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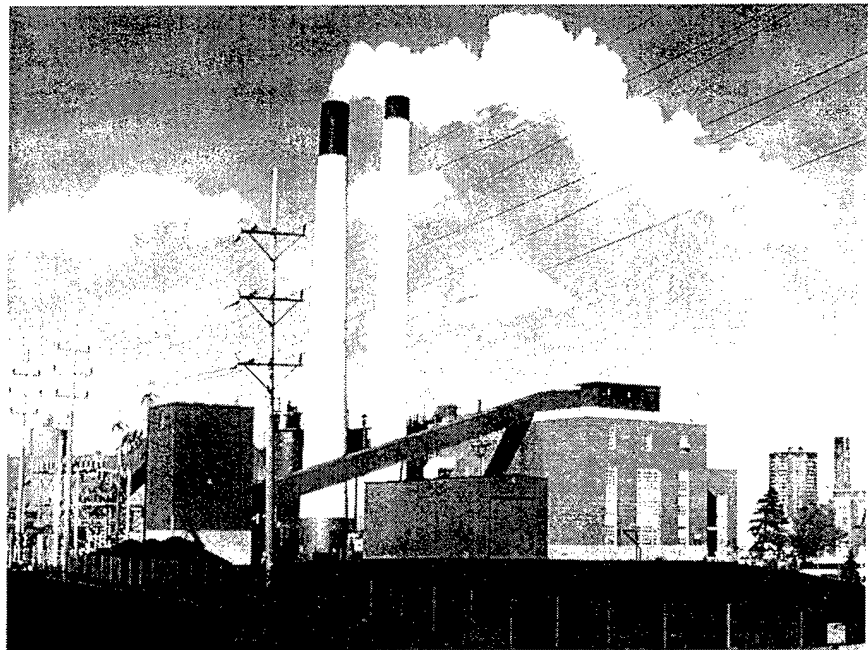
# Central Heating Plant Coal Use Handbook

## Volume 1: Technical Reference

by

Ralph Moshage, Mike Lin, Charles Schmidt, Christopher Blazek, and Frederick Karlson

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The mechanisms involved in the combustion of coal are so complex that it is often difficult for central energy plant personnel to quantify the impact of coal quality on boiler operating and maintenance costs. Since many Department of Defense (DOD) installations employ coal-fired central energy plants, the U.S. Army Construction Engineering Research Laboratories (USACERL) was tasked with developing a Coal Use Handbook for use at DOD installations.

This Handbook provides comprehensive information on how to minimize coal-fired central heat plant operations cost by improving coal quality specifications. The Handbook is tailored for military installation industrial-sized coal-fired central energy plants. Each section focuses on a different aspect of coal quality:

developing coal quality-based procurement specifications, measuring and monitoring coal quality throughout the coal use cycle, or identifying and solving boiler coal quality-related problems. The handbook is published in two volumes:

- Volume 1: Technical Reference
- Volume 2: Coal Specifications Troubleshooting Guide.

Volume 1 is designed as a reference and guide for operations, management, and procurement personnel involved in using coal as a boiler plant fuel. Volume 2 provides logic diagrams to help diagnose and correct 490 specific boiler system problems.

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## Foreword

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The work was performed by the Industrial Operations Division (UL-I) of the Utilities and Industrial Operations Laboratory (UL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL principal investigator was Dr. Mike C.J. Lin. Walter J. Mikucki is Chief, CECER-UL-I, and John T. Bandy is Operations Chief, CECER-UL. Gary W. Schanche, CECER-UL, is the associated Technical Director. The USACERL technical editor was William J. Wolfe, Technical Resources.

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# **1 Introduction**

## **1.1 Background**

The mechanisms involved in the combustion of coal are so complex that it is often difficult for central energy plant personnel to quantify the impact of coal quality on boiler operating and maintenance costs. Since many Department of Defense (DOD) installations employ coal-fired central energy plants, the U.S. Army Construction Engineering Research Laboratories (USACERL) was tasked with developing a Coal Use Handbook for use at DOD installations.

This handbook provides comprehensive information on how to minimize coal-fired central heat plant operations cost by improving coal quality specifications. The information is tailored to military installation, industrial-sized, coal-fired central energy plants. Each handbook section focuses on a different aspect of coal quality: developing coal quality-based procurement specifications, measuring and monitoring coal quality throughout the coal use cycle, or identifying and solving boiler coal quality-related problems.

## **1.2 Objective**

The objective of this study was to gather and publish comprehensive information on how to minimize coal-fired central heat plant operations cost by improving coal quality specifications.

## **1.3 Approach**

This Handbook is designed as a reference and guide to help operations, management, and procurement personnel reduce operating costs and problems associated with using coal as a boiler plant fuel. Information was compiled from a number of diverse sources to comprise a reference and guide for the operations, management and procurement personnel of a coal-fired central heating plant. This handbook covers coal quality specifications for acquisition and quality assurance. It also

provides a series of troubleshooting guides to identify and solve coal quality-related problems.

The *Central Heating Plant Coal Use Handbook, Volume 1: Technical Reference* is composed of eight chapters.

*Chapters 2 and 3: Introduction to Coal and Coal Quality Parameters* provide general information concerning coal and its properties. They also provide information concerning contracting, sampling, and testing of coal.

*Chapters 4 and 5: Coal Preparation and Handling* provide information concerning the cleaning and handling of coal from the time it was mined until the time it enters the furnace.

*Chapters 6 and 7: Combustion Control and Air Pollution Control Systems* provide information about combustion control systems and air pollution control systems. Combustion control deals with maintaining boiler efficiency. Air pollution control deals with removal of pollutants from flue gas to comply with State or Federal standards.

*Chapter 8: Coal-Fired Boiler System Descriptions* provides an overview of the coal combustion technologies used in the DOD. This chapter presents baseline coal quality specifications for each technology and identifies the operational impacts of off-spec coal. The following technologies are included:

- spreader stoker boilers
- overfeed stoker boilers
- underfeed stoker boilers
- pulverized coal boilers
- topfeed static grate boilers
- atmospheric fluidized bed boilers.

## 1.4 Scope

This handbook provides quality specifications for anthracite, bituminous, sub-bituminous, and lignite coals. The information presented in the handbook is generalized and is not intended to supersede the instruction manuals that accompany specific equipment.

## 1.5 Mode of Technology Transfer

It is recommended that the *Central Heating Plant Coal Use Handbook* be distributed to installations with coal-fired heating plants, and to procurement personnel at DOD fuel supply centers.

## 2 An Introduction to Coal

### 2.1 Formation

The coal that exists today began as plant material of vast prehistoric swamps. Over millions of years, these woody swamps accumulated thick layers of partially decayed vegetation called “peat.” As time passed, these peat fields became buried by sediment. Once underground, the peat began the process of coalification—the slow transformation of plant materials from peat to coals such as lignite, subbituminous, bituminous, and anthracite.

Coal can have a wide range of chemical and physical properties. These properties depend on the various conditions of coal formation, including:

- the species of plants that formed the peat
- the composition of sediment that became intermixed with the peat
- the intensity of underground temperatures and pressures
- the age of the coal deposit.

As a result, coal is not a single, definable substance; it is a complex and its make-up can vary even within a single coal sample.

### 2.2 Coal Characteristics

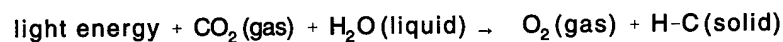
Generally speaking, coal is made of three materials: hydrocarbons, impurities, and moisture. Hydrocarbons are molecules of hydrogen and carbon that store energy that is released when coal is burned. Impurities (materials that were in the plants during coalification) do not burn well and reduce boiler efficiency. Moisture refers to the water content in the coal.

#### 2.2.1 *Hydrocarbons*

Since coal is formed from plants, some general knowledge of the makeup and functioning of plants will aid in understanding the composition of coal and the importance of hydrocarbons. Plants use energy from the sunlight to convert carbon

dioxide and water into oxygen and hydrocarbon chains, the basic sugars used to build the plant. This process, called photosynthesis, is sparked by chlorophyll, a chemical in the plant cells. Chlorophyll gives plants their green color.

The carbon dioxide (CO<sub>2</sub>) is drawn from the atmosphere while the water (H<sub>2</sub>O) is taken from the ground. The oxygen (O<sub>2</sub>) generated through photosynthesis is released back to the air, while the hydrocarbons (H-C), which store energy, form the bulk of the plant material. The following relationship illustrates the chemical reaction that takes place during photosynthesis.



The energy stored in the plant's hydrocarbon molecules remains trapped during coalification. This stored energy, which is released when the coal is burned in the furnace, makes coal a usable fuel. The high temperature in the furnace causes the hydrocarbons to break their bonds and combine with oxygen, releasing the stored energy and forming carbon dioxide and water.



The energy content in coal exists in two forms: volatile matter and fixed carbon. Unlike fixed carbon, volatile matter burns rapidly and is released as a gas. Fixed carbon, however, lasts longer in storage than volatile matter and contains the bulk of coal's energy. If coal were composed solely of hydrocarbons, combustion would be very clean.

### 2.2.2 *Impurities*

Unfortunately, plants are not composed of hydrocarbons alone. To live and grow, plants draw nutrients from the soil and store them within the hydrocarbons. In terms of combustion, these nutrients are considered impurities because they either end up as ash or as part of the flue gases.

Mineral deposits constitute a second form of impurity in coal. These mineral deposits exist because of:

- precipitation of minerals from the swamps during dry periods
- minerals washed into the coal from surrounding formations
- earth movements during coal formation



- mining techniques that do not differentiate between coal and accompanying materials.

### 2.2.3 Moisture

Moisture is another primary constituent of coal. Moisture that accompanies coal is broadly classified as either "surface moisture" or "inherent moisture." Surface moisture is caused by external sources such as ground water, rain and condensation. The amount of surface moisture present in coal is highly variable, depending on conditions during mining, transportation, and storage. Inherent moisture (also called "bed moisture") refers to water trapped within the pores of the coal. The inherent moisture content of coal is relatively constant, depending on the properties of the coal.

## 2.3 Classifications

Coal classifications began as a method of setting coal prices to reflect performance differences. This practice led to the development of more sophisticated schemes for ranking coals. Four generally accepted methods for classifying coals are:

- *Optical Classification.* This standardized approach uses microscopic identification techniques to classify coals.\*
- *Chemical Classification.* The chemical classification scheme (as developed by Seyler) is a graphical method comparing the chemical and physical makeup of a particular coal sample to those reflected on a diagram. The diagram maps certain coal properties as they change during coalification. The comparison is based on chemical composition, heating value, volatile matter, moisture and free swell index.\*\*
- *International Classification.* This classification technique is based on a coal's volatile content, caking properties and coking properties.
- *U.S. Classification.* This scheme is based on a coal's fixed carbon content, heating value, agglomerating characteristics, and weathering characteristics.

