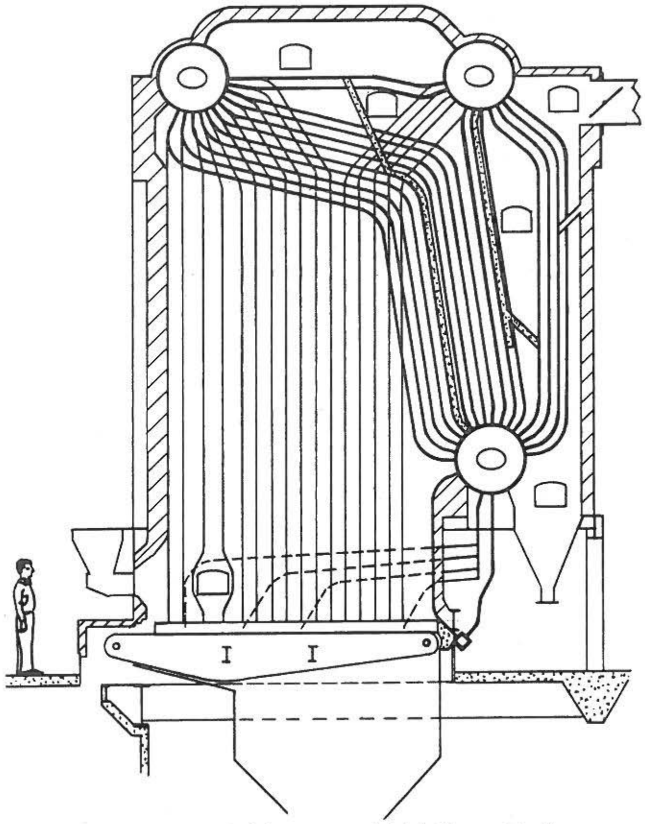

Figure 4 Field Erected 'A' Type Boiler

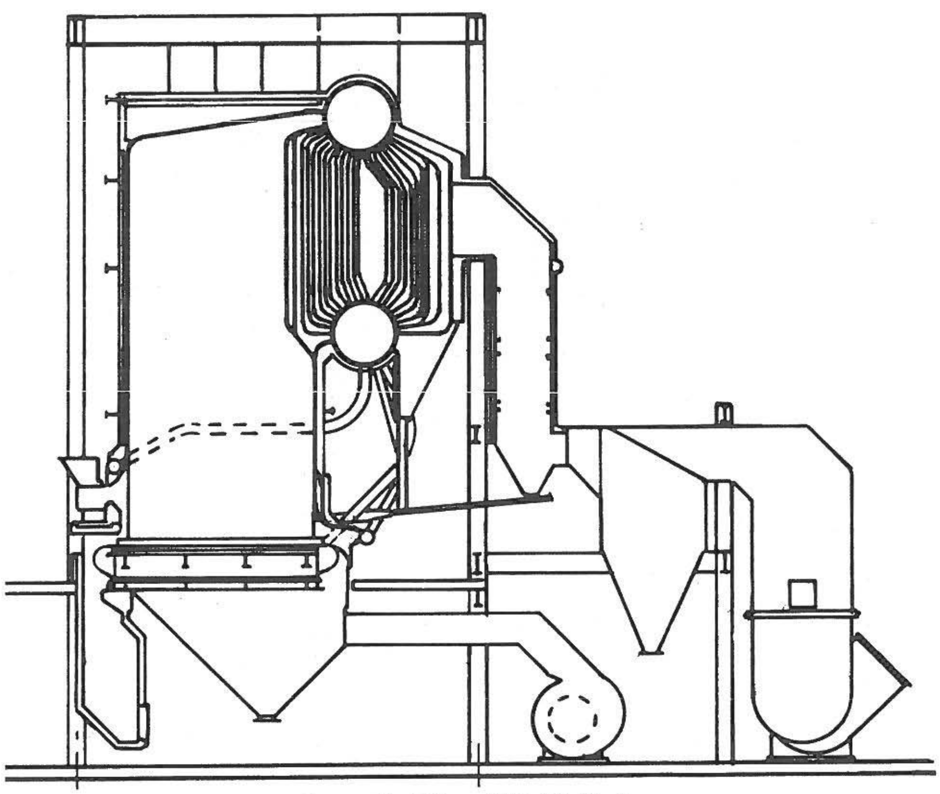

Figure 5 Riley VO-SP Boiler

As is evident in Figures 3, 4, and 5, the boiler industry has come a long way in industrial boiler design and technology, taking what is applicable from the utility boiler experience to provide better, more efficient, easily operable steam generators that are more available to meet the industry's growing needs.

Stoker-fired boilers have been the backbone of the industrial coal burning power equipment. Today, with the more stringent air pollution requirements and higher costs, pulverized coal is again making an appearance in the industrial market. However, there is, for the most part, a consensus that the stoker-fired boiler is the industrial users' boiler.

When considering coal burning and stoker firing, the following equipment available on the market should be discussed:

STOKERS

Traveling Grate Stoker or chain grate stoker of the Riley Harrington type, (Figure 6), is fed coal from a front mounted hopper and designed to efficiently burn fuels with a broad range of characteristics. However, today it is reserved for burning fuels such as anthracite, coke breeze, etc. Also, it is usually used on smaller units up to about 150,000 pounds of steam per hour. Boilers with base loads or loads that do not fluctuate rapidly can use this stoker. The change in firing rate of this stoker is slow and cannot follow rapid load changes.

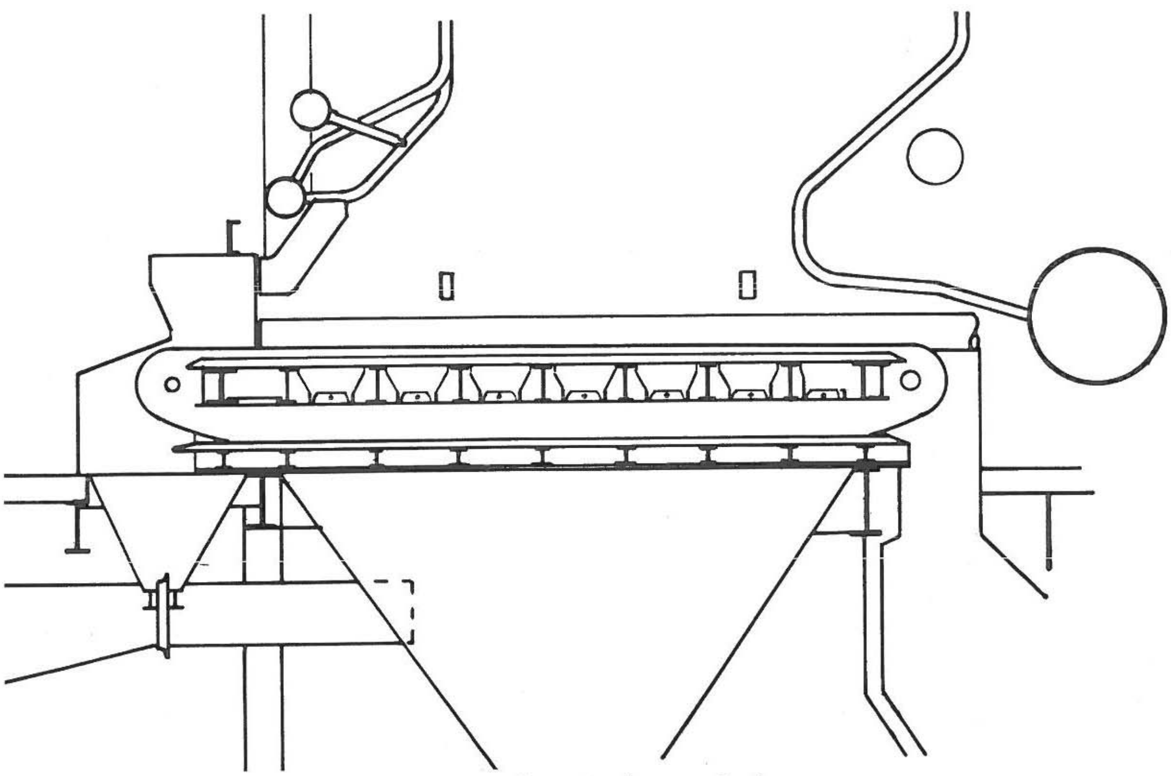

Figure 6 Riley Harrington-Stoker

Traveling Grate Spreader Stoker The traveling grate spreader stoker, (Figure 7), is the most widely used stoker for coal burning in industrial applications. Today, it is designed to handle most types of coal presently available to the industrial user. It can burn a much greater range of coals than the traveling grate-type stoker. Similar in design to the chain-type stoker as far as grate surface construction, it differs in that it has a distributing coal feeder, which throws coal over the bed and provides some burning in suspension. This degree of

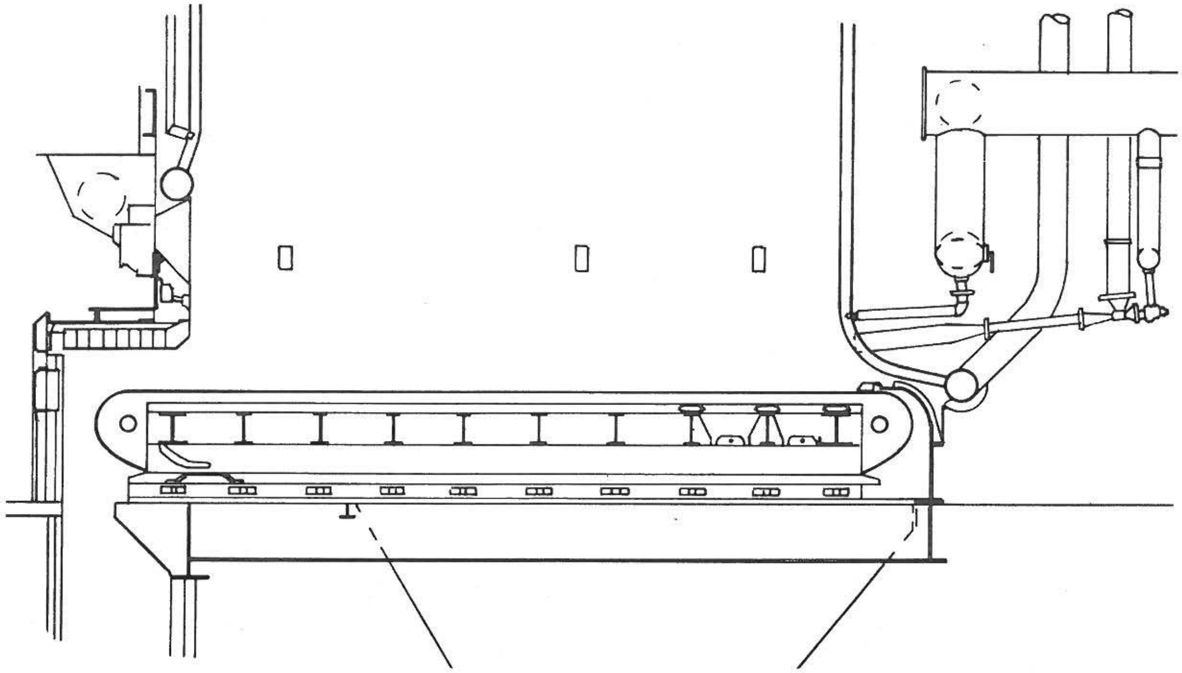

Figure 7 Riley Traveling Grate Stoker

suspension burning aids in following rapid load changes. Further discussions in this paper regarding stoker-fired boilers will be based on the Traveling Grate Spreader Stoker and discussed in more detail as we progress.

Oscillating Grate Stoker Some companies still manufacture the oscillating grate-type stoker, (Figure 8), for application on small units around 40M pph, which burn very low-ash fuels such as waste fuels, cellulose fuels, and some paper products.

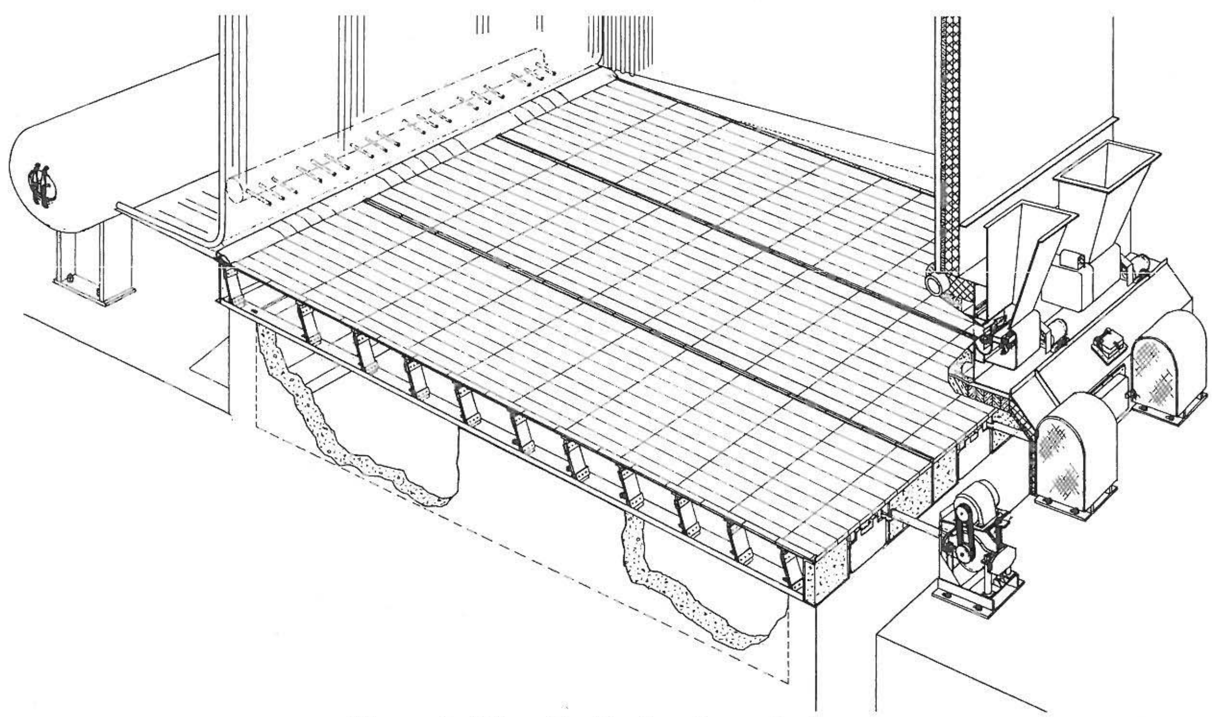

Figure 8 Riley Oscillating Grate Stoker

Coal Feeder Drum type feeder. The Riley Model F type feeder, (Figure 9), is an individually driven and controlled drum-type feed expressly designed for use with the traveling grate spreader stoker and provides uniform coal feed to suit operation over a wide range of coal characteristics such as high moisture and fines in coal as received today. The drum-type feeder provides positive, accurate metering of coal without avalanching or overloading the distributor. Anti-sifting provisions prevent overfeeding.

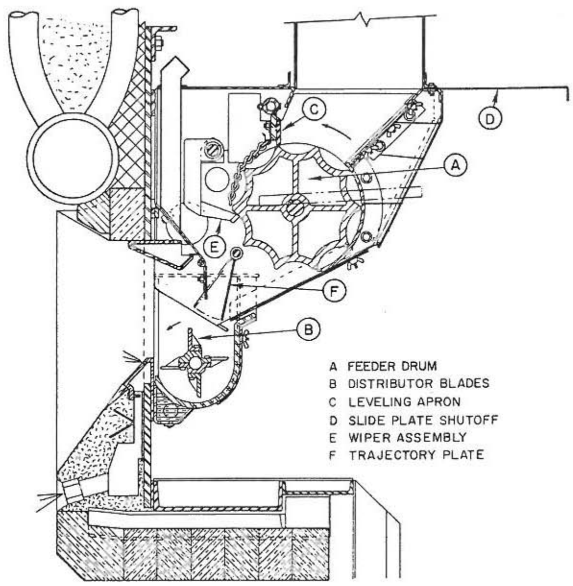

Figure 9 Riley Model 'F' Feeder

Chain type feeder - The chain-type feeder, (Figure 10), shears coal from the bottom of the coal hopper and feeds it to the overthrowing rotor. The coal feed rate is controlled by the speed of the chain and is usually designed for operation off a line shaft drive with linkages, clutches, and pulleys to provide individual feeder control. As with the above feeder, the chain-type was designed primarily for larger spreader-stoker-fired boilers.

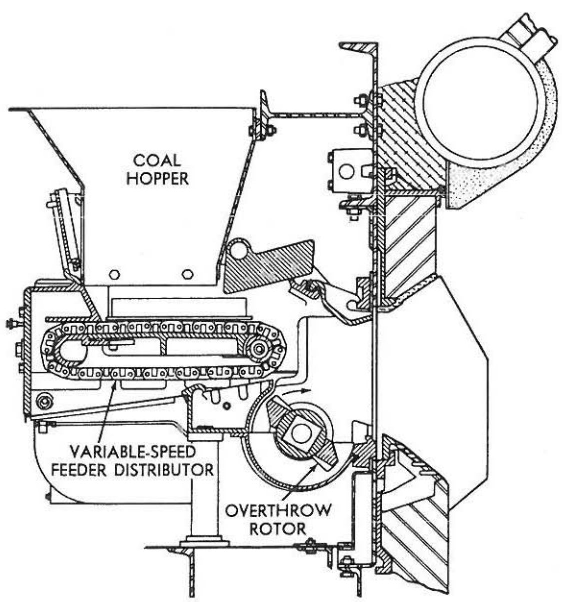

Figure 10 Variable Speed Chain Type Feeder

Reciprocating type feeder - The reciprocating-type feeder, (Figure 11), is a variable stroke feeder, which pushes coal onto the overthrowing rotor. This feeder has been around for many years and today is used, for the most part, on smaller units below 150M pph. This type of feeder can handle some of the wet coals with medium percentages of fines as found on the market today.

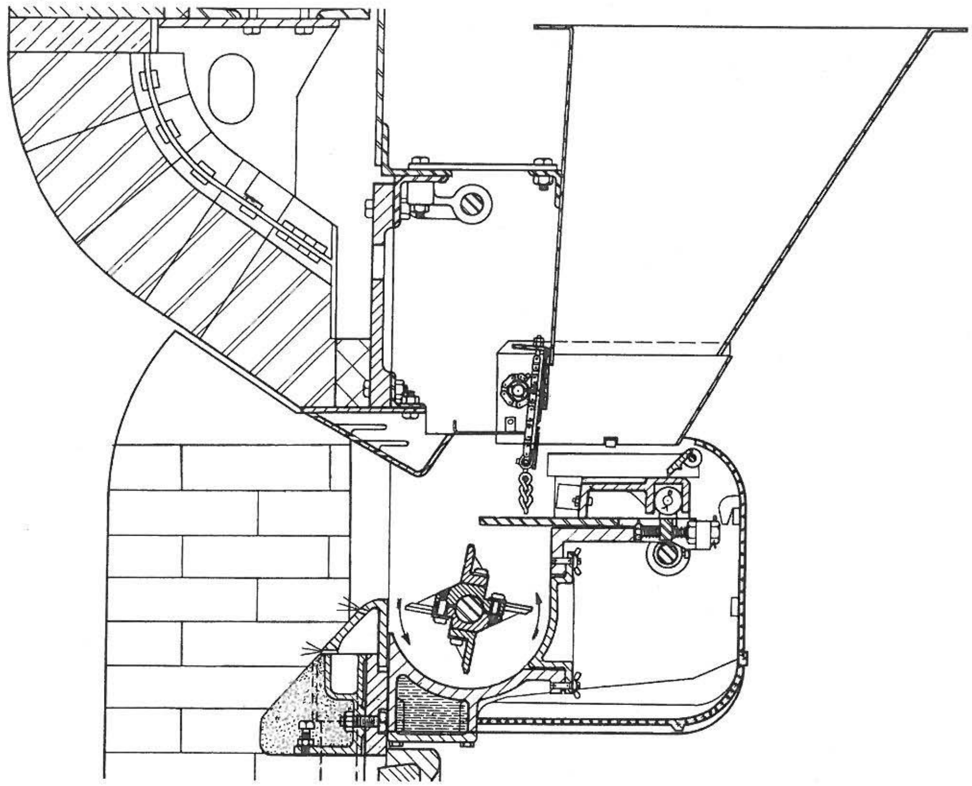

Figure 11 Riley Model 'B' Feeder

The traveling grate stoker and spreader feeder are probably the two most important pieces of fuel burning equipment that have to be considered when coal is to be burned.

Other pieces of equipment that should be mentioned in regard to the stoker are cinder and fly ash return, overfire air, fan, stoker drives (piston, hydraulic motor, or mechanical), boiler-stoker side and rear seals, air supply and siftings hopper, ash hopper, and conical distribution. These all play a very important part in the overall fuel burning equipment system.

STEAM GENERATING EQUIPMENT

Single Pass Boiler - Two basic types of boilers are available for stoker-fired applications: the top-supported single pass boiler, (Figure 5), and the bottom-supported multiple pass boiler. Of these two units, Riley has standardized on the top-supported single pass unit as the industrial coal burning boiler because of the following:

1. Expansion downward - drum remains in same relative position, minimizing expansion requirements for downstream piping.
2. Minimization of differential expansion between the furance and the convection section.
3. Minimization of the use of refractory and the elimination of baffles.
4. Incorporation of stoker and building steel with boiler steel, minimizing total steel and foundations.

5. Facilitation of the addition of multiple fuel firing, especially with the superheater.
6. Independent sizing of furnace and boiler bank to consider slagging and fouling with lower grade coals.
7. To facilitate the use of external downcomers which will definitely improve and maintain circulation.

Multiple Pass Bottom-Supported Boiler - The bottom-supported multiple pass unit is still offered by some manufacturers and has been around for many years. Figure 12 depicts a Riley bottom-supported tube and refractory-type boiler, which is primarily used for wood and bagasse fuel firing. Here, little consideration is given to slagging and fouling. There is a high ash carryover requiring very low velocities and mass flow to prevent tubes and baffles from erosion and there is a requirement for additional convection surface due to the lower heat transfer in the furnace. The furnace tubes are widely spaced with refractory tile behind them that is exposed to the furnace and is used to maintain high furnace temperatures to assist in burning the very high moisture fuels (40-60% moisture). The above characteristics are not normally associated with coal firing.