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\* Detail on optical classification methods is given in the *International Handbook of Coal Petrography* (1971).

\*\* More information on chemical and international classification methods is given in Paris (1963).

The U.S. classification is the most common method for ranking coals in the United States. This scheme divides coal into four broad categories: anthracite, bituminous, subbituminous, and lignite. For heating plants, coal is usually described as one of these types. For greater accuracy, each category is subdivided. Table 1 highlights the coal properties for each of these subcategories.

This classification scheme is summarized in terms of heat content, fixed carbon, volatile matter and agglomerating character as defined by ASTM D 388-88.

Table 2 describes the properties of the coals outlined in Table 1.

In general, as coals move from lignite to anthracite, fixed carbon and heating value increase, while volatile matter and moisture decrease. Figure 1 shows those trends.

## **2.4 Reserves**

### **2.4.1 World Reserves**

Table 3 summarizes the distribution of the world's supply of economically recoverable coal. Economically recoverable reserves are those that can be extracted at an acceptable cost. Note that the former Soviet Union, China and the United States hold approximately 79 percent of the world's recoverable reserves.

### **2.4.2 U.S. Reserves**

The United States holds 26 percent (approximately 180 billion tons) of the world's recoverable coal reserves. Each year the United States mines approximately 1 billion tons or about 0.5 percent of its reserve. Of this 1 billion tons, the Department of Defense consumes nearly 0.14 percent. Approximately half is by the Army, one-third by the Air Force and one-sixth by the Navy.

Figure 2 identifies the major coal fields of the United States. In general, coal rank increases from West to East. The Rocky Mountains and northern plains contain mostly lignite and subbituminous coals; the Midwest down through Texas contains primarily bituminous coals; and the Appalachian region contains anthracite and bituminous coals.

Table 1. Summary of U.S. coal classifications by rank.

| Class              | Group                              | Fixed Carbon Limits, %<br>(Dry, Mineral-Matter-Free Basis) |                    | Volatile Matter Limits, %<br>(Dry, Mineral-Matter-Free Basis) |                    | Gross Calorific Value Limits, Btu/lb (Moist, A Mineral-Matter-Free Basis) |           | Agglomerating Character             |
|--------------------|------------------------------------|--|--------------------|---|--------------------|---|-----------|-------------------------------------|
|                    |                                    | Equal or Greater Than                                      | Equal or Less Than | Greater Than  | Equal or Less Than | Greater Than  | Less Than |                                     |
| I. Anthracitic     | 1. Meta-anthracite                 | 98   | —                  | —   | 2                  | —   | —         | nonagglomerating                    |
|                    | 2. Anthracite                      | 92   | 98                 | 2   | 8                  | —   | —         | nonagglomerating                    |
|                    | 3. Semi-anthracite <sup>B</sup>    | 86   | 92                 | 8   | 14                 | —   | —         | nonagglomerating                    |
| II. Bituminous     | 1. Low volatile bituminous coal    | 78   | 86                 | 14  | 22                 | —   | —         | commonly agglomerating <sup>D</sup> |
|                    | 2. Medium volatile bituminous coal | 69   | 78                 | 22  | 31                 | —   | —         | commonly agglomerating <sup>D</sup> |
|                    | 3. High volatile A bituminous coal | —  | 69                 | 31  | —                  | 14 000 <sup>C</sup>   | —         | commonly agglomerating <sup>D</sup> |
|                    | 4. High volatile B bituminous coal | —  | —                  | —   | —                  | 13 000 <sup>C</sup>   | 14 000    | commonly agglomerating <sup>D</sup> |
|                    | 5. High volatile C bituminous coal | —  | —                  | —   | —                  | 11 500  | 13 000    | commonly agglomerating <sup>D</sup> |
| III. Subbituminous | 1. Subbituminous A coal            | —  | —                  | —   | —                  | 10 500  | 11 500    | nonagglomerating                    |
|                    | 2. Subbituminous B coal            | —  | —                  | —   | —                  | 9 500   | 10 500    | nonagglomerating                    |
|                    | 3. Subbituminous C coal            | —  | —                  | —   | —                  | 8 300   | 9 500     | nonagglomerating                    |
| IV. Lignite        | 1. Lignite A                       | —  | —                  | —   | —                  | 6 300   | 8 300     | nonagglomerating                    |
|                    | 2. Lignite B                       | —  | —                  | —   | —                  | —   | 6 300     | nonagglomerating                    |

<sup>A</sup> Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.

<sup>B</sup> If agglomerating, classify in low-volatile group of the bituminous class.

<sup>C</sup> Coals having 69% or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of gross calorific value.

<sup>D</sup> It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class, and that there are notable exceptions in high volatile C bituminous group.

Table 2. Description of U.S. coal classifications.

| Classification |                            | Description  |
|----------------|----------------------------|--|
| Anthracite     | Meta-anthracite            | A high-carbon coal that is similar to graphite in structure and composition. It is usually slow to ignite and difficult to burn. Currently it has little commercial importance.  |
|                | Anthracite                 | Dense and shiny black. It is hard and can be handled with very little breakage. It burns with a short, clear, bluish flame. It ignites with some difficulty and burns with a short, smokeless and blue flame.  |
|                | Semianthracite             | Dense, but softer than anthracite. It burns with a short, clean, bluish flame and is ignited more easily than anthracite. Its uses are about the same as for anthracite.   |
| Bituminous     | Low-volatile bituminous    | Grayish black, granular in structure and friable on handling. It cakes in a fire and burns with a short flame that is usually considered smokeless under all burning conditions.   |
|                | Medium-volatile bituminous | An intermediate stage between high-volatile and low-volatile bituminous coal. Therefore, it has some of the characteristics of both. Some are fairly soft and friable, but others are hard and do not disintegrate on handling. They cake in the fuel bed and smoke when improperly fired.   |
|                | High-volatile A bituminous | Hard and handles well with little breakage. It cakes when fired and smokes when burned improperly. The moisture, ash and sulphur content is low and the heating value high.  |
|                | High-volatile B bituminous | Similar to high volatile A bituminous coal. However, it has a slightly higher bed moisture and oxygen content.   |
|                | High-volatile C bituminous | Similar to high volatile A and B coals. However it is higher in moisture, ash and sulphur.   |
| Subbituminous  | Subbituminous A            | Brownish-black or black in appearance and has smooth surfaces. It has a high moisture content which causes it to audibly crack and disintegrate as it dries (called "slacking"). In the fire, this coal has no caking tendency and therefore crumbles into small pieces.   |
|                | Subbituminous B            | Similar to subbituminous A coal. However, it has a higher moisture content and a lower heating value.  |
|                | Subbituminous C            | Similar to subbituminous A and B coals. However, it had a higher moisture content and a lower heating value.   |
| Lignite        | Lignite A                  | Brown in color and the remains of woody fibers are frequently apparent. Freshly mined lignite is tough but not hard. When exposed to air, it loses moisture rapidly and disintegrates. Even when it appears dry, the moisture content may be as high as 30 percent. Because of its high moisture content and low heating value, it is not economical to transport it long distances. It can be burned quite efficiently on traveling-grate, spreader stokers and in pulverized form. Because of the tendency of the lignite to disintegrate, the fuel bed must not be agitated since agitation speeds up the disintegration. |
|                | Lignite B                  | Similar to lignite A, however, it has a higher moisture content and lower heating value.   |

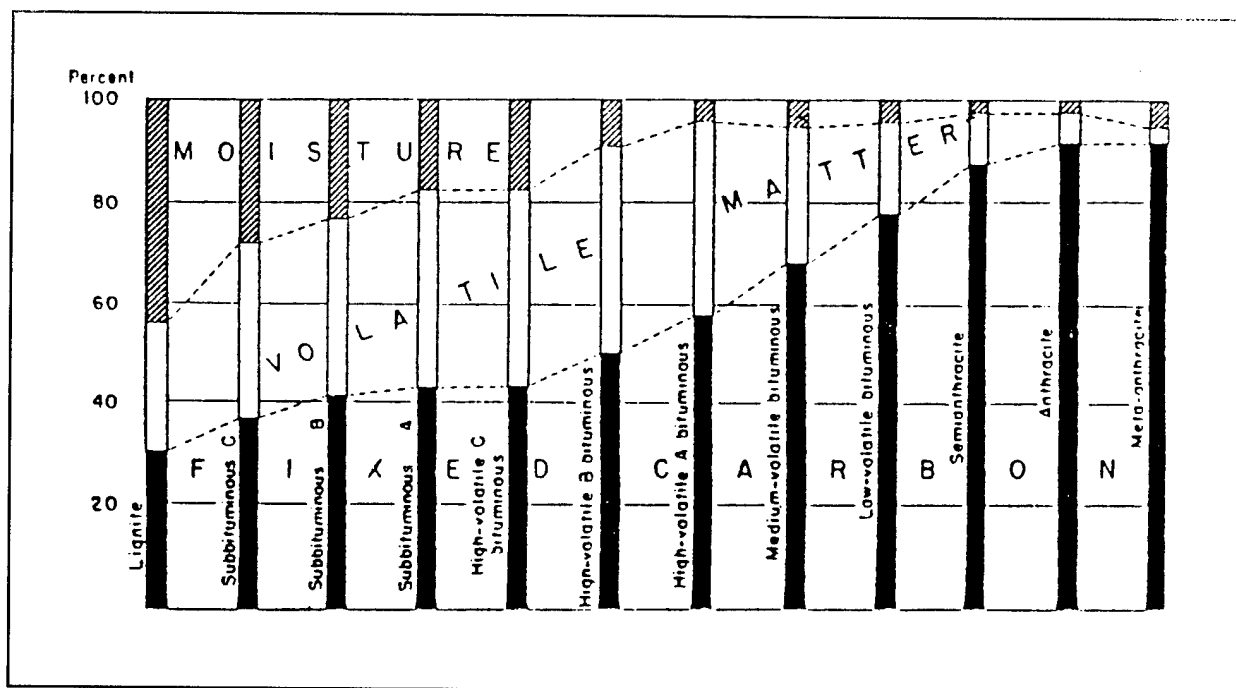


Figure 1. Volatile and moisture trends.

Table 3. Major coal reserves of the world.

| Continent                 | Country               | Recoverable Reserves | %   |
|---------------------------|-----------------------|----------------------|-----|
| Europe                    | Soviet Union          | 39%                  | 50% |
|                           | Germany               | 6%                   |     |
|                           | Yugoslavia            | 2%                   |     |
|                           | Others                | 3%                   |     |
| North and Central America | United States         | 26%                  | 27% |
|                           | Others                | 1%                   |     |
| Asia                      | China                 | 14%                  | 16% |
|                           | India                 | 2%                   |     |
|                           | Others (less than 1%) | --%                  |     |
| Oceania                   | Australia             | 4%                   | 4%  |
|                           | Other (less than 1%)  | --%                  |     |
| Africa                    | South Africa          | 2%                   | 2%  |
|                           | Others (less than 1%) | --%                  |     |
| South America             | Brazil                | 1%                   | 1%  |
|                           | Others (less than 1%) | --%                  |     |
| Total: 100%               |                       |                      |     |

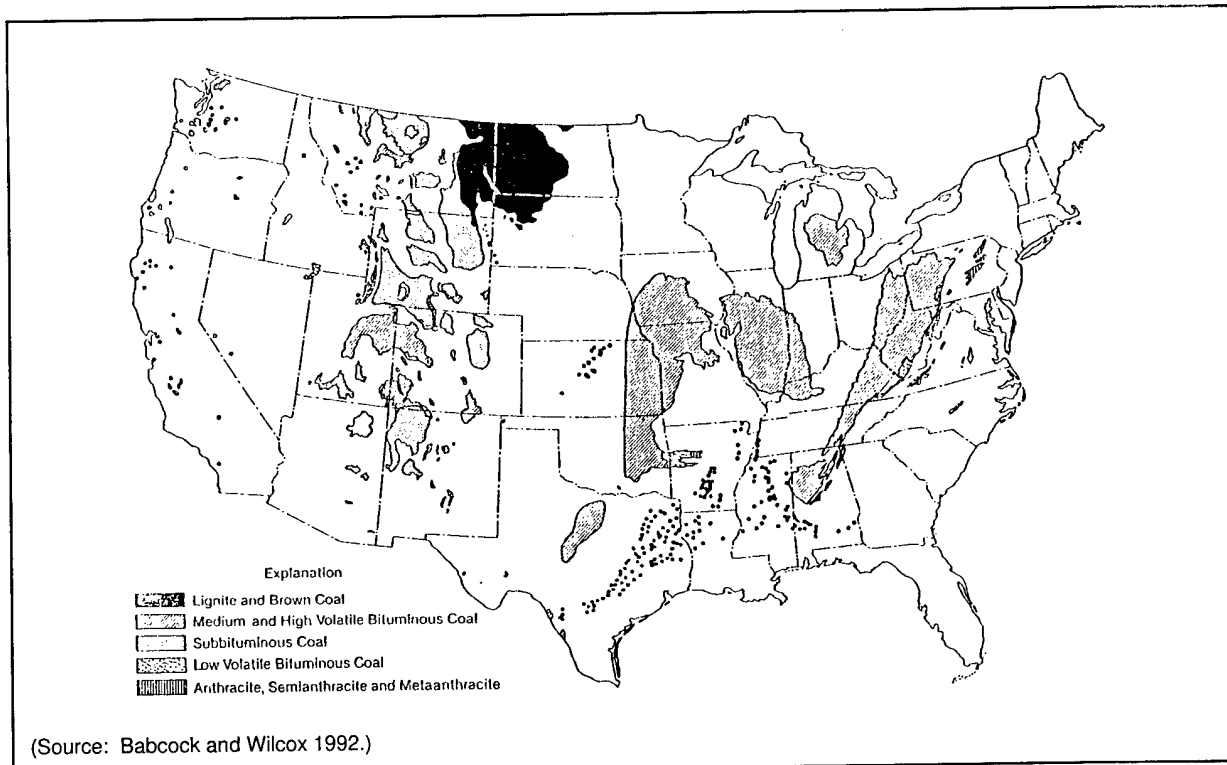


Figure 2. Coal reserves of the United States.

## 2.5 Mining

Coal is mined by either surface or underground methods. These methods are described below.

### 2.5.1 Surface Mining

Coal deposits shallower than 150 feet are mined from the earth's surface. This technique is called "surface mining" (or "strip mining") and accounts for over half of the annual coal production in the United States. The procedure works as follows:

1. Earthmoving equipment relocates soil and rock that covers the coal.
2. The coal is broken into manageable pieces by machinery or explosives.
3. Power shovels remove the coal from the ground.
4. The stripped area is graded, covered with topsoil and then reseeded.

### 2.5.2 Underground Mining

Underground mining (or "deep mining") is required when coal deposits lie deeper than 150 ft beneath the earth's surface. Most mines are less than 1,000 ft deep; however, a few are 1,500 to 2,000 ft deep.

There are two widely used techniques for mining coal underground. One is called "the room-and-pillar method" and the other is called "longwalling." The room-and-pillar method is a system of cutting coal that leaves pillars of undisturbed coal to support the roof of the mine while loose coal is being removed. Longwalling is considered superior to the room and pillar method since the mining tool itself supports the roof while the coal is being cut and removed. When the coal cutting device finishes its sweep along the face of the coal seam, the entire machine advances, allowing the roof to cave in behind it. Longwalling is more efficient for mining coal than the room-and-pillar method, however, surface subsidence can be a more of a problem. In both techniques of mining, coal is transported to the earth's surface using conveyors, elevators, or rail cars.

## 2.6 Uses

Seventy percent of the coal consumed in the United States is used by electric power utilities. Sixteen percent is converted to coke and 12 percent is consumed by manufacturing and mining industries.

In manufacturing and chemical industries, coal is separated into chemicals such as methanol and ethylene. These chemicals are used to make plastics, tar, synthetic fibers, and medicines.

### 3 Coal Quality

When selecting the coal to use in a plant, an operator attempts to purchase a coal that will carry the load, meet all of the plant's design constraints, and cost the least. This task is complicated by the nonuniform nature of coal. Because coal can have a wide range of properties and because these properties play a significant role in the performance of boilers and their components, it is important for operators to have a good understanding of coal properties and their effects on plant performance.

Various methods have been developed to quantify coal properties. Plant personnel need to understand these measurement systems and their limitations. The remainder of this chapter describes three categories of coal properties that are important for coal specifications:

- combustion parameters
- composition parameters
- physical parameters.

The chapter concludes with a section devoted to coal analysis test results, which discusses the various bases for testing coal and the eventual results.

#### 3.1 Combustion Parameters

Hydrocarbons, as the name indicates, contain carbon. Carbon is responsible for most of the energy released during combustion. Different coal types contain different quantities of carbon. For example, a ton of anthracite contains much more carbon than a ton of lignite. Because of this difference in carbon content, anthracite delivers much more energy than lignite.

It would be convenient if all similarly classified coals (for instance, all anthracite coals) contained the same quantity of carbon. It would also be convenient if a coal's carbon content solely defined the energy it released during combustion. Unfortunately, this is not the case. In fact, each coal classification describes only a range of carbon contents, and it is the quantity of carbon as well as the quantity of volatile matter that describe the energy released during combustion.



Combustion parameters consist of volatile matter, fixed carbon, and heat content. These parameters have a great influence on furnace design, including volume, heating surface area, and arrangement of heating surfaces.

### **3.1.1 Volatile Matter**

Volatile matter describes a portion of the coal that escapes as a gas when the coal is heated. The gases released are predominantly hydrogen ( $H_2$ ), carbon-monoxide (CO), methane ( $CH_4$ ) and sulfur-oxides (SOx). Such gases are highly combustible. Within the furnace, volatile matter ignites and burns rapidly, keeping furnace temperatures high. Such high temperatures encourage carbon burnout and increase combustion efficiency. Although a high volatile coal is desired for combustion, a low volatile coal is preferred for transportation and storage because:

- Low volatile coal is less susceptible to spontaneous combustion.
- High volatile coal can lose up to 3 percent of its volatile matter in the first year of storage. (A plant that burns such coal obtains less energy than was originally purchased and may end up using a coal that no longer meets specifications and lowers plant efficiency, often causing operating problems.)

### **3.1.2 The Standard for Measuring Volatile Matter**

The determination of volatile matter is included in the proximate analysis of coal. ASTM Test Method D 3175 estimates the quantity of volatile matter in a coal sample. In this test, the weight loss of a dry coal sample that is heated under rigidly controlled conditions is measured. The volatile matter is expressed as a percentage of the sample's weight.

### **3.1.3 Fixed Carbon**

Fixed carbon\* is the combustible material remaining after volatile matter has been removed. This residue consists primarily of carbon, but may contain traces of oxygen, hydrogen, nitrogen, and sulfur. Fixed carbon has a high ignition temperature, in contrast to volatile matter, which ignites at much lower temperatures.

The quantity of fixed carbon can be used as an indicator of coal combustion tendencies, for instance:

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\* Fixed carbon should not be confused with *total carbon*. Total carbon represents the sum of the fixed carbon and the carbon contained in the volatile matter.

- Coals having a low fixed carbon content typically contain more volatile matter, making the coal more susceptible to spontaneous combustion or degradation. On the other hand, these coals generally show a high level of carbon burnout.\*
- Coals having a high fixed carbon content take longer to burn and therefore must remain on the furnace grate longer to ensure complete combustion. If the grates are discharged too soon, unburned coal is dumped into the ash pit. This lowers efficiency and can cause ash handling problems.

### **3.1.4    *The Standard for Measuring Fixed Carbon.***

The determination of fixed carbon is included in the proximate analysis of coal. ASTM Test Method D 3172 presents a method for calculating the fixed carbon content of a coal sample. Fixed carbon is expressed as a percentage of the sample's weight.

### **3.1.5    *Heat Content***

Heat content is the single most important characteristic of coal, because energy units are bought when fuel is purchased. Heat content describes the total energy content of a coal sample and is described numerically using a "heating value" (or "calorific value").

Coal with a large heating value releases more energy per ton than coal with a lesser heating value. A large heating value reduces shipping and handling costs because fewer tons are consumed. In terms of combustion, less coal in the furnace means less ash on the grate, lower waste disposal costs, and reduced wear and tear on ash-handling equipment. Furthermore, coals with large heating values typically contain less moisture and less ash, thereby enhancing the benefits described above.

There are two standards for describing the heating value of coal:

1. Higher heating value (or "gross calorific value")
2. Lower heating value (or "net calorific value").

A coal's higher heating value establishes a theoretical maximum for the quantity of energy that can be released during combustion. In practical terms, however, the higher heating value tends to overstate the coal's usable energy. Because of

---

\* Carbon burnout is the degree to which the carbon is completely combusted. High levels of carbon burnout are desirable.

extremely high temperatures in the furnace, moisture created during combustion (as well as any that accompanies the coal into the furnace) is vaporized. This vaporization process consumes some of the energy being released and carries it away with the flue gases. The lower heating value accounts for this vaporization of moisture and is consequently a more accurate measure of heating value.