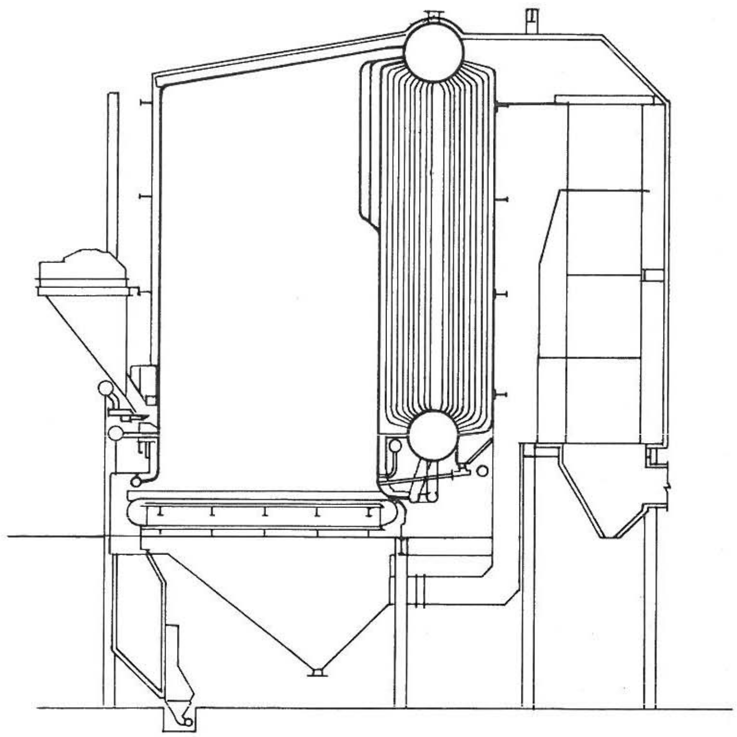

Figure 12 Riley Wood and Bagasse Fired Boiler

Auxiliary Equipment - Other equipment normally associated with the boiler are the heat recovery and emission control equipment. Heat recovery, economizers and air heaters, will be covered in a later section under Design Parameters, and a separate part will be devoted to the complete subject of Emission Control.

Stoker Fired Boiler Design Parameters - In order to understand the special requirements of coal burning in the stoker-fired boiler, the design parameters around which a boiler is built and operated must be discussed. We shall do so in the following paragraphs.

Coal Analysis - The key design parameter is the coal analysis, (ultimate analysis) as shown in a sample analysis, (Figure 13), with percentage of fines, free swelling index, and ash

TYPICAL FUEL ANALYSIS
FIGURE 13

1. PROXIMATE ANALYSIS – % (AS RECEIVED)	
a. MOISTURE	14.00
b. VOLATILE MATTER	31.16
c. FIXED CARBON	43.83
d. ASH	11.01
e. HIGHER HEATING VALUE, BTU/LB.	11,048
2. ULTIMATE ANALYSIS – % (AS RECEIVED)	
a. MOISTURE	14.00
b. CARBON	61.18
c. HYDROGEN	4.21
d. NITROGEN	1.24
e. CHLORINE	.30
f. SULFUR	2.95
g. ASH	11.01
h. OXYGEN (BY DIFFERENCE)	5.11
3. MINERAL ANALYSIS OF ASH – %	
a. PHOSPHATE PENTOXIDE, P_2O_5	0.25
b. SILICA, SiO_2	39.43
c. ALUMINA, Al_2O_3	15.63
d. TITANIA, TiO_2	0.83
e. FERRIC OXIDE Fe_2O_3	28.95
f. LIME CaO	10.99
g. MAGNESIA, MgO	0.68
h. POTASSIUM OXIDE, Ka_2O	1.99
i. SODIUM OXIDE, Na_2O	0.64
j. UNDETERMINED	0.61
4. ASH FUSION TEMPERATURES, F	
a. REDUCING ATMOSPHERE:	
(1) INITIAL DEFERMATION (ID)	1980
(2) SOFTENING (H=W)	2080
(3) SOFTENING (H=½W)	2120
(4) FLUID TEMPERATURE (FT)	2230
b. OXIDIZING ATMOSPHERE:	
(1) INITIAL DEFERMATION (ID)	2240
(2) SOFTENING (H=W)	2400
(3) SOFTENING (H=½W)	2430
(4) FLUID TEMPERATURE (FT)	2520
(5) T250	2180
5. GRINDABILITY - HARDGROVE INDEX	64.7

6. MOISTURE:
   a. THE AVERAGE EQUILIBRIUM MOISTURE OF THE COAL IS 14.0 PERCENT. THE NORMAL RANGE IS 8 PERCENT TO 20 PERCENT AS RECEIVED.
   b. ALL FUEL FIRING EQUIPMENT SHALL BE DESIGNED AT THE CAPACITIES SPECIFIED, WITH 12% SURFACE MOISTURE IN ADDITION TO 8% INHERENT MOISTURE.
7. SIZE: 100% THROUGH 1¼" ID RING.
8. AVERAGE DENSITY: 45 LBS/CU. FT.

Figure 13 Typical Fuel Analysis

analysis. From the ultimate analysis and information, the slagging and fouling characteristics of a coal ash can be calculated. These characteristics are used in the determination of sizing the furnace and convection section. The slagging and fouling characteristics are not necessarily a major factor in stoker-fired boiler design until lower grade fuels are considered for burning. Coal ash fouling also has an effect on convection tube spacing requirements.

Heat Release Rates and Exit Temperatures - With the above fuel analysis information, the boiler can be selected in general by using the stoker-fired boiler design parameters as indicated in Figure 14. When the grade of coal improves, or the slagging and fouling characteristics improve, the design release rates can be increased allowing for a less conservative boiler. Grate surface release rates will remain relatively constant. Variation in grate surface release rates will affect the maximum turndown possible with the unit. Higher release rates at maximum continuous load up to maximum grate release rates of 750M BTU per sq. ft. per hour will provide for the greatest possible turndown. Heat release rates above the allowable will result in excessive carryover of fly ash.

STOKER FIRED BOILER DESIGN PARAMETERS

FIGURE 14

(MCR) AT MAXIMUM CONTINUOUS RATING	MID-WEST COAL	LIGNITE SUB-BITUMINOUS	CELLULOSE FUELS
FURNACE VOLUME RELEASE RATE K BTU/CU.FT./HR.	18-35	15-20	25+
FURNACE PROJECTED SURFACE[1] RELEASE RATE K BTU/SQ.FT./HR.	60-75	MAX. 70	MAX. 100
FURNACE OR SUPERHEATER EXIT °F	1900	1700	1800-2000
ECONOMIZER EXIT TEMP. °F	350 MIN.	330 MIN.	300 MIN.
GRATE SURFACE RELEASE RATE MAX @ MCR MIN @ MCR MAX @ 2 HR. PEAK BTU/FT^2 GRATE/HR.	750,000 625,000 850,000	SAME	SAME

[1] ASME STANDARD PRACTICE

Figure 14 Stoker Fired Boiler Design Parameters

Feedwater Temperature - Feedwater supplied in the industrial plant not burning coal is usually 220° F. Here, there are no major problems with corrosion and the heat recovery equipment. With the coal-fired boilers, sulfur in the coal creates the possibility of corrosion if the flue gases are cooled to below the dew point of flue gas. The use of 240° F feedwater, which can be delivered from either the existing feedwater supply system or a mud drum preliminary feedwater heater, will result in reduced corrosion problems. This will be discussed in more detail in the area of heat recovery equipment.

Carbon Loss and Fly Ash Reinjection - In recent years, there has been emphasis on efficiency and fly ash reinjection because stack discharge problems have become more evident. Fly ash reinjection increases dust loading to collectors and simply eliminating reinjection on existing boilers resulted in a reduced dust loading leaving the collector. In many cases, this resulted in compliance with pollution ordinances. Because of the rapidly increasing cost of coal, maximum efficiency is of prime interest. In spreader stoker firing, a great amount of carbon is carried out of the furnace, and if not returned, represents a "carbon loss" and thus reduced efficiency.

It is industry practice to reinject from the boiler bank and the economizer hopper on all stoker-fired units. This accounts for 30-35% total fly ash reinjection. The addition of a kicker plate at the economizer hopper outlet can provide for another 5-10% fly ash reinjection to a total maximum of 40%. Riley believes this to be the maximum reinjection that can be claimed for a single pass boiler configuration. This is also the maximum reinjection allowable without affecting the pollution control equipment design on the back end of the boiler. Any additional reinjection would be done partially or totally by a mechanical collector and would result in the addition of an electrostatic precipitator or other high efficiency dust collecting device.

The Industry-accepted carbon loss prediction is shown in Figure 15 "Carbon Loss from Stokers"[2] Carbon loss is a major factor in the efficiency of the spreader-stoker fired boiler. Consideration of carbon loss becomes an economic evaluation of efficiency gain so that a decision may be made on what equipment will be selected. This will be covered in a little more detail in the sample evaluation including Pollution Control Equipment.

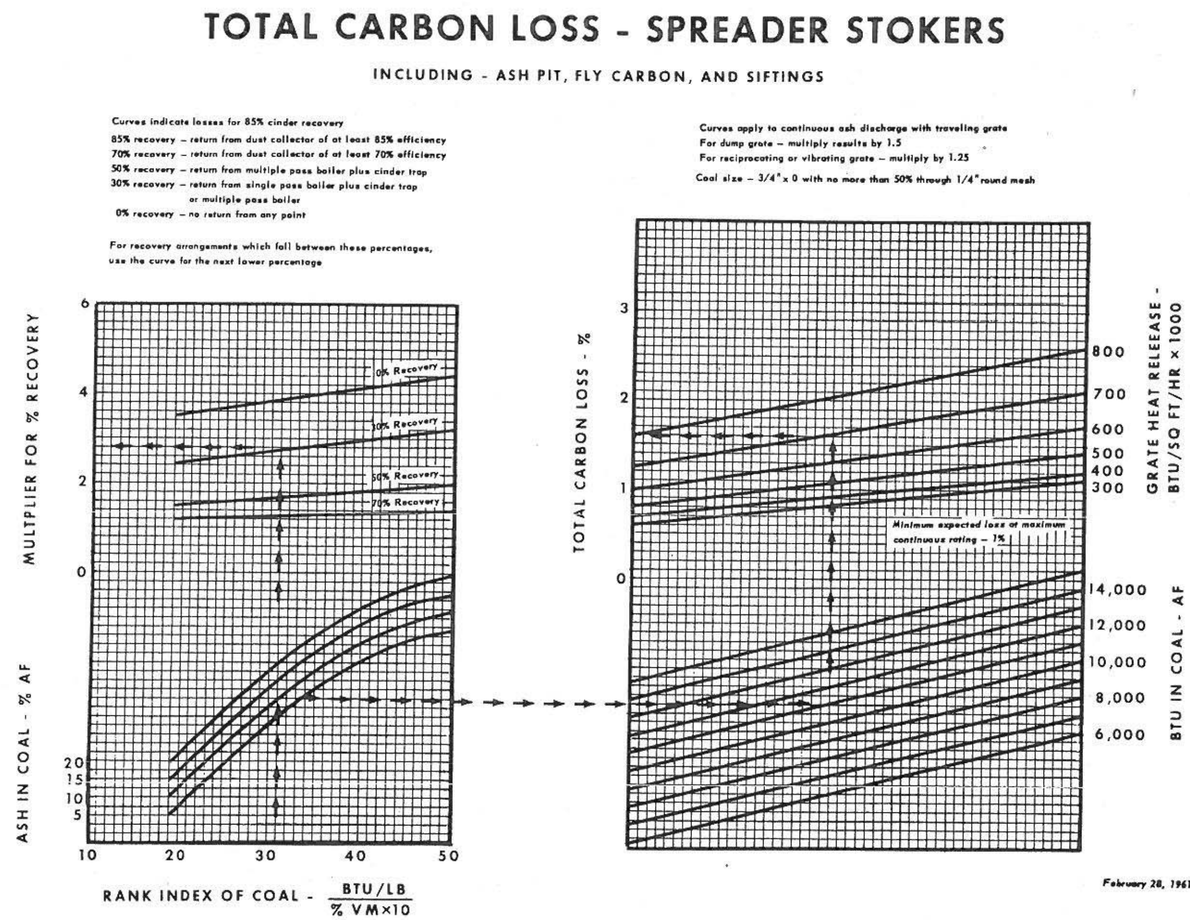

Figure 15 Carbon Loss From Stokers

Coal Sizing - Coal sizing must be considered in the design of the individual pieces of equipment. Equipment should be designed around the basic assumption that coal as received is 50% less than 1/4", not washed or screened more than once. Generally it is not washed or screened. An optimum coal size distribution range can be seen in Figure 16.

[2] Funk, Max O. "Carbon Loss from Stokers," presented at the American Power Conference, March 26-28, 1963.

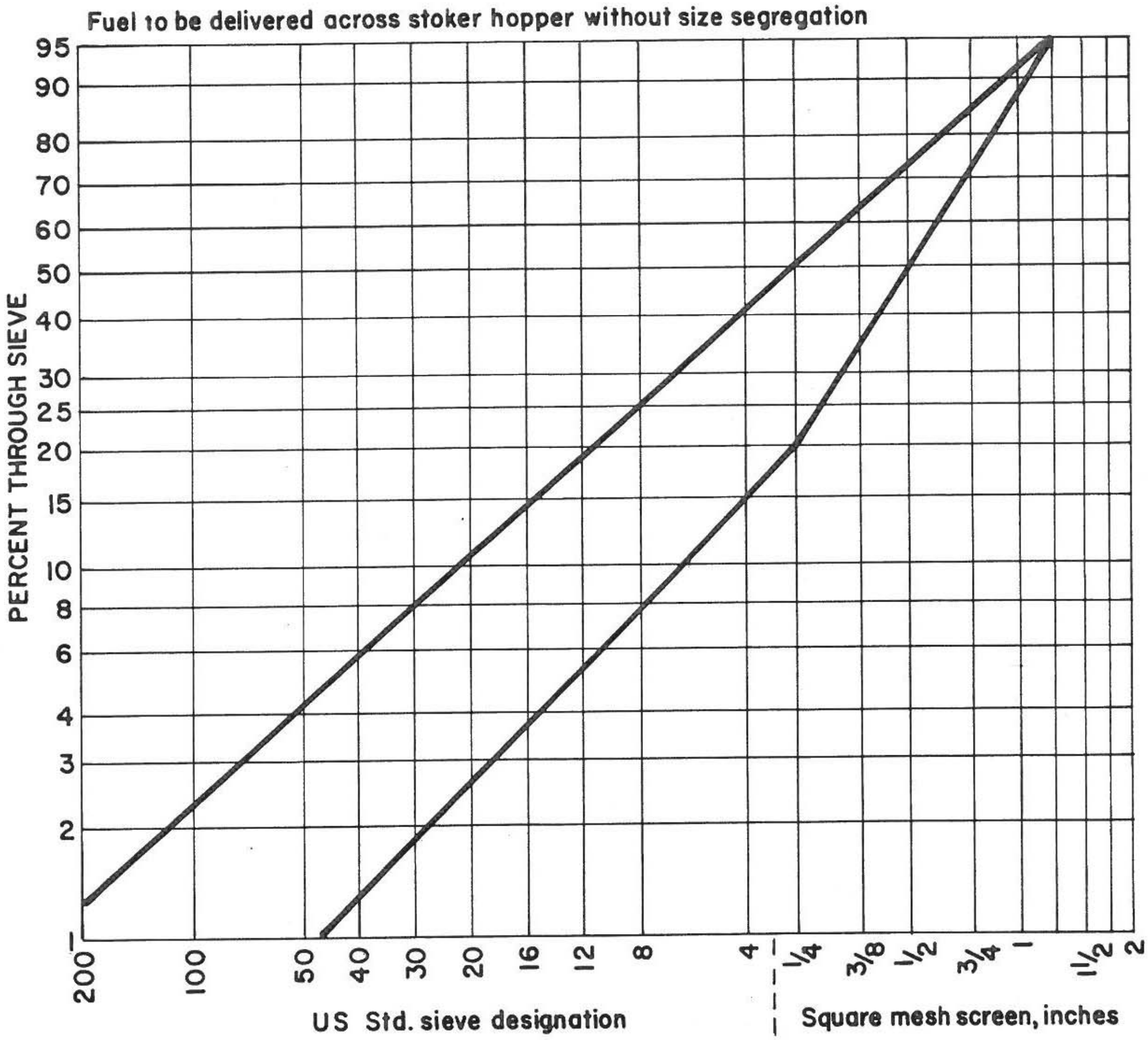

Figure 16 Coal Size Distribution Range

Coal Feeder-to-Stoker Width Ratio - Coal sizing is an important consideration in assuring even distribution of the coal over the entire stoker by the feeders. A general rule of design to insure even distribution is that total feeder width should be at least 40-50% of the effective stoker width.

Heat Recovery - Today very few medium and large industrial boilers are sold with no heat recovery equipment in the basic design. Heat recovery for the stoker-fired boiler consists of either an economizer or an air heater: in some cases, both.

Economizers - Economizers normally add 5-7% to the overall boiler efficiency with a minimum capital expense. Points that should be considered regarding economizers will be discussed briefly in the following two paragraphs.

It is general practice that economizers are designed and installed in front of the mechanical collectors, and if required, a feedwater bypass is used to prevent low load corrosion at the economizer outlet. The use of this arrangement also allows a higher concentration of fly ash particulate in the flue gases to help scrub the economizer and keep it relatively clean with minimum erosion.

There are two main design parameters for use in incorporating an economizer into the boiler system. First, the economizer water outlet temperature must be at least 35° below the boiler drum saturation temperature for units of 450 psig operating pressure or below. The economizer water outlet temperature for units operating at higher pressure should be at least 50° below the boiler drum saturation temperature to guard against having a steaming economizer. Second, a 350° F flue gas economizer exit temperature should be used to allow for low load operation without reaching the flue gas dew point. As mentioned earlier, a feedwater temperature of 240° F provides additional protection against reaching the dew point temperature.

Air Heaters - Air heaters are not normally used with stoker-fired boilers because of the added horsepower requirements, duct work costs, arrangement, and limited maximum air temperature to the stoker. Because of the limits of air heater exit air temperature, an air heater will not always develop optimum efficiency from a stoker-fired boiler. In some cases, an air heater is a definite application when the burning of lower grade coals or the burning of very high moisture (40-50% moisture) fuels are considered. In these cases, an economizer is often added to increase the overall efficiency of the unit.

ADVANTAGES AND DISADVANTAGES OF STOKER-FIRED UNITS COMPARED WITH PULVERIZED-FIRED COAL UNITS

Advantages:

Lower Cost

Lower particulate carryover with a larger percent of particles greater than 10 microns

Simplified particulate removal equipment

Generally requires less overall space

Lower horsepower requirements

Lower maintenance and wear

Less sophisticated auxiliary equipment and controls

Less skilled labor requirements. Not necessarily skilled boiler operators.

Disadvantages:

Efficiency 4-7% lower

Limited coal size flexibility

Limited load swing and pickup capability

Higher excess air.

PART II: PULVERIZED COAL FIRED UNITS

1930	1950	Today
170M pph*	260M pph*	Unlimited
Figure 17	Figure 18	Figure 19

The above Figures 17 and 18 are units normally associated with old electric utility companies. However, many industrial users operated pulverized coal units during this time, also. In the range of boiler sizes considered for this paper, Figure 19 shows a sketch of what might be a typical 200,000 PPH unit for an industrial plant today. Different boiler designs will be discussed in more detail later.

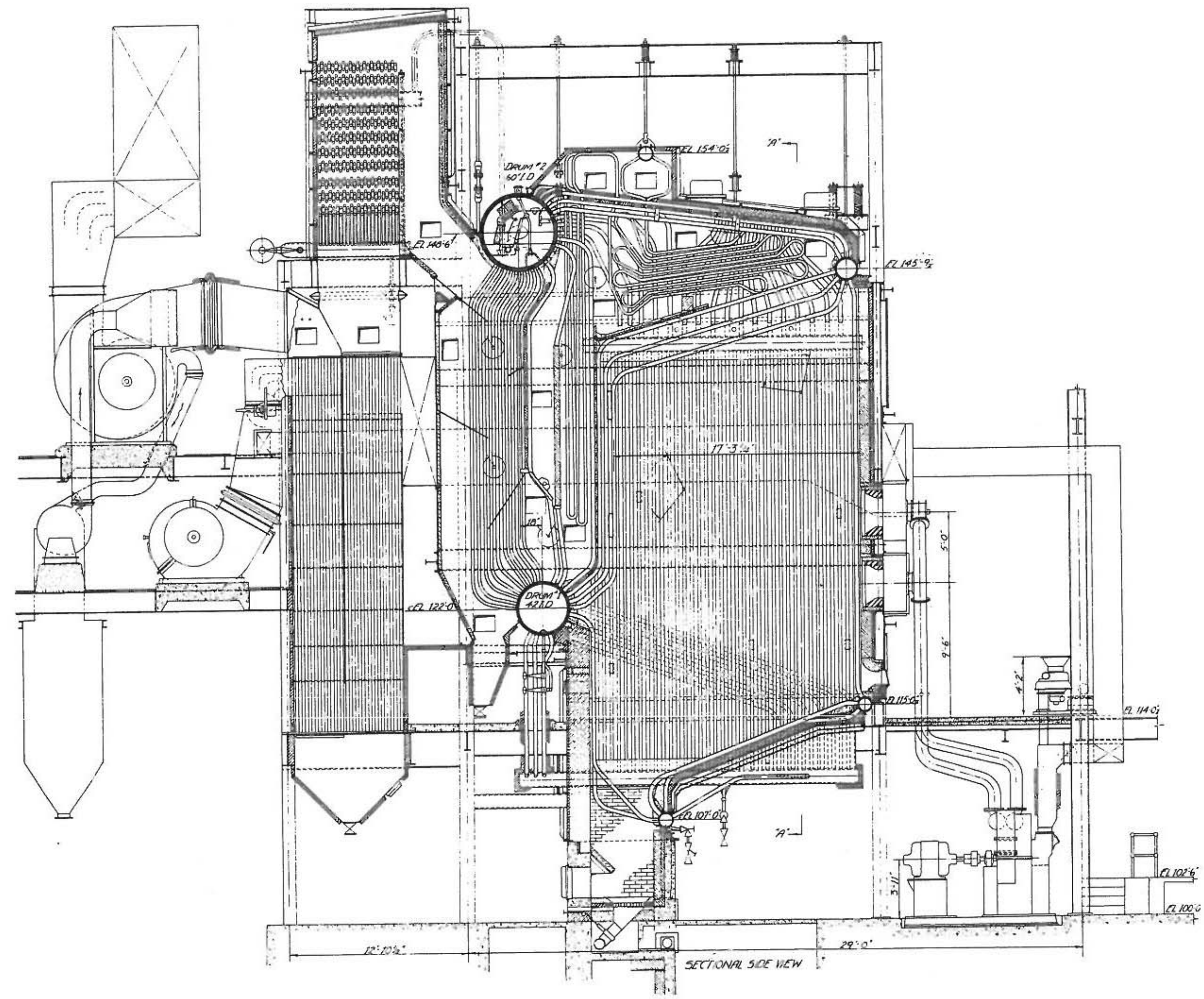

Figure 17 Riley 170,000 lbs/hr. Coal Fired Utility Boiler

* Approximate unit size available during this period of time.