In the United States, it is standard practice to use the higher heating value to signify the heat content of a fuel. Given the higher heating value, the lower heating value can be estimated using the following formula:

$$\text{LHV} = \text{HHV} - 9,270 \text{ H}$$

where:

- LHV = lower heating value (Btu/lb)
- HHV = higher heating value (Btu/lb)
- H = hydrogen content as a fraction of the coal's weight.

### **3.1.6 Standards for Measuring Heating Value.**

The determination of the higher heating value of a sample of coal is described in the following ASTM Test Methods:

- *ASTM Test Method D 2015*, "Gross Calorific Value of Coal by the Adiabatic Bomb Calorimeter"
- *ASTM Test Method D 3286*, "Gross Calorific Value of Coal by the Isothermal-Jacket Bomb Calorimeter."

Both these test procedures involve burning a sample of coal under rigidly controlled conditions and measuring the amount of energy released.

Higher heating values can also be calculated using Dulong's formula (below) in conjunction with the results of an ultimate analysis. For anthracite and bituminous coals, values calculated using this formula are usually within 2 to 3 percent of those determined experimentally. For subbituminous and lignite coals, calculated values are typically within 5 percent of experimental ones.

$$\text{HHV} = 14,544 \text{ C} + 62,028 (\text{H} - \text{O}/8) + 4,050 \text{ S}$$

where:

- HHV = higher heating value (Btu/lb)
- C = carbon content as a fraction of the coal's weight

- H = hydrogen content as a fraction of the coal's weight
- O = oxygen content as a fraction of the coal's weight
- S = sulphur content as a fraction of the coal's weight.

## 3.2 Composition Parameters

Composition parameters define the chemical make-up of the coal. Except for carbon, hydrogen, and oxygen, composition parameters are considered impurities. Although these impurities do not add any heating value, they may be very important factors influencing the processes involved in coal combustion. With this in mind, it is important to have an understanding of all the composition parameters typically used to define a coal. The coal composition parameters most important to central heating plant staff are:

- mineral matter (ash content)
- total carbon
- moisture
- sulfur
- nitrogen
- chlorine
- hydrogen
- oxygen.

### 3.2.1 Mineral Matter

Mineral matter is the major impurity present in coal. It is present in three forms:

1. *Inherent mineral matter*: minerals that existed as part of the original plant material that formed the coal
2. *Included mineral matter*: minerals that settled in among the coal during its formation
3. *Excluded mineral matter*: minerals surrounding the coal field that are mined with the coal

Mineral matter does not contribute to the heating value of coal. In fact, coals high in mineral matter typically have a lower carbon and volatile matter content. Also, the abrasive nature of minerals makes them hard on coal-handling equipment. For these reasons it is desirable to remove mineral matter before shipment to the plant. Coal cleaning techniques are often used to remove *excluded* and *included* mineral matter.

During combustion, mineral matter combines with oxygen to form ash. In the furnace, ash takes the form of either flyash or bottom ash; flyash is airborne and travels with the flue gases, while bottom ash remains on the fuel bed and is deposited into the ash pit. The production of flyash is always undesirable, whereas the production of bottom ash is very important to the combustion process. Flyash is the primary cause of slagging and fouling on boiler surfaces. This ash buildup lowers boiler efficiency. In addition, flyash can cause problems for electrostatic precipitators.

Bottom ash serves to insulate the grate from extreme temperatures of the fuel bed while controlling the flow of combustion air through the grate. If the ash bed grows too shallow, the grate can be damaged. If the ash bed grows too deep, air flow through the grate can become inconsistent, reducing combustion efficiency and increasing the production of flyash. (Excess ash reduces combustion efficiency by 0.33 percent for every 1 percent rise in ash content.) In addition, ash fused together on the grate can impede the flow of combustion air.

Boiler performance is greatly affected by the size, distribution, and types of minerals contained in the coal. It is therefore important to know the mineral makeup of coals that work well with a given boiler system.

### ***3.2.2 Standards for Measuring Ash Content.***

The determination of ash content for a coal sample is included in the proximate and in the ultimate analyses. ASTM Test Method D 3174 estimates the quantity of ash developed by a coal sample. The ash content is determined by the amount of residue after a coal sample is burned under rigidly controlled conditions. Ash is expressed as a percentage of the sample's weight.

### ***3.2.3 Standards for Measuring the Mineral Composition of Ash.***

Usually, determination of the mineral composition of coal ash is not required for operation of the plant. As a guide in troubleshooting operational problems, however, the mineral composition analysis may be invaluable. Figure 3 shows the results of an ash mineral analysis. The ASTM Test Methods D 2795 and D 3682 evaluate the mineral composition of ash. Method D 2795 is the least expensive. These methods test for the minerals listed in Table 4. The ASTM Test Method D 3683 procedure evaluates the presence of trace elements in ash: beryllium, chromium, copper, manganese, nickel, lead, vanadium, and zinc.

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► SCHMIDT ASSOCIATES  
7333 Fair Oaks Road  
Cleveland, OH 44146

August 18, 1987

Sample identification  
by SCHMIDT ASSOCIATES

|                               |           |          |  |
|-------------------------------|-----------|----------|--|
| Kind of sample reported to us | Coal      | IDENT:   | Holston Ammunition Plant<br>D.S. Bituminous #3 |
| Sample taken at               | xxxxx     |          | 7/29/87  |
| Sample taken by               | Submitted | JOB NO:  | 86-120-4                                       |
|                               |           | P.O. NO: | SA 87-136                                      |
| Date sampled                  | xxxxx     |          |  |
| Date received                 | 8/4/87    |          |  |

**Analysis report no. 81-8873****MINERAL ANALYSIS OF ASH****Percent Weight Ignited Basis**

|   |                |
|---|----------------|
| Silica, SiO <sub>2</sub>                        | 53.61          |
| Alumina, Al <sub>2</sub> O <sub>3</sub>         | 26.49          |
| Titania, TiO <sub>2</sub>                       | 1.47           |
| Ferric oxide, Fe <sub>2</sub> O <sub>3</sub>    | 8.28           |
| Lime, CaO                                       | 2.56           |
| Magnesia, MgO                                   | 1.70           |
| Potassium oxide, K <sub>2</sub> O               | 2.28           |
| Sodium oxide, Na <sub>2</sub> O                 | 0.51           |
| Sulfur trioxide, SO <sub>3</sub>                | 1.66           |
| Phos. pentoxide, P <sub>2</sub> O <sub>5</sub>  | 0.35           |
| Strontium Oxide, SrO                            | 0.20           |
| Barium Oxide, BaO                               | 0.20           |
| Manganese Oxide, Mn <sub>2</sub> O <sub>3</sub> | 0.00           |
| Undetermined                                    | 0.69           |
|   | <u>100.00%</u> |

Alkalies as Na<sub>2</sub>O, Dry Coal Basis = 2.01

Silica Value = 81.04

Base: Acid Ratio = 0.19

ESTIMATED VISCOSITY at critical viscosity

Temperature of °F = Poises

T<sub>750</sub> Temperature = 2758 °F

Fouling Index =

Slagging Index =

Respectfully submitted,  
COMMERCIAL TESTING & ENGINEERING CO.

  
Manager, Cleveland Laboratory


Charter Member

bkb

Original Copy Watermarked  
For Your Protection

Figure 3. Sample mineral analysis of ash.

### 3.2.4 Total Carbon

Typically, the degree to which coalification has occurred is measured by the carbon content of the coal. Carbon is the major indicator of all other coal properties and is often used to correlate the other composition and physical properties. For example, coals with a low carbon content are subject to spontaneous ignition and frequently cause yard fires. Yet, these coals generally show a high level of carbon burn out, which leads to higher combustion efficiency. Another example involves the relationship between the hardgrove grindability index and the carbon content. Figure 4 illustrates this relationship.

Carbon content is used to calculate the amount of oxygen required for coal combustion. The carbon content can also be used to estimate the heating value for a coal using Dulong's Formula.

### 3.2.5 Standards for Total Carbon Content.

The determination of total carbon content for a coal sample is included in the ultimate analysis. ASTM Test Method D 3178 provides a methodology for determining the total carbon in a coal sample. A dry coal sample is burned in a closed system and the products of combustion are captured in an absorption train. The change in weight of the elements in the absorption train determines the amount of carbon present. The total carbon is expressed as a percentage of the sample's weight.

### 3.2.6 Moisture

Moisture accompanies coal in two forms:

- *Inherent moisture (bed moisture)* consists of moisture trapped within the pores of the

Table 4. Mineral composition of ash.

| Mineral Oxide                                     | Method D 2795 | Method D 3682 |
|---|---------------|---------------|
| silicon oxide (SiO <sub>2</sub> )                 | X             | X             |
| aluminum oxide (Al <sub>2</sub> O <sub>3</sub> )  | X             | X             |
| ferric oxide (Fe <sub>2</sub> O <sub>3</sub> )    | X             | X             |
| titanium oxide (TiO <sub>2</sub> )                | X             | X             |
| calcium oxide (CaO)                               | X             | X             |
| magnesium oxide (MgO)                             | X             | X             |
| sodium oxide (Na <sub>2</sub> O)                  | X             | X             |
| potassium oxide (K <sub>2</sub> O)                | X             | X             |
| phosphorus oxide (P <sub>2</sub> O <sub>5</sub> ) | X             |               |
| manganese oxide (MnO <sub>2</sub> )               |               | X             |

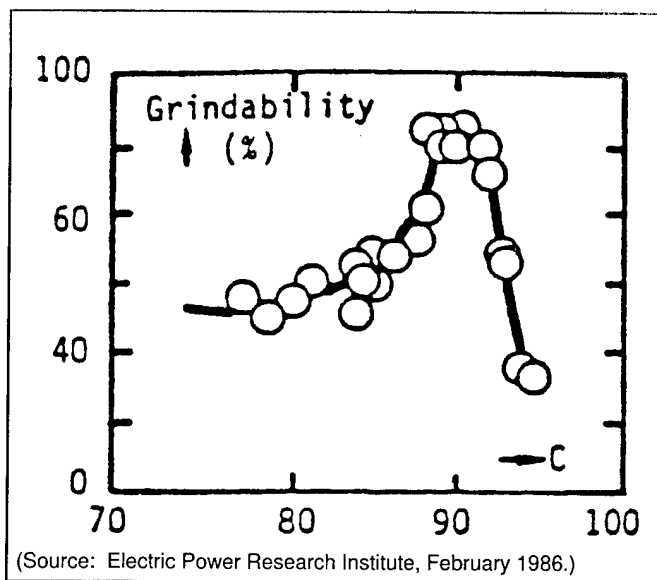


Figure 4. Carbon content versus hardgrove grindability.

coal. Inherent moisture is a function of the coal bed conditions and changes slowly over time. Figure 5 shows how the bed moisture varies with coal rank. Note that, as the carbon content decreases towards a lignitic coal, the amount of bed moisture in coal increases significantly.

- *Surface moisture* refers to moisture due to external sources such as groundwater, rain, and condensation. The amount of surface moisture present in coal is highly variable and depends on conditions during mining, transportation, and storage. Generally, surface moisture tends to increase with smaller coal size.

In general, moisture is undesirable. It can reduce plant efficiency and cause handling problems. During combustion, temperatures in the furnace are so high that all inherent and surface moisture is vaporized. This vaporization process consumes some of the energy released during combustion and, as this water vapor leaves the furnace with the flue gases, it carries away some of the combustion energy, reducing boiler efficiency by 0.1 percent for every 1 percent rise in moisture content. Consequently, a high moisture content lowers the heating value of the coal. Coal with excessive surface moisture can clog feeders and conveyor systems while frozen surface moisture can cause handling problems in the coal yard.

An understanding of a coal's moisture content is very important to ensure that the amount and quality of coal paid for reflects what was actually received. If samples of coal are allowed to dry out before being analyzed, the results will suggest a higher

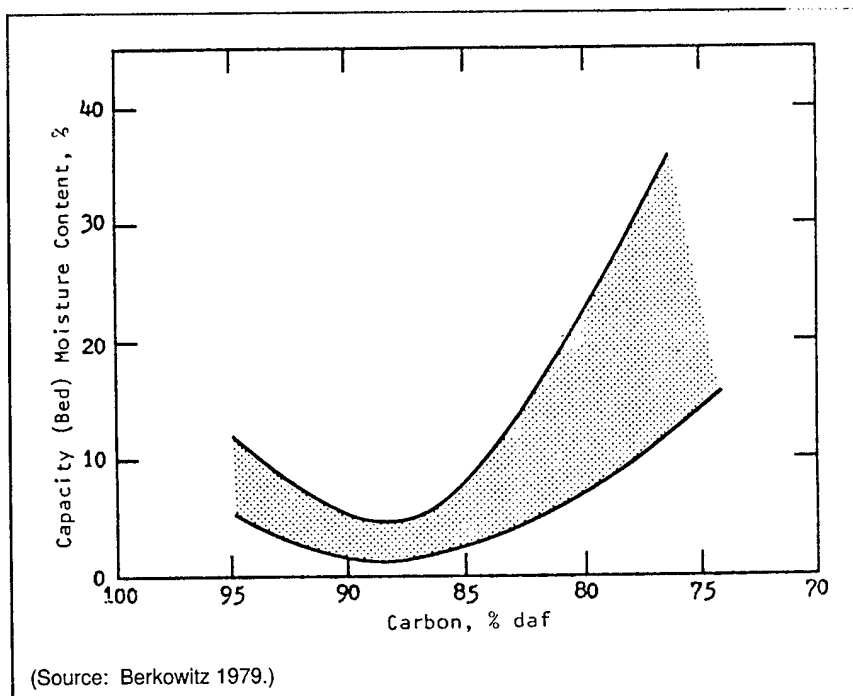


Figure 5. Bed moisture versus coal rank.



quality coal than was actually delivered. Conversely, if excessive moisture, snow, or ice is present in the truck or rail car when it is weighed, the quantity of coal purchased will exceed that actually delivered. In either case, it is essential that the correct coal sampling and acceptance procedures be followed. This section of the handbook outlines the appropriate procedures.

Note, however, that in some cases moisture is desirable. For instance, on chain and traveling grate overfeed stokers, moisture accompanying the coal boils and rises through the fuel and ash bed. These blow holes provide paths for combustion air to flow through the bed. Where moisture is lacking, the coal can be dampened, or "tempered."

### **3.2.7 Standards for Measuring Moisture Content.**

The determination of moisture content for a coal sample is included in the proximate and ultimate analyses. The analysis for total moisture content is actually done in stages. The sample is first air dried to bring it to near equilibrium with the atmosphere in the analysis lab. The moisture content measured up to this point is called the air dry loss. The sample is next reduced in size to prepare it for the determination of residual moisture. Residual moisture, or "as determined moisture," is measured by the weight loss of a sample heated under rigidly controlled conditions. Finally, the total moisture, or "as received moisture," is determined by adding the residual moisture to the air dry loss moisture.

ASTM Test Method D 3173 is used to measure the residual moisture content of a coal sample. The residual moisture determined by this method is used for converting other lab analysis results to a moisture-free or "dry basis."

ASTM Test Method D 3302 is used to measure the total moisture content in coal as it exists when it is sampled. The total moisture determined by this method is used for converting results reported on a dry basis to an "as received basis." Total moisture is reported as part of the proximate and the ultimate analysis results when they are reported on an as received basis. The moisture is expressed as a percentage of the sample's weight. This method is recognized as the standard procedure for measuring total moisture.

### **3.2.8 Sulfur**

Sulfur contributes to the heating value of coal, as shown in Dulong's Equation. In coal, sulphur occurs in three forms:

1. *Organic sulfur* is bound to the coal's hydrocarbon chains. Organic sulfur may constitute anywhere from 20 to 85 percent of the total sulfur in the coal.
2. *Pyritic sulfur* exists in combination with iron as marcasite,  $\text{FeS}_2$ , or pyrite. Typically, pyrite and marcasite have a yellowish metallic appearance; however marcasite can appear nearly white.
3. *Sulfate sulfur* exists in combination with oxygen and iron (or calcium) to form iron sulfate,  $\text{FeSO}_4$  (or calcium sulfate,  $\text{CaSO}_4$ ). In freshly mined coal, sulfate sulphur occurs in very small quantities of less than 0.1 percent by weight. However, as coal weathers (oxidizes), its sulfate content climbs.

Pyritic sulfur and sulfate sulfur are jointly called inorganic sulfur because neither are chemically bound to the coal. In fact, both of these compounds exist as loose crystals. The presence of sulfur in coal can cause operational problems and is also the focus of considerable environmental concern for the following reasons:

- The presence of sulfur increases the chances of spontaneous combustion during storage. When pyritic sulfur breaks down to form sulfate sulfur, its volume increases, causing the coal to crack. This cracking generates fines that allow more rapid oxidation of the coal while holding in the generated heat.
- After combustion, sulfur travels among the flue gases as sulfur oxides. If the flue gas temperature drops below the acid dew point, sulfuric acid will condense and corrode heat exchangers, duct work, air pollution control devices, and stacks. The acid dew point temperature increases as the percentage of sulfur increases. For example, the dew point temperature increases from 265 to 275 degrees when going from 0.7 to 2.5 percent sulfur.
- Once released from the plant, sulfur oxides present significant environmental hazards. Local, State, and Federal Environmental Protection Agencies strictly limit the amount of sulfur oxides that may be released from a heating plant stack.

To comply with environmental regulations, techniques have been developed to remove sulfur from the coal and flue gas. Note, however, that the sulfur content of a coal is in no way systematically related to the coal's rank; therefore a maximum sulfur content may be specified regardless of the other coal properties required.

Before combustion, inorganic sulfur can be removed using physical cleaning techniques, such as washing or coal flotation separation. Organic sulfur can also be

removed, however this process requires chemical cleaning techniques, which tend to be uneconomical.

After combustion, sulfur can be removed using a wet or dry scrubbing system. These scrubbers use limestone or lime to chemically combine sulfur in the flue gas, forming a material that is easily extracted. In the case of a dry scrubber, this material is dry and can be removed via a mechanical collector followed with a bag house. In the case of a wet scrubber, the waste product is in the form of a slurry or a wet solid. Chapter 7 describes these SO<sub>2</sub> control systems in more detail.

When using an electrostatic precipitator (ESP) for particulate control, a minimum amount of sulfur is required for optimum operation of the ESP. As the sulfur content of the fired coal decreases, the ability of the ash particles to hold a static charge also decreases, making the ESP less effective. The efficiency of an ESP can drop from 99.5 to 90 percent by switching from a 2 percent sulfur eastern bituminous coal to a 0.5 percent sulfur western subbituminous coal.

### **3.2.9 Standards for Measuring Sulfur Content.**

The determination of sulfur content is included in the ultimate analysis. ASTM Test Method D 3177 provides the methodology for this determination. The sulfur content is expressed as a percentage of the sample's weight. The ASTM Test Method D 2492 measures the percentages of the three forms of sulfur in a coal sample: organic, pyritic, and sulfate sulfur. When a plant has no SO<sub>2</sub> removal equipment, the following formula is useful for determining the allowable percentage of sulfur in coal based on the maximum amount of sulfur oxides permissible in the flue gas.

$$\text{Sulfate Sulfur, \%} = [(A - B) \times 13.735] / W$$

where:

A = grams of BaSO<sub>4</sub> precipitated

B = grams of BaSO<sub>4</sub> in the blank

W = grams of sample used.

### **3.2.10 Nitrogen**

The nitrogen content of coal rarely exceeds 1 percent. Although small compared to the other elements, fuel nitrogen content will influence nitrogen oxides (NO<sub>x</sub>) emissions from combustion. The formation of NO<sub>x</sub> under excess air conditions is directly proportional to the nitrogen content of the coal. This NO<sub>x</sub> is a form of air

pollution as serious as that of  $\text{SO}_2$ . Nitrogen, unlike sulfur, does not contribute to the heating value of coal.

Control of the  $\text{NO}_x$  emissions from a boiler plant can take place during the combustion process when the  $\text{NO}_x$  is formed, or the  $\text{NO}_x$  can be removed from the flue gas before it leaves the plant. During combustion,  $\text{NO}_x$  formation can be controlled by reducing excess air, recycling part of the flue gas, or using some form of staged combustion. After the  $\text{NO}_x$  is formed, it may be removed from the flue gas through a scrubbing method. In one successful scrubbing technique, the  $\text{NO}_x$  is converted to nitrogen by ammonia. Chapter 7 gives a more detailed description of these  $\text{NO}_x$  control systems.