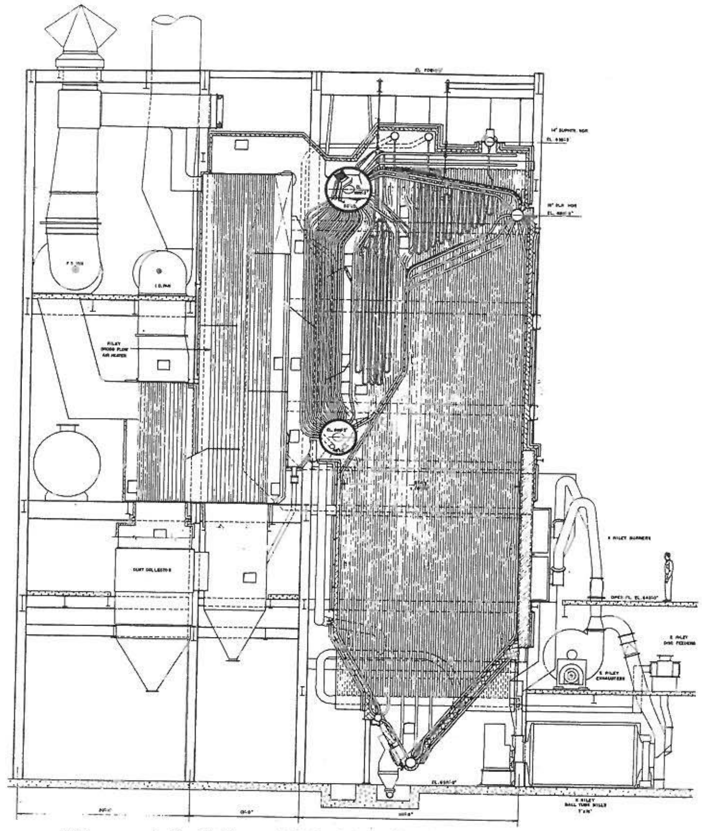

Figure 18 Riley 230,000 lbs/hr. Utility Boiler

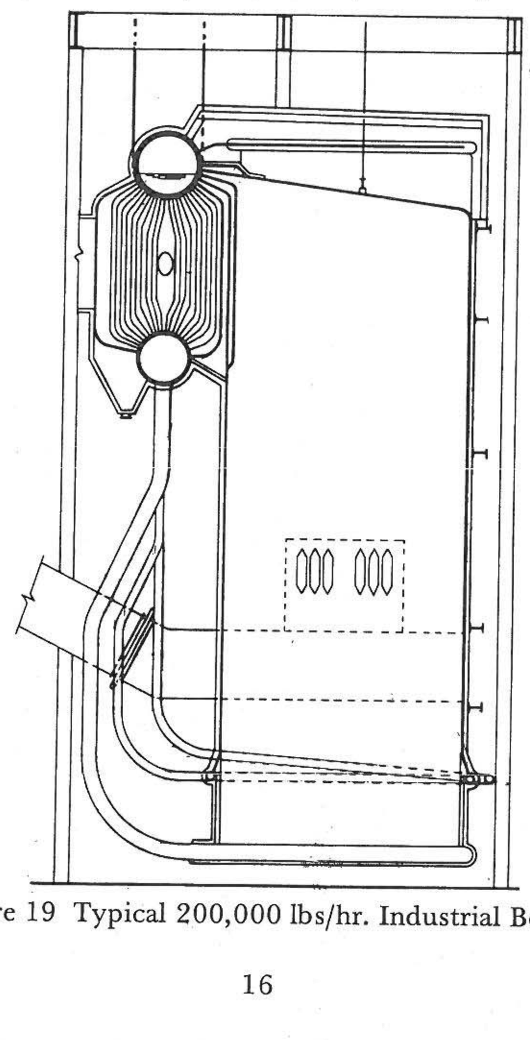

Figure 19 Typical 200,000 lbs/hr. Industrial Boiler

An interesting note that might be included here is that pulverized coal firing has normally been associated with the utility industry since the first pulverized coal unit was bought by a utility. Despite the fact that larger units could be manufactured using pulverized coal firing, it is felt that the reason for utilities' having selected pulverized coal firing in the 20's and 30's was availability.

Since most of the fuel burning (pulverizers) equipment was outside the boiler, unlike the stoker, a malfunction in the fuel burning equipment, not necessarily including the burners, did not require shutting down the complete boiler. When using stokers in the 20's and 30's, unlike today where the stoker is a relatively trouble-free piece of equipment, a malfunction would mean a complete boiler shutdown. A utility company could not afford this. The industrial user, at that time, had some flexibility with boilers and availability was not a prime concern.

There have been many changes in attitudes, philosophies, and motivating design criteria leading to today's present designs. When the industrial user, or anyone, is considering the purchase of a boiler or other comparable equipment, there are five considerations that tend to prompt a decision on which equipment will best suit the specific application:

1. Capitalized Costs
2. Fuel and Labor Costs
3. Efficiency
4. Availability
5. Pollution Control Requirements

Stoker-fired boilers have maintained their position as the industrial boiler; however, in recent months with fuel costs and efficiencies having a much higher priority in the industrial buying mind, pulverized coal firing has been a very viable consideration in the larger industrial units approaching the Federal EPA regulation size range of 250,000,000 BTU per hour input and larger. Since pollution control regulations have affected the evaluated position on larger units, the pulverized coal versus stoker evaluation has been a much more difficult one. In some cases, pulverized coal is a justifiable answer to some specific industrial applications.

EQUIPMENT

As covered under Stoker Part I, equipment and considerations will be covered under Part II, followed by Pollution Control in Part III.

Feeders - Much like stokers, there are two basic pulverized coal system feeders, the drum feeder and the belt weigh type feeder.

Drum-Type Feeder - The drum-type feeder accurately measures and feeds coal by volume to the pulverizer, or crusher-dryer, if one is included in the fuel burning system. Figure 20 shows a drum feeder capable of handling very wet coals with high fines. The feeder has a motorized wiper blade, which scrapes each drum pocket to assure that accurate volumes are fed to the pulverizer.

Belt Weigh Feeder - Figure 21 - The gravimetric feeder actually weighs the coal on a belt and feeds it to the pulverizer. This feeder is normally used when accurate metering of coal is desired for pulverizer operation in conjunction with boiler load demand.

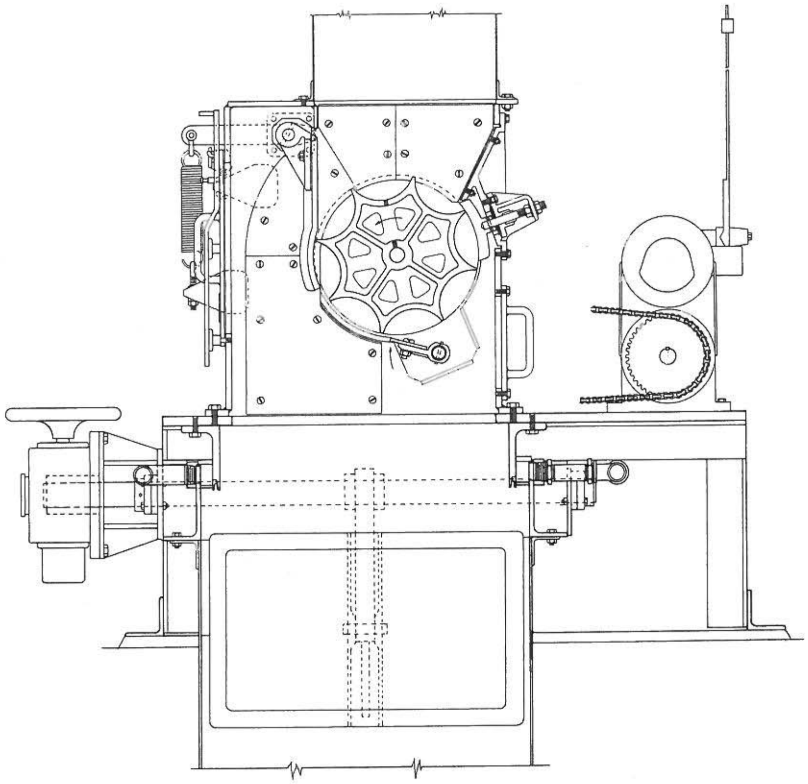

Figure 20 Riley Drum Type Feeder

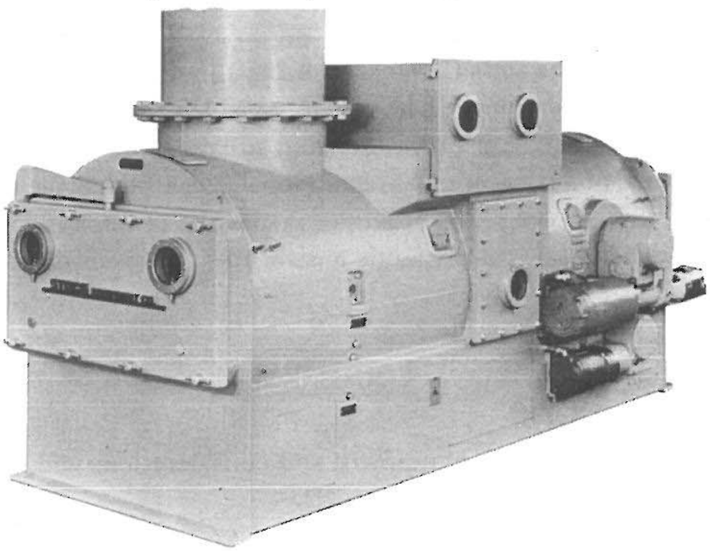

Figure 21 Gravimetric Type Feeder

Both of the above type feeders are equipped with magnetic separators for any tramp iron that might be mixed with the coal and create severe wear or malfunctions in the pulverizer.

Crusher-Dryers - On larger utility boilers, crusher-dryers are used to pre-dry the surface moisture, crush the coal to a relatively fine size, and also dry some of the inherent moisture before the coal reaches the pulverizer. This type of equipment, as shown in Figure 22, is adaptable to all types of pulverizers and is especially applicable when low grade or high moisture coals are to be burned. The crusher-dryer is usually located between the feeder and the pulverizer.

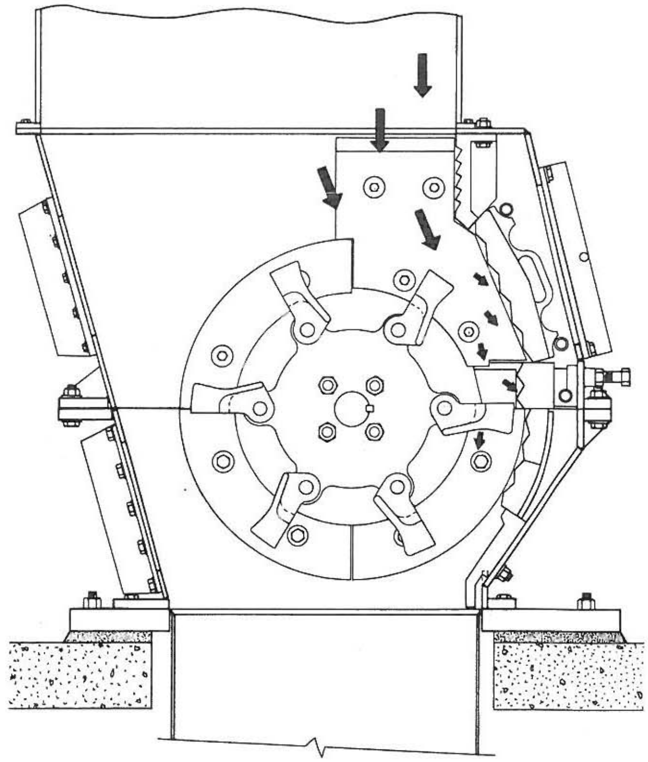

Figure 22 Riley Crusher-Dryer

Pulverizers - For the complete boiler system, the two most important parts are the boiler and the pulverizer. There are three main types of pulverizers which will be considered in this paper: high speed, attrition-type; medium speed, roller or ball and race type; and low-speed, ball mill-type pulverizers.

For the industrial application, the slow speed ball mills are very seldom used, since they are applied to larger utility-type boilers and are not usually manufactured for sizes compatible with the industrial boiler. Hence, only the attrition and medium speed mill will be discussed.