### 3.2.11 Standards for Measuring Nitrogen Content

The determination of nitrogen content is included in the ultimate analysis. ASTM Test Method D 3179 provides the methodology for this determination. The nitrogen content is expressed as a percentage of the sample's weight. Note that the nitrogen content of a coal is in no way systematically related to the coal's rank.

### 3.2.12 Hydrogen

Hydrogen contributes to the heating value of coal, as shown in Dulong's Equation. Coals with a high hydrogen content are very reactive and prone to spontaneous combustion. In addition, high hydrogen levels frequently accompany high levels of oxygen, which reduces the heating value of the coal. The hydrogen content of coal is related to the coal's rank (Figure 6).

### 3.2.13 Standards for Hydrogen Content.

The determination of hydrogen content for a coal sample is included in the ultimate analysis. ASTM Test Method D 3178 provides a methodology for this determination. The coal sample is burned in a closed system and the products of

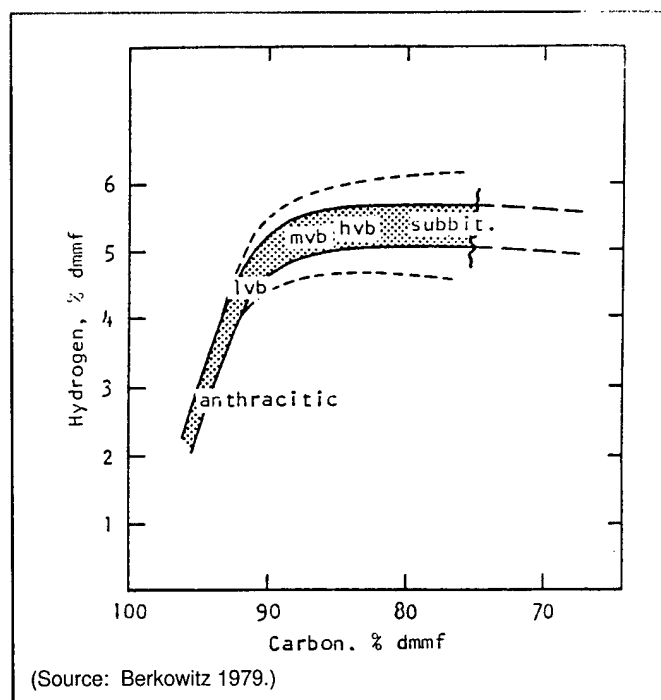


Figure 6. Hydrogen content versus carbon content.

combustion are captured in an absorption train. The change in weight of the elements in the absorption train is used to determine the amount of hydrogen present. The hydrogen content is expressed as a percentage of the sample's weight.

### 3.2.14 Oxygen

Oxygen is a significant element that can contribute up to 30 percent of the weight of low rank coals such as lignite. Oxygen does not contribute to the heating value of coal. In fact, it has the opposite effect, as seen in the Dulong Equation. The oxygen content of coal is related to the coal's rank (Figure 7).

### 3.2.15 Standards for Measuring Oxygen Content.

The determination of oxygen content for a coal sample is included in the ultimate analysis. ASTM Test Method D 3176 provides a methodology for this determination. The oxygen content is calculated by subtracting from 100 the sum of the other components of the ultimate analysis. Oxygen is expressed as a percentage of the sample's weight.

### 3.2.16 Chlorine

The chlorine content of coal can be related to the corrosion, fouling and slagging properties of the coal. During combustion, chlorine combines with hydrogen to form an acid hydrogen chloride (HCl). This HCl is a form of air pollution that is vented with the flue gases. Chlorine does not contribute to the heating value of coal; its content in U.S. coals is normally minimal.

### 3.2.17 Standards for Measuring Chlorine Content.

The ASTM Test Method D 2361 provides a methodology for determining the total chlorine content of a coal sample. This test

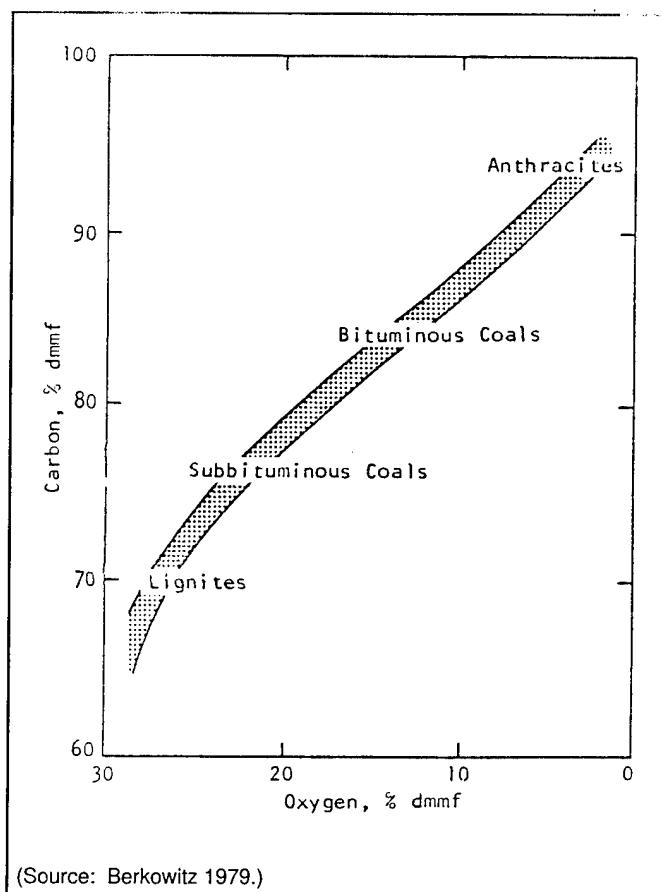


Figure 7. Oxygen content versus carbon content.

should be requested as part of an ultimate analysis for a coal sample. The chlorine content is expressed as a percentage of the sample's weight.

### **3.2.18 Proximate Analysis**

For practical purposes, the general composition of coal is always defined using the proximate analysis. This analysis reports four key properties of the coal: (1) moisture, (2) ash, (3) volatile matter, and (4) fixed carbon.

The proximate analysis procedure is described by ASTM Test Method D 3172. Figure 8 shows the results of a proximate analysis for a sample of bituminous coal. Although the proximate analysis provides only a rough measure of coal properties, it is an extremely useful indicator of a coal's behavior because of the immense body of information that has been correlated with it.

Although the proximate analysis is widely used and accepted, it should be understood that the results can be misleading because of the order of the three tests. Lower rank coals tend to contain higher concentrations of volatile matter and may lose some of these volatiles during the moisture test. This occurrence tends to overstate the coal's moisture content and understate its volatile content. Similar problems exist with the determination of volatile matter and fixed carbon. The ultimate analysis provides a more accurate description of a coal's composition.

### **3.2.19 Ultimate Analysis**

The ultimate analysis is widely recognized as an accepted standard of coal evaluation. The ultimate analysis results describe a coal in terms of its primary constituents: ash, nitrogen, moisture, hydrogen, carbon, oxygen., and sulphur. This procedure is described by ASTM Test Method D 3176. The determination of chlorine is frequently included with the ultimate analysis. Figure 9 shows the results of an ultimate analysis for a sample of bituminous coal. The information obtained from this test is required when performing boiler efficiency tests as well as EPA compliance tests. Because of the cost and time required to perform this analysis, several other techniques for analyzing coal have been developed. Several of these techniques use automated gas chromatography or nuclear methods.

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LAKES DIVISION MANAGER  
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OFFICE TEL: (216) 224-2261

► SCHMIDT ASSOCIATES  
7333 Fair Oaks Road  
Cleveland, OH 44146

August 18, 1987

Sample identification  
by

SCHMIDT ASSOCIATES

|                               |           |          |                          |
|-------------------------------|-----------|----------|--------------------------|
| Kind of sample reported to us | Coal      | IDENT:   | Holston Ammunition Plant |
| Sample taken at               | xxxxx     |          | D.S. Bituminous #3       |
| Sample taken by               | Submitted |          | 7/29/87                  |
| Date sampled                  | xxxxx     | JOB NO:  | 86-120-4                 |
| Date received                 | 6/4/87    | P.O. NO: | SA67-136                 |

Analysis report no. 81-8873

## PROXIMATE ANALYSIS

|                | <u>As Received</u> | <u>Dry Basis</u> | <u>NAF</u> |
|----------------|--------------------|------------------|------------|
| % Moisture     | 1.91               | xxxxx            |            |
| % Ash          | 8.05               | 8.82             |            |
| % Volatile     | 34.05              | 34.71            |            |
| % Fixed Carbon | 55.39              | 56.47            |            |
|                | <u>100.00</u>      | <u>100.00</u>    |            |
| Btu/lb.        | 13570              | 13634            | 15172      |
| % Sulfur       | 0.80               | 0.62             |            |

## FUSION TEMPERATURE OF ASH

|                       | <u>Reducing</u> | <u>Oxidizing</u> |  |
|-----------------------|-----------------|------------------|--|
| Initial Deformation   | 2340 °F         | xxxxx °F         |  |
| Softening (H = W)     | 2600 °F         | xxxxx °F         |  |
| Softening (H = 1/2 W) | 2665 °F         | xxxxx °F         |  |
| Fluid                 | 2700 °F         | xxxxx °F         |  |

H = Cone Height  
W = Cone Width

Vibrated Bulk Density 44.50 Lbs/ft<sup>3</sup>

Respectfully submitted,  
COMMERCIAL TESTING & ENGINEERING CO.

Lkt

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*K.R. Main*  
Manager, Conneaut Laboratory



Figure 8. Sample lab analysis report—proximate analysis.

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Cleveland, OH 44146

August 18, 1987

Sample identification  
by SCHMIDT ASSOCIATES

|                               |           |          |                          |
|-------------------------------|-----------|----------|--------------------------|
| Kind of sample reported to us | Coal      | IDENT:   | Holston Ammunition Plant |
| Sample taken at               | xxxxxx    |          | D.S. Bituminous #3       |
| Sample taken by               | Submitted |          | 7/29/87                  |
| Date sampled                  | xxxxxx    | JOB NO:  | 86-120-4                 |
| Date received                 | 8/4/87    | P.O. NO: | SA87-136                 |

Analysis report no. 81-8873

**ULTIMATE ANALYSIS**

|                  | <u>As Received</u> | <u>Dry</u>  |
|------------------|--------------------|-------------|
| % Moisture       | 1.91               | xxxxxx      |
| % Carbon         | 76.49              | 77.98       |
| % Hydrogen       | 4.88               | 4.98        |
| % Nitrogen       | 1.40               | 1.43        |
| % Chlorine       | xxxxxx             | xxxxxx      |
| % Sulfur         | 0.80               | 0.82        |
| % Ash            | 8.65               | 8.82        |
| % Oxygen (diff.) | <u>5.87</u>        | <u>5.97</u> |
|                  | 100.00%            | 100.00%     |

1k


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COMMERCIAL TESTING & ENGINEERING CO.
  