The industrial application is not as severe an application as the utility boiler, where downtime is an extreme cost factor. This is important regarding maintenance on the pulverizers. Utility boilers do not have periods of low load operation like an industrial plant, which might have to perform maintenance on one or more pulverizers. Thus, for the industrial plant with some available maintenance time, pulverizer systems are sized with two or more pulverizers (an exception being with the ball tube mill) for the maximum continuous load on the boiler, considering the worst coal to be burned.

High Speed Mills - Attrition-type mills such as the one shown in Figure 23, the Riley Atrita(TM) Pulverizer, pulverize coal by means of attrition. Coal passes through a crusher-dryer section, where it is pre-dried and crushed to a size not larger than ¼". This section also removes any tramp material (iron, etc.), which might have passed the magnetic separator. Coal passing from the crusher-dryer passes through a set of turning pins and stationary pegs, where it is pulverized and carried by primary air through the exhauster to a classifier, and then on to the burners. The attrition-type pulverizers have no interfacing of grinding elements; thus with the industrial possibility of low load operation, pulverizer wear is a func-

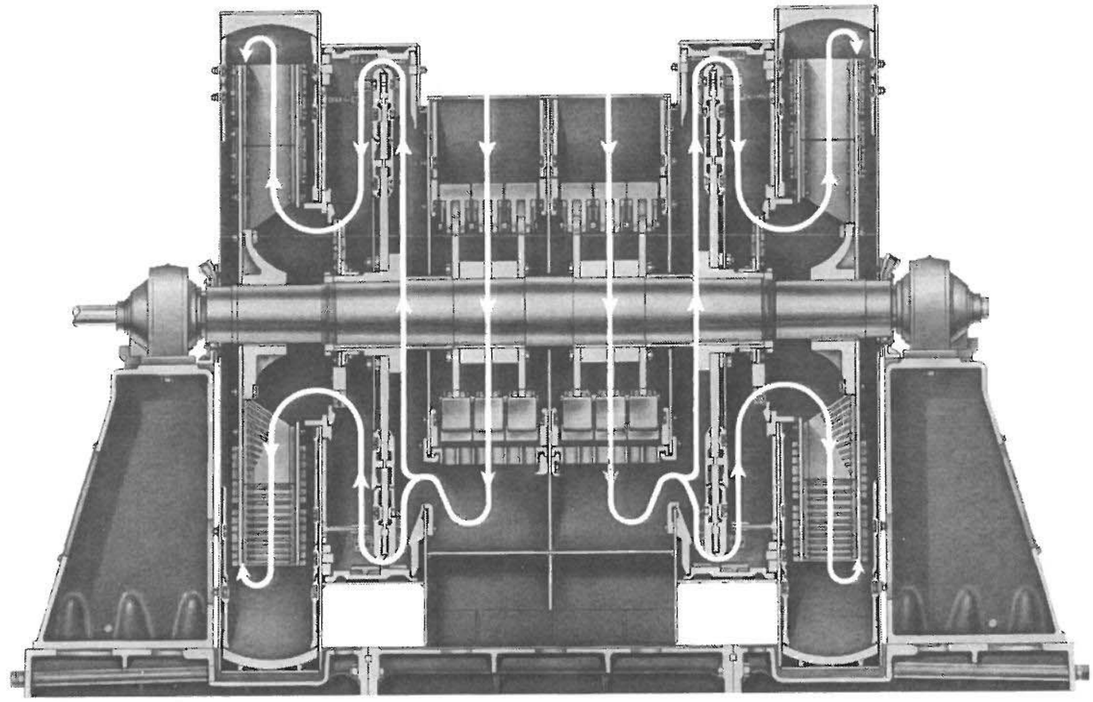

Figure 23 Riley Duplex Atrita Pulverizer

tion of coal throughput. The percent wear decreases as coal throughput decreases. Normal maintenance on this type of pulverizer can usually be accomplished within eight to ten hours, including the replacement of all pulverizing parts unlike the long maintenance time required for other pulverizers.

Medium Speed Mills - The ball and race mill, or bowl-type, mill (Figure 24) as offered for pulverized coal applications today, use the principle of contact to pulverized coal. The coal

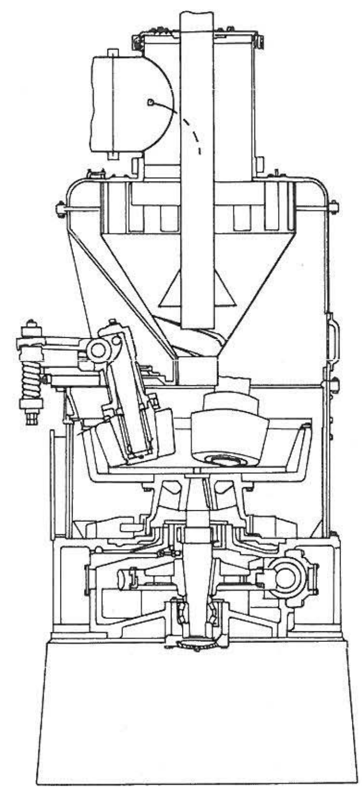

Figure 24 Bowl Type Pulverizer

is pulverized between two grinding surfaces rotating with respect to each other. Coal is ground between the two surfaces, then pulled by a separate exhauster through a classifier, and then moved to the burners. Air flow through the mill determines the coal quantities carried to the burners.

The above three types of pulverizers because of size, economics, and technology, are the pulverizers that would be considered for the industrial application. Although pulverizers are able to handle a wider range of coal sizing than the stoker-fired boilers, the coal quality must be much the same to minimize wear and pulverizer downtime. For the industrial pulverized boiler system, a washed coal would be best, especially if the coal would normally be high in clay, pyrites, and any other highly abrasive material. Increased wear and cost of mill maintenance can be directly associated with a change in coal quality.

Auxiliary Pulverizer System Equipment

There are a number of other pieces of equipment that play an important part in the pulverized coal system:

Exhausters - As mentioned earlier, exhausters move the pulverized coal/air mixture from the mill, sending it to the burner. The exhauster can be either a separate or integral piece of equipment with the mill.

Classifiers - Classifiers can be either before or after an exhauster. The classifier rejects uncombustible-sized coal back to the mill for further pulverization.

Burners - There are many different types of burners available today, each with a particular application to one or all boiler designs: circular flare-type burners, axial flow type burners for Turbo and tangential firing, Venturi-type burners for low excess air applications, and many more. A book could be written on this subject alone. The advantages of a given burner should be considered relative to the particular application.

Safety Systems - Pulverized coal mixed with air is a highly explosive mixture and must be considered like a gaseous fuel requiring the same explosion control system. The safety system sequencing and programming is made more complicated by the use of multiple burners, pulverizers, and the requirements for scanners to read both ignition flames and coal flames.

Steam Generators

With the last two years since pulverized coal has come to light again as a viable alternative to the stoker-fired industrial boiler, there have been many adaptations of utility experience to the market. There has also been the introduction of package pulverized coal fired boilers. For purposes of this paper relative to current experience in the package boiler field, the package pulverized coal burning boiler will be considered unproven technology and the paper will cover strictly field-erected pulverized coal burning equipment.

There are a number of units that are offered for pulverized coal firing; however, only three of these are generally offered for the industrial user: the old standard front fired unit, the opposed fired boiler, and the Turbo Furnace. Riley feels the range of boilers 200,000 pph or more, under special cases, can justify pulverized coal firing as the best alternative. Below this 200,000 pph range, the pulverized coal versus stoker evaluation becomes somewhat vague and subjective.

Front-Fired Boilers - Figure 25 depicts a front fired pulverized coal unit typical of one that could be offered for the industrial application. Note that the pulverized coal unit is basically a single pass design, similar to the stoker-fired unit profile. However, when very high pressures are requested above 1000 psig, a longer convection section is necessary because of additional required convection surface, and a bottom supported unit may sometimes be offered because of economics.

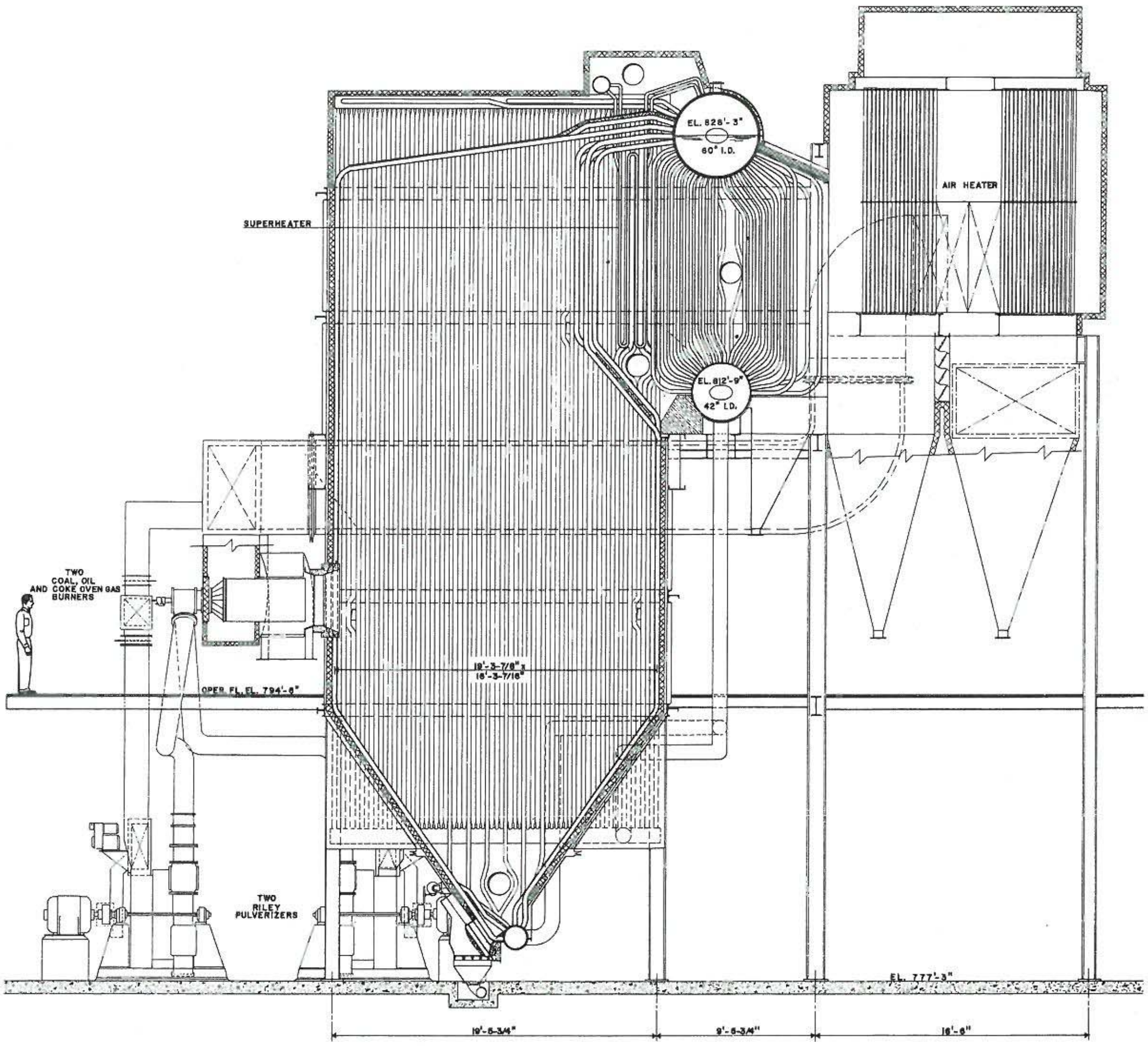

Figure 25 Riley Front-Fired Industrial Type Boiler

Care must be taken with the front-fired unit to minimize slagging and maintain even heat distribution across screen tubes and superheaters to maintain optimum gas and temperature distribution.

Opposed-Fired Boilers - An opposed-fired unit of the same basic design as a front-fired unit can be offered, allowing for some flexibility in design and arrangement.