Manager, Cleveland Laboratory


Figure 9. Sample lab analysis report—ultimate analysis.



### 3.3 Physical Parameters

#### 3.3.1 Size

The size consist, or proper mixture of sizes, has a direct influence on boiler operation and efficiency. Size consist is one of the few coal specification parameters that is completely controlled by mining operations. Coal is sized by dropping it onto a sieve or screen with holes of a known size. Small coal falls through the sieve; large coal remains on top. This process is called "single screening" (Figure 10). Screening smaller sized coal a second time is called "double screening." Coal that passes through the first sieve but not the second has a known size range and is designated as "double-screened" coal.

#### 3.3.2 Standards for Coal Sizing

To achieve a degree of consistency within the coal industry, standards have been established for classifying coal sizes. In addition, common size ranges have acquired names over the years. Tables 5 and 6 show standard terminology and ASTM screen and sieve sizes for bituminous, subbituminous, and lignite coals. Tables 7 and 8 show the same information for anthracite coals. These sizing methods are described by ASTM Test Methods D 431 and D 4749. For pulverized coal, the ASTM Test Method D 197 is used.

Figure 11 shows a sample complete coal size specification for a spreader stoker boiler. This same relationship is shown graphically in Figure 12. Each combustion technology has a different sizing curve. The two inner curves border the range of the desired size distribution, while the outer curves border the absolute acceptance limits.

1- $\frac{1}{4}$   $\times$  1- $\frac{1}{4}$ -in.

Figure 10. Using one double-screening to indicate size consistency.

Table 5. Standard terminology for bituminous, subbituminous, and lignite coals.

| Standard Terminology | Description  |
|----------------------|--|
| Run of mine (ROM)    | Coal as delivered from the mine  |
| Lump                 | Coal bigger than 5-in.   |
| Egg                  | Coal smaller than 5-in., but bigger than 2-in.                             |
| Nut                  | Coal smaller than 2-in., but bigger than 1 $\frac{1}{4}$ -in.              |
| Stoker               | Coal smaller than 1 $\frac{1}{4}$ -in., but bigger than $\frac{3}{4}$ -in. |
| Slack                | Coal smaller than $\frac{3}{4}$ -in.                                       |

**Table 6. Screen and sieve sizes for bituminous, subbituminous, and lignite coals.**

| Round Hole Screens  | Wire Cloth Sieves with Square Openings |
|---------------------|--|
| 8-in. (...)         |  |
| 6-in. (...)         |  |
| 5-in. (125-mm)      |  |
| 4-in. (100-mm)      |  |
| 3-in. (75-mm)       |  |
| 2 1/2-in. (63-mm)   |  |
| 2-in. (50-mm)       |  |
| 1 1/2-in. (37.5-mm) |  |
| 1 1/4-in. (31.5-mm) |  |
| 1-in. (25.0-mm)     |  |
| 3/4-in. (19.0-mm)   |  |
| 1/2-in. (12.5-mm)   |  |
| 3/8-in. (9.5-mm)    |  |
| 1/4-in. (6.3-mm)    |  |
|                     | No. 4 4.75-mm                          |
|                     | No. 8 2.36-mm                          |
|                     | No. 16 1.18-mm                         |
|                     | No. 30 0.60-mm                         |
|                     | No. 50 0.30-mm                         |
|                     | No. 100 0.15-mm                        |
|                     | No. 200 0.075-mm                       |
|                     | No. 400 0.038-mm                       |

**Table 7. Standard terminology for anthracite coals.**

| Standard Terminology | Description  |
|----------------------|--|
| Run of mine (ROM)    | Coal as delivered from the mine                        |
| Broken               | Coal smaller than 4 3/8-in. but bigger than 3-in.      |
| Egg                  | Coal smaller than 3 3/4-in. but bigger than 2 7/16 in. |
| Stove                | Coal smaller than 2 7/16 in. but bigger than 1 5/8 in. |
| Chestnut             | Coal smaller than 1 5/8 in. but bigger than 1 3/16 in. |
| Pea                  | Coal smaller than 1 3/16 in. but bigger than 9/16 in.  |
| No. 1 (Buckwheat)    | Coal smaller than 9/16 in. but bigger than 5/16 in.    |
| No. 2 (Rice)         | Coal smaller than 5/16 in. but bigger than 3/16 in.    |
| No. 3 (Barley)       | Coal smaller than 3/16 in. but bigger than 3/32 in.    |
| No. 4                | Coal smaller than 3/32 in. but bigger than 3/64 in.    |
| No. 5                | Coal smaller than 3/64 in.                             |

When placing an order for coal, it is important to properly specify the size consist required. The standard method for designating the size range of double screened coal is to give the upper and lower limits for the 80 percent of the coal retained. The sieve defining the upper limit shall be the smallest sieve on which less than 5 percent of the coal is retained. The sieve defining the lower limit shall be the largest sieve through which less than 15 percent of the coal passes. Note that, by contractual agreement, the percentages used to designate the top and bottom size may be altered to meet special requirements. The following examples illustrate this system for designating the size range of a coal sample:

- 1-1/4 in. x 1/4 in.
- 4 in. x 2 in.

While the complete size specification is a more accurate means of describing a coal's size, it makes the coal more expensive. Unless there are unique operational requirements that require the complete size specification, the specifications should

**Table 8. Screen sizes for anthracite coals round hole screens.**

|            |          |
|------------|----------|
| 4-3/8-in.  | (110-mm) |
| 3-1/4-in.  | (83-mm)  |
| 3-in.      | (76-mm)  |
| 2-7/16-in. | (62-mm)  |
| 1-5/8-in.  | (41-mm)  |
| 3/16-in.   | (21-mm)  |
| 9/16-in.   | (14-mm)  |
| 5/16-in.   | (8-mm)   |
| 3/16-in.   | (4.8-mm) |
| 3/32-in.   | (2.4-mm) |
| 3/64-in.   | (1.2-mm) |

|                 |            |
|-----------------|------------|
| plus 1-1/4-in.  | 5%         |
| 1-1/4 × 3/4-in. | 15%        |
| 3/4 × 1/2-in.   | 30%        |
| 1/2 × 1/4-in.   | 30%        |
| 1/4 × No. 8     | 12%        |
| Less than No. 8 | 8%         |
|                 | <hr/> 100% |

**Figure 11. Using several double-screenings to indicate size consistency.**

be reduced to a single size range. The following paragraphs describe some relationships between coal size and furnace operation.

Small pieces of coal burn more rapidly than large ones. If coal is shoveled into a furnace by hand, a shovelful of coal dust would burn faster than a similarly sized block of coal because the coal dust has a greater surface area exposed to the heat and air within the furnace. Consequently, by decreasing the top size of coal entering the furnace, the speed of ignition can be increased. Such a reduction in coal size, however, has its downside. For instance, if the top coal size fed to the furnace is decreased too far, there can be problems with the distribution of fuel on the grate. Poor coal distribution can cause hot spots on the grate leading to the formation of clinkers and flyash.

Correctly sized coal and properly distributed coal sizes are important when using spreader stokers. As coal is flung into the furnace, it segregates. Larger coal lands toward the back of the furnace, while smaller particles land near the front. If a certain size range of coal is missing, holes will form in the fuel bed causing combustion problems. For this reason, coal must be double screened for spreader stoker systems. Single screening, however, can be used for underfeed and overfeed mass burning technologies.

Excessive fines (dust) will magnify the problems caused by coal segregation. If too many fines exist, segregation will be increased each time the coal is handled or stored. Coal segregation in the stoker-feeding system leads to problems with incomplete combustion on the grate. Fine coal piles do not allow the underfire air

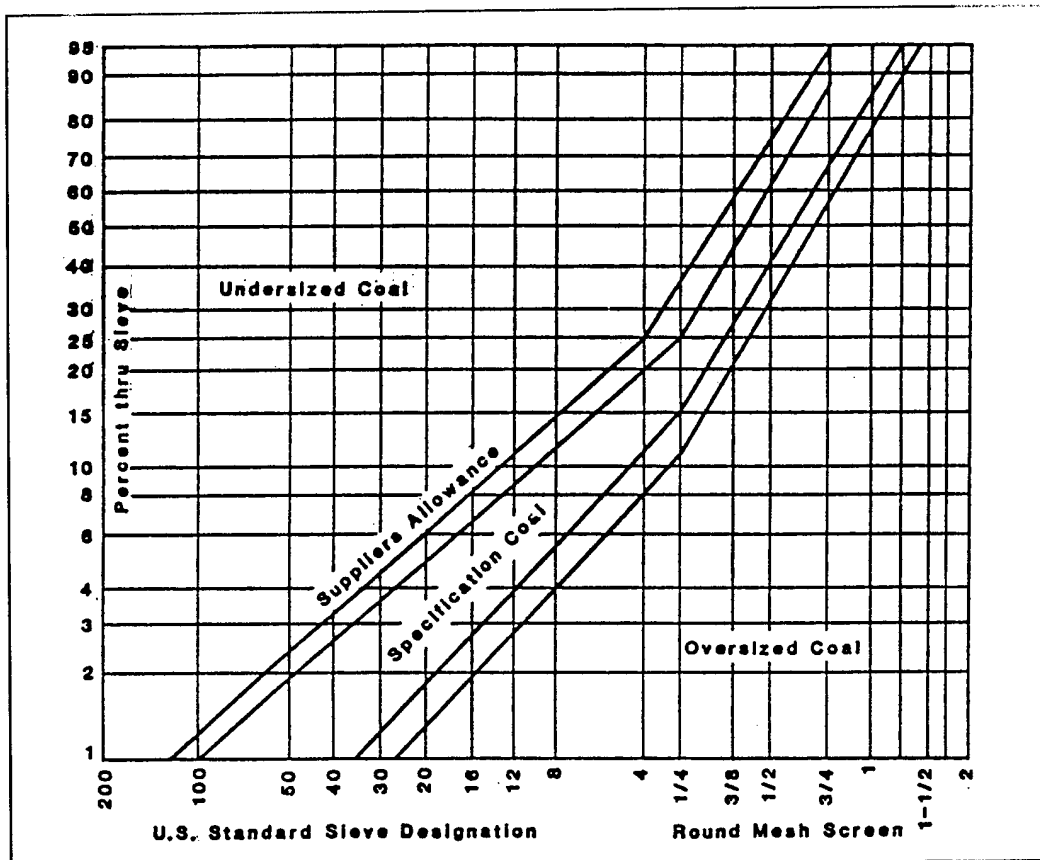


Figure 12. Graphical representation of Figure 11.

to penetrate the bed and can lead to clinker formation and high grate temperatures. High grate temperatures will cause damage to the grate and increase maintenance costs.

### 3.3.3 Free Swelling Index

Swelling refers to the tendency of a coal to swell when heated. A high swelling coal can hamper ignition in two ways. If ignition is accomplished by means of an arch, it is very important for the coal to have a high volatile matter content and for combustion air can to get through the coal bed to enhance combustion. If the coal swells too much, the underfire air is cut off and the flame walks away from the arch. When the coal swells and sticks together, it is called agglomeration. Agglomeration causes smoking and can result in the formation of large clinkers. If coal contains a large amount of fines, the swelling will be more severe.

Understanding the swelling characteristics of a coal helps indicate its caking characteristics. Using a coal with milder swelling properties helps the fuel and ash bed to be more porous. This will assist enhances air distribution and the mixing of fuel and air.

### 3.3.4 Standard for Measuring Free Swell Index.

ASTM Test Method D 720 is used to estimate a free-swelling index. The Free Swell Index (FSI) is based on the size and shape of a coke button created by heating a sample of pulverized coal. The size and shape of this button is visually compared to a series of standard profiles (Figure 13). This technique is very subjective, however and the coal is ranked accordingly.

### 3.3.5 Ash Fusion

Ash fusion refers to the melting of ash. Ash is usually thought of as a fine powder; however, in the heat of a furnace, ash can melt and fuse together. The temperature at which this fusion takes place is called the "ash fusion temperature" (or "ash softening temperature").

Ash fusion can have a profound effect on the operation of the chain grate, traveling grate, underfeed, and spreader stokers. If the ash softening temperature is too low for the type of combustion process, clinkers can form. These clinkers can plug the holes that supply underfire air to the furnace. If too many of these holes are plugged, air passing through the remaining holes enters too quickly. As a result, ash is stirred up and fine coal exits with the flue gases. This situation reduces combustion efficiency, increases abrasion and erosion, increases slagging, and can overload air pollution control equipment.

Unfortunately, determination of ash fusion temperatures is not a simple process. The degree to which ash fuses depends not only on the temperature, but also on the

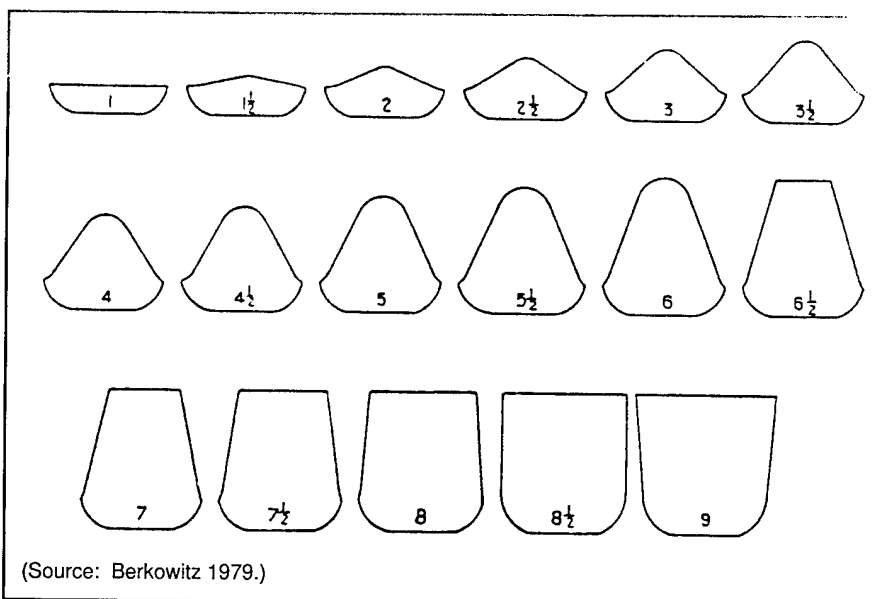


Figure 13. Free-swelling index, standard profiles.

rate at which the temperature is achieved. For these reasons, a standard scheme has been developed for classifying ash fusion. Beginning with ash molded into a triangular cone, the ash is heated and observed as it passes through the following four stages. (Figure 14 shows the initial cone and its appearance as it passes through the four stages of ash fusion.)

1. *Initial Deformation Temperature (IT)* is the temperature at which the first rounding of the apex of the cone occurs. Shrinkage or warping of the cone is ignored if the tip remains sharp.
2. *Softening Temperature (ST)* is the temperature at which the cone has fused down to a spherical lump with a height equal to the width of its base ( $H = W$ ).
3. *Hemispherical Temperature (HT)* is the temperature at which the cone has fused down to a hemispherical lump with a height equal to one-half the width of its base ( $H = \frac{1}{2} W$ ).
4. *Fluid Temperature (FT)* is the temperature at which the cone is nearly flat with a maximum height of 1/16th of an inch ( $H = 1/16 \text{ in.}$ ).

These ash fusion temperatures provide a relative comparison of ash melting characteristics. However, several limitations are recognized with this test method. These include:

- operator dependant results based on the degree to which the cones have melted
- different results for different heating rates
- initial deformation temperature, which is not necessarily the point at which the ash begins to melt
- ash content, which may not be entirely molten at the fluid temperature
- ash sample, which may not represent the mineral matter in the coal due to the ash preparation method
- difficulty producing a sample that is reflective of the entire coal quantity.

### 3.3.6 Standard for Measuring the Ash Fusion Temperature

ASTM Test Method D 1857 outlines a procedure for determining ash fusion temperatures. The ash fusion temperatures should always be specified for exposure to a

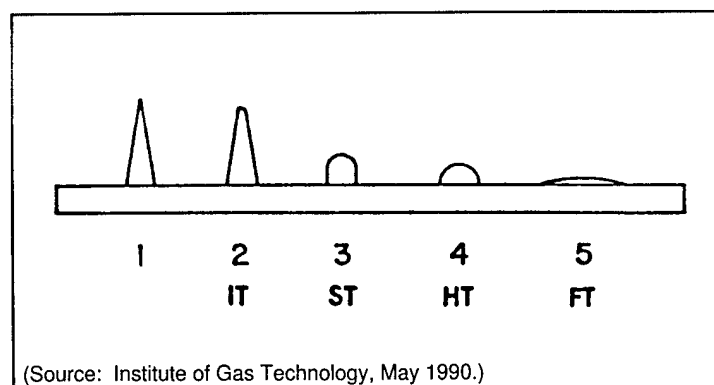


Figure 14. Ash fusion temperatures.

reducing atmosphere, not an oxidizing atmosphere, because the reducing atmosphere is always the worst case obtained in the combustion zone.

### **3.3.7 Hardness and Grindability**

Hardness and grindability describes the ease with which coal is pulverized. Consequently, pulverized coal boilers are the only technology sensitive to this characteristic. Equipment wear and power requirements are two concerns associated with grindability. Hard-to-pulverize coal requires more power to grind, thus increasing the cost of operation. Also, pulverizing hard coal increases the need for machinery maintenance because of excessive wear.

The grindability of a coal can be related to its carbon content (Figure 4). Essentially, the hardgrove index increases until the carbon reaches 90 percent, then it begins to taper off. Similar correlations show that coal is easiest to grind when volatile matter is roughly 20 percent. Unfortunately, these correlations do not always hold since the coal's grindability is also affected by moisture content. For this reason, grindability tests should be performed on an "as received" basis.

### **3.3.8 Grindability Indices.**

The standard measure for grindability is the Hardgrove grindability test—ASTM Test Method D 409. The Hardgrove test is used to predict the capacity and power consumption of bowl mill and roller/race mill pulverizers. The results of this test are expressed as an index ranging from 20 (hardest to grind) to 120 (easiest to grind). A reading of 100 defines a specific coal in Pennsylvania.

The Hardgrove grindability index has proven useful for higher rank coals. Unfortunately, when applied to lower rank coals, the index does not provide a good indication of mill capacity. This weak correlation is associated with the higher moisture content of lower rank coals. The Hardgrove grindability test should not be used in evaluating the performance of ball/tube mills that operate according to a different grinding mechanism. For these mills, the "bond work index" should be used. This index is used by Riley Stoker and corresponds approximately to the Hardgrove index.

### **3.3.9 Friability**

Friability refers to the tendency of coal to break apart during handling. For pulverized coal boilers, this characteristic is desirable because the coal is easy to grind. For most other boiler systems, however, friability is not desired.

Friable coals generate more fines during handling leading to storage and combustion problems. Increased fines raises the surface moisture held by the coal, accelerates oxidation, and increases the likelihood of spontaneous combustion. The most friable coals typically have a carbon content of about 90 percent.

Spreader stokers are particularly sensitive to friability because coal hitting the stoker paddles can be shattered, dropping coal fines at the front of the grate. Coal placed at the front of the grate may be discharged into the ash pit before it can be combusted.

### ***3.3.10 Standards for Measuring Friability.***

ASTM Test Methods D 440 and D 441 indicate the extent to which coal will break on impact and abrasion.

### ***3.3.11 Slaking***

Slaking describes the disintegration of coal into smaller pieces because of changes in moisture content. Coals with a high moisture content (typically low rank coals) are the most susceptible to slaking. Slaking is usually not important for coals with initial moisture content of less than 10 percent. For lignite and subbituminous coals with moisture content of greater than 30 percent, however, slaking becomes an important parameter.

Weathering, which is defined as slaking greater than 5 percent, is the defining criterion that separates bituminous from subbituminous coal.

### ***3.3.12 Weathering***

As coal degrades slowly when exposed to air, it is actually undergoing very slow combustion. Weathering causes some loss of heating value, with less than 1 percent the first year of storage for most coals, but up to 3 percent for low-rank coals. Firing characteristics can be affected by weathering, which also tends to make the majority of coal slack and promotes a reduction in size or crumbling. Slaking is greatest near storage pile surfaces and is greatest for low-rank coals. If conditions are such that oxidation of coal proceeds at a rapid rate, enough heat can be generated to cause spontaneous combustion.



### **3.3.13 Slagging**

Slagging is the accumulation of sticky flyash on boiler surfaces. Slagging occurs when the ash temperature exceeds fusion temperature, causing the ash to become molten or partially fused. When it hits the wall or tube surfaces, it chills and solidifies. Such slag build-up reduces heat transfer, thus lowering boiler efficiency.

Slagging deposits typically