Turbo® Furnace Boilers - Figure 19 is offered as an industrial boiler for pulverized coal firing because of its flexibility in alternate provisions for burning most any type fuels easily and efficiently while complying with NO_x regulations, which become a definite problem as the unit approaches or exceeds 250,000,000 BTU/hr input.

This furnace can be designed easily to accommodate pulverized coal firing with other fuels such as refuse processed for pneumatic handling, blast furnace gases, coke oven gases, waste oils, and many others. With the emphasis on fuel costs and efficiencies, industrial users are more than ever considering any waste product at its BTU value for possible burning as fuel. It should be noted that refuse burning in pulverized coal boilers might not be considered proven technology.

Auxiliary Equipment

Air Heaters - Air heaters are an integral part of any pulverized coal boiler design because of the requirement for hot primary air to the coal pulverizer. The use of an air heater also allows for the use of lower exit flue gas temperatures than economizers in initial boiler design because of air heater coal end material. This allows for an additional gain in overall unit efficiency. If a unit was to operate at maximum continuous rating (MCR) or close to MCR, the flue gas exit could be as low as 290° F uncorrected, in lieu of 350° for stoker-fired units. However, in this case, a steam coil air heater for the cold end of the air heater would be required to prevent corrosion at low load operation.

Sootblowing System - The pulverized coal-fired boiler, because of the method of burning coal, inherently has approximately 80% fly ash carryover. Some of this ash deposits as slag or sticks and fouls the convection banks. This requires a much more elaborate sootblowing system than the stoker-fired boiler, including furnace wall blowers, high temperature retractable sootblowers for screen tubes and initial convection tubes, and a system for sequential operation are almost considered mandatory for pulverized fired boilers. This sootblower system does not have to be as elaborate as a utility boiler's, and the sootblower manufacturers could be contacted to see what system would be best for the industrial application. In any case, the boiler manufacturer is the only party capable of sizing and selecting number of sootblowers and positions for adequate cleaning of the boiler to maintain efficiencies.

Other Equipment - Equipment such as F.D. fans, I.D. fans and drives, structural steel, ladders and walkways, and the normal complement of valves and trim are not much different from their counterpart on oil- and gas-fired boilers. These will not be discussed in any detail in this paper.

Pulverized Coal-Fired Boiler Design Parameters

This paper will discuss the design parameters for pulverized coal firing particular to the pulverized coal boiler in its design and operation. The following paragraphs will discuss some of these design considerations.

Coal Analysis - The design beginning of any boiler must be with fuel analysis, in this case, coal analysis as given earlier in Figure 13. When pulverized coal firing is considered, ash fusion temperature and coal grindability are also necessary before design can begin.

Although fines are a problem with stokers, this is not so with the pulverizers; however, coal quality, amounts of clay, sand, pyrites, and other abrasive materials are important with respect to pulverizer maintenance, wear, and malfunctions. An actual cost sample survey could be advantageous to facilitate the design of a pulverizer system for a particular application.

Heat Release Rates and Exit Temperatures - Once the slagging and fouling characteristics of the coal are calculated and compared with ash softening temperatures and the base-to-acid ratio, a determination is made of how the coal will react when burned in the boiler. The worse a coal is determined to be, the more conservatively a boiler is designed. Figure 26, like Figure 14 for stoker-firing, gives the range of heat releases and temperatures of design for a given fuel depending on its burning and ash characteristics.

AT MAXIMUM CONTINUOUS LOAD	MIDWEST COAL SLAGGING HIGH — LOW	LIGNITE & SUB-BITUMINOUS SLAGGING HIGH — LOW
VOLUMETRIC RELEASE BTU/FT^3/HR.	12,000 – 21,000	10,000 – 16,000
PROJECTED RELEASE* BTU/FT^2/HR.	60,000 – 75,000	55,000 – 70,000
FURNACE EXIT °F	1900	1700
AIRHEATER EXIT TEMP. °F		
MINIMUM	290	290
NORMAL	310	310

* PROJECTED SURFACE PER ASME CODE.

FIGURE 26

PULVERIZED COAL DESIGN PARAMETERS

Feedwater Temperatures - Boiler manufacturers would like to see feedwater temperatures of 240° F for the pulverized coal-fired boiler; however, this is not always possible. With the pulverized coal unit - air heater and no economizer, the feederwater temperature is not as critical and 220° F feedwater would be suitable for normal operation in units with pressures of up to 450 psig. For units with higher pressures, higher feedwater temperature would be desired.

Oxides of Nitrogen - In the industrial boiler sizes where pulverized coal is a most definite alternative, NO_x must be considered as a problem in units with over 250,000,000 BTU input, as well as a potential problem for units approaching that size. Consideration must be given to unit design for low NO_x firing, excess air requirements, addition of overfire air and off-stoichometric firing if conditions are such (high fuel nitrogen, burning time and temperature) as to produce NO_x.

Air Heater - It is most important with coal as a fuel to consider cold end temperatures (See Figure 26) and air heater materials as well as sootblowing. Air heater leakage and corrected and uncorrected temperatures must be determined relative to the economics of degree temperature removed from the flue gases and potential corrosion. A recovery of 40° F from the flue gases equals about 1% efficiency savings. A cold end steam coil air heater is usually supplied with air heaters on industrial boilers because of the possibility for low load operation.

Particulate Carryover - With Pollution Control Laws becoming more and more rigid, it is important to remember that approximately 80% of the ash from a pulverized coal fired boiler is carried through the boiler as fly ash, and 45-50% of that is less than 10 microns in size. This requires special consideration and the use of sootblowing systems and electrostatic precipitators, or other high efficiency collector systems to handle the fly ash.

Mill Exit Temperatures - Under most circumstances, and with most mills, a mill exit temperature range from 140° F to 180° F is desired to assure dry coal for combustion. This temperature is obtained by different methods with different mill systems and provides the basic information required before selection of the primary air temperature and control.

Coal Pipe Velocities - When using pulverized coal as a fuel, it is imperative to assure that coal pipe velocities are not below 3000 ft. per minute in any straight run of pipe. Lower velocities will result in coal drop-out, the possibility of fires, and plugging.

PART III: EMISSIONS, EMISSION CONTROL, AND REGULATIONS

Within the last five years, tremendous pressure has been exerted on all people in industry to stop pollution. Today, we have not reached the realistic "Aristotle's golden mean" for this subject and thus most of our pollution control regulations are in a state of flux. This part will try to present a brief overview of the implications of pollution control on the discussions regarding boiler selection and design relative to particulate and SO_2 removal to meet current codes.

Particulate Removal - New units above 250,000,000 BTU input must comply with the Federal regulation of .1#/million BTU input particulate emission. For units designed below the 250,000,000 BTU range, state codes prevail and, in some cases, emissions of .3 to .6#/ million BTU input are allowed. The following equipment listed in an order of what is felt to be industry preference will detail, in general, what equipment is applicable to either pulverized coal or stoker units, as well as some general considerations for their application:

Mechanical Collectors - The mechanical collector, the most popular piece of pollution control equipment, has been around for many years and maintains its position through further development of high efficiency collection capabilities that are applied to stoker-fired boilers. This piece of equipment is the least expensive means of meeting local pollution control requirements of .3 to .6#/million BTU emissions providing not more than 25% of the total fly ash flue gas loading is below 10 microns in size.

Development and technology have shown that the use of one or two dust collectors in a series is sufficient to meet the local pollution requirements for spreader stoker-fired boilers. Mechanical collectors are not applicable to pulverized coal-fired boilers or cases where pollution control requirements are below .3#/million BTU emissions.

Cold Electrostatic Precipitators - The Cold Electrostatic Precipitator (CEP) is applicable to all stoker-fired boilers burning any coal and to pulverized coal-fired boilers burning coal with above 1.5% sulfur as received. The reason for this 1.5% sulfur cutoff in pulverized coal units is that there is not enough carbon in the fly ash to counteract the low sulfur properties of coal in the CEP. Precipitators are applied when the control code is below .3#/million BTU emissions or there is a greater than 25% of the fly ash below 10 microns.

Precipitators are usually very large and costly compared to mechanical collectors. Because of this, stoker-fired boilers with electrostatic precipitators are usually supplied with a mechanical collector approximately 70% efficient to recoup some carbon loss and help defer the precipitator cost within approximate 2 to 2.5% efficiency gain over a stoker with mechanical collector only. Precipitator manufacturers will guarantee 0.1#/million BTU emission for CEP installations.

Wet Scrubbers - A paper presented at the American Power Conference in 1975 indicated that wet scrubbers were preferred over other types of pollution control equipment.[3] Scrubbers are high efficiency particulate removers and are applied to boilers, pulverized coal or stoker, to meet codes of .1#/million BTU outlet emissions regardless of the sulfur content of the fuel. Materials of construction have been perfected today to cope with potential corrosions due to the very low PH observed with particulate removal only. The added advantage of the wet scrubber for particulate removal is the ability of the scrubber to be converted to handle SO_2 removal. Wet scrubbers are competitive with electrostatic precipitators; however, the disposal of the wet, very low PH effluent, may sometimes be a problem.

Hot Electrostatic Precipitators - The Hot Electrostatic Precipitator (HEP) is applied to pulverized coal burning boilers as the above CEP, with the exception that coal sulfur is below 1.5% as received. This precipitator is usually much more expensive, requires much more space, and provides for a very difficult arrangement with heat recovery equipment. This type precipitator is not normally offered with the industrial boiler.

Baghouses - Numerous papers have been written regarding the application of baghouses to boilers. A baghouse is a highly efficient collector applied when .1#/million BTU emissions are required. However, it seems most boiler manufacturers are somewhat skeptical in regard to their application. In any case, the application is gaining a more favorable evaluation.

Sulfur Dioxide Removal

Low sulfur coal, oil, and gas availability as mentioned in the beginning of the paper are not what might be called plentiful, and with the adjusting of priorities, increasing demand for clean fuels, and increasing prices, high sulfur coal will be a more available and used fuel.

When high sulfur fuel is used and emission codes are adjusted to realistic levels, sulfur will still have to be removed from flue gases. Today, there is only one effective way to remove sulfur from flue gas, and that is by the use of a wet scrubber.

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[3] Faught, Lyle E., Standard, Thomas A., "Wet Scrubbing for Particulate Removal on Industrial Boilers," presented at the American Power Conference, April 21-23, 1975.

At present, there is much controversy regarding the sulfur emission regulations between state and federal agencies, as well as between these agencies and industry. Until these controversies are settled, it is impossible to discuss specifics regarding the application of SO_2 removal to the industrial boilers in great detail, except for brief information regarding alternatives for scrubber application to the industrial market.

Two basic systems are available: the throwaway system and the sulfur recovery system. The latter is very expensive and for the industrial user, only justifiable on a very large scale. Therefore this paper will confine comments to the throwaway system as the more economical and applicable industrial system.

When considering a throwaway system, the ultimate end product is $CaSO_3$ and $CaSO_4$, which are disposable as a heavy sludge approximately 70% solid. The systems most applicable to the industrial needs today are lime, limestone, or the dual alkali system.

To try to cover any further detail will result in pages of explanation and background, which would be beyond the scope of this paper. However, for evaluation purposes, Figure 27 shows a budget cost for SO_2 removal systems relative to total system pounds per hour. This graph is based on lime or limestone as a base reagent, and approximately 10% would have to be added to the total capital equipment cost for consideration of a dual alkali system.

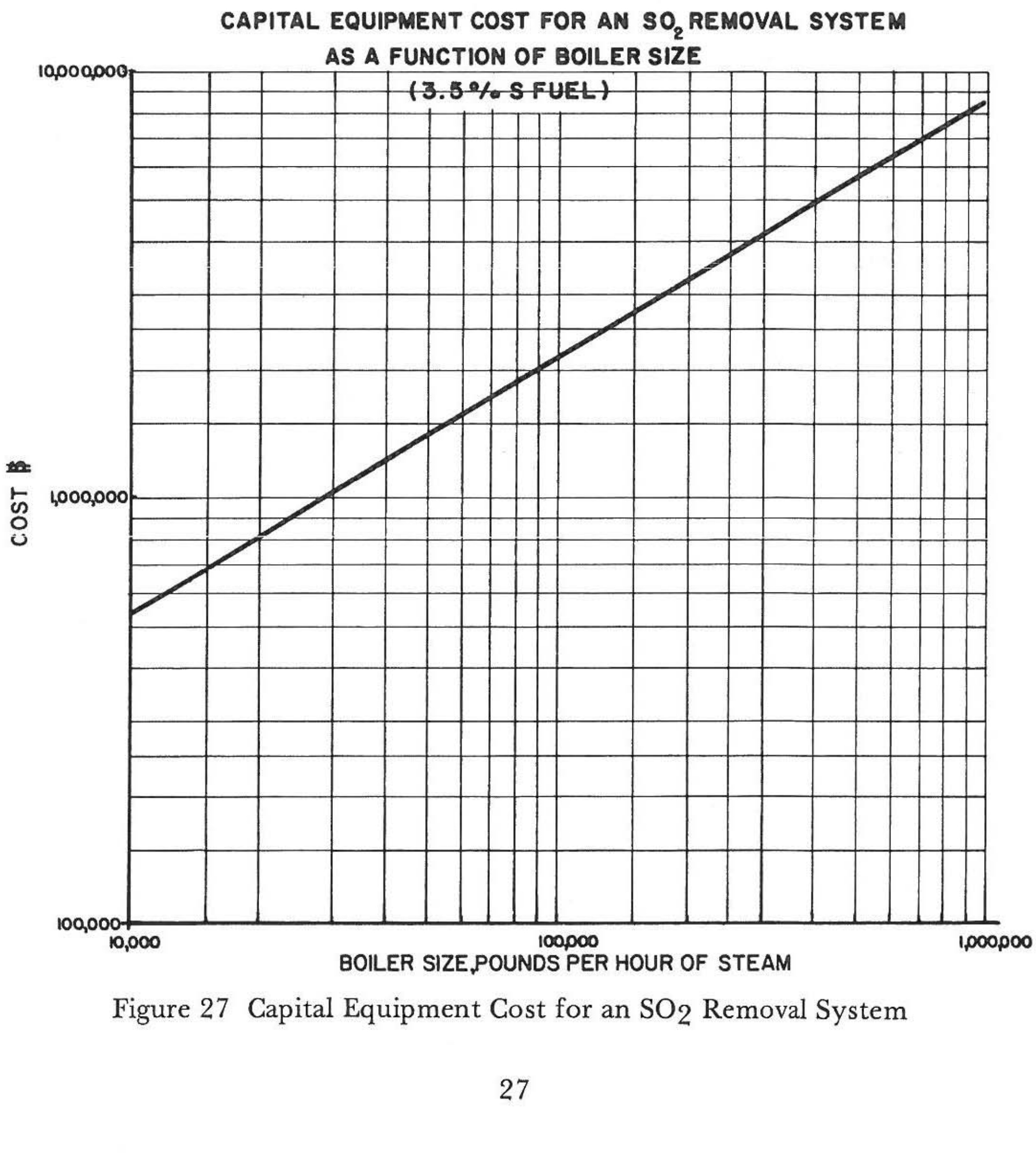

Figure 27 Capital Equipment Cost for an SO_2 Removal System

PART IV: CONVERSION OF EXISTING EQUIPMENT TO COAL

All of the factors discussed earlier, plus additional items, must be considered when converting an existing boiler from oil or gas to coal or back to coal. Figure 28 is an outline of all items that must be reviewed whether stoker firing or pulverized coal firing is to be considered.

1. F.D. FAN CAPACITY
2. I.D. FAN CAPACITY
3. PULVERIZER CAPACITY
4. GRATE CAPACITY
5. BURNER CAPACITIES
6. FLAME PLACEMENT
7. FURNACE SLAGGING
    a. FURNACE HEAT RELEASE RATES
8. ASH FOULING (CONVECTION SECTION)
9. SOOT BLOWERS
10. ASH REMOVAL SYSTEM
11. OBSERVATION PORTS
12. CONTROL SYSTEMS
    a. COMBUSTION CONTROL
    b. BURNER MANAGEMENT CONTROL
13. EROSION IN BOILER PASSES
14. LOW TEMPERATURE CORROSION
    a. ECONOMIZER
    b. AIR HEATER
15. HIGH TEMPERATURE CORROSION IN SUPER-HEATER
16. AIR POLLUTION CONSIDERATIONS
    a. PARTICULATE
    b. SULFUR OXIDES
    c. NITROGEN OXIDES

CHECK LIST FOR BOILER CONVERSION TO PULVERIZED COAL OR STOKER FIRING

FIGURE 28

Converting Gas or Oil-Fired Boilers

Special conditions must be considered when converting a boiler designed to fire gas and/or oil to fire coal. Boilers of this type were designed with very high furnace heat release rates, close tube spacing in the convection section, fin tube economizers, and closely spaced air heater baskets if a regenerative type was used. In most cases, the boiler would have to be deaerated to approximately 60% of its original capacity, and even then many changes would have to be made in the areas mentioned above. If there is physical space available, and the furnace can be increased in size, along with the back end changes, it may be possible to obtain 80% of the original capacity. Conversions of this type are generally not economical.

Converting Back to Coal

A boiler that had been designed to burn coal but is later converted to oil or gas, must also be reviewed in all the areas listed in Figure 28. Changes may have been made to the boiler when the conversion was made.

If the boiler was originally designed for pulverized coal-firing, it would not be economical to change to stoker-firing. Likewise, if the boiler was designed for stoker-firing, it would not be economical to change to pulverized coal. In both cases, extensive furnace modifications would be needed.

Converting Boiler with Future Coal Design

The final consideration would be the boiler designed for future coal-firing but which had been initially installed to burn oil and/or gas. Every item on the check list must be reviewed and the comments above regarding the application of either pulverized coal, or stoker-firing, would apply. In addition to the above would be the requirement of coal storage and handling facilities.

Economic Considerations

It is difficult to place a dollar value on conversion costs because every plant will have different requirements. One example that could be a base or study point would be the boiler that had coal burning equipment removed and was converted to fire oil. Also, the coal and ash handling systems were in place but needed updating, and air pollution equipment was in place. A boiler of 200,000 pounds of steam per hour under these conditions would have a minimum conversion cost of about $500,000, material delivered and erected. Any additional considerations such as precipitators, scrubbers, etc., would increase these costs dramatically, and it is beyond the scope of this paper to even guess at these costs.

Maintenance costs that must be considered would cover fuel storage and handling equipment, pulverizers and burners, or stokers, ash handling equipment, and sootblowing equipment. Increased auxiliary power requirements such as pulverizers, additional fans, electrostatic precipitators, etc., must be evaluated.

The fuel savings when changing from gas to coal can be substantial. In general, efficiency of a coal-fired boiler can be approximately 8% above the gas-fired boiler. This, plus the direct fuel cost savings on a BTU basis will be the total dollar savings to evaluate against conversion costs and increased operating costs.

The fuel savings when changing from oil to coal would be somewhat less because the change in efficiency would be approximately 4%.

Check List for New Boiler Information

When requesting a quotation from a boiler manufacturer, whether it is for a new boiler or a conversion requirement, certain information is needed. The following tabulations provide a check list for this use:

1. Design Considerations
   a. Steam flow (PPH)
   b. Operating Pressure (PSIG)
   c. Steam Temperature
   d. Feedwater Temperature
   e. Mode of operation
      1. Swing, etc.
      2. Load factor
2. Future Considerations
   a. Temperature and pressure of steam
   b. Peaking Service
   c. Change in mode of operation
3. Fuel Analysis (most important)
   a. Proximate Analysis
   b. Ultimate Analysis
   c. Ash Analysis
      1. Fusion temperatures
      2. Chemical
   d. Coal Size Analysis (for stoker design)
   e. Coal Grindability (for pulverizer design)
   f. Auxiliary Fuel Analysis
      1. Oil
      2. Gas
      3. Wood
      4. Waste
4. Space Limitations
5. Location
6. Conversions of existing boilers
   a. Design conditions
      1. Drawings with details

Summary and Conclusions

As stated in the introduction, the purpose of this paper is to acquaint the modern engineer with as many of the basics as possible in order to become familiarized with coal-firing equipment and its use today. We hope that the many areas covered have served this purpose and will provide a reference tool that is useful for years to come.

To complete this thought process, we have attached a sample evaluation covering a pulverized coal-fired boiler versus a stoker-fired boiler. This covers equipment only and can be used as a guidelines to begin a complete evaluation.

SAMPLE EVALUATION

Pulverized Coal versus Spreader Stoker

(A) Prices firm to 1-77 erection completion for a normal labor area in the Midwest.

(B) Scope: Boiler pressure parts, setting, combustion controls, burner controls, air pollution control (Particulate), sootblowers, gas and air ducts; Economizer (Stoker), Air heater w/steam coil (PC); F.D. and I.D. Fan with motors or turbines; Stoker or Pulverizer System and motors, mill feeders or Conical Distributor, Electrostatic Precipitator (PC); and CEP & Mechanical Collector (Stoker).
Structural steel has not been included.

(C) Design Coal

Design Coal	H_2O	10%	S.	1.7%
	Ash	14%	H_2	4.6%
11,000 BTU/lb.	C.	56.5%	N	1.2%
	O_2	12%		

(D) Statics of Pulverized Coal and Stoker Steam Generators

	Pulverized Coal		Spreader Stoker		
Type	Turbo Furnace (Figure 19)		"VO" (Figure 5)		
MCR PPH	210,000		200,000		
BTU Input K/HR	240,680		243,529		
Operating PSIG	175		175		
Flue Gas Exit ° F	330	290	350		
Efficiency %	86.5	87.5	81.5*		
Excess Air	30		35		
No. of Burners or Feeders	4		5		
Reinjection %	—		0	40*	70
Carbon Loss	.5		8.2	4.6*	2.5
Volumetric Release Rate, BTU/ft^3/hr.	20,000		20,000		
Surface Release Rate, BTU/ft^2/hr.	71,000		71,000		
Grate Surface Release, BTU/ft^2/hr	—		725,000		
Horsepowers					
F.D.	140		73		
I.D.	155		236*		
OFA	—		45		
Stk. Drive	—		5		
Pulverizers	306		—		
Total	601		359		

*Evaluation Based on two (2) Mechanical Collectors in Series.

(E) General Capital Equipment Cost Evaluation From Recently Bid Units

(1) Assume that electrostatic precipitator for pulverized coal and EP and Mech. for Stoker are equal in dollar value.

	P.C. Turbo Furnace	Stoker "VO" Type	
MCR	210,000	200,000	200,000
Emission Requirement, #/million BTU	0.1	0.1	0.6
Unit Efficiency	87.5	83.6	81.5
Base Unit Cost outlined Scope w/o Collectors, I.D. Fan and Ducts	$2,675,000.	$1,890,000.	$1,890,000.
Mechanical Coll. (2) in Series			158,000.
EP or Mech and EP Comb.	610,000.	610,000.	
I.D. Fan and Gas Ducts	275,000.	275,000.	155,000.
Total Unit Cost	$3,560,000.	$2,775,000.	$2,203,000.*

Note: The above costs are for capital equipment only. No consideration has been given for individual variable items such as coal cost, cost of money, equipment capitalization, maintenance expense, or other operating expenses. These must be considered for the individual application.

*Evaluation based on two (2) Mechanical Collectors in Series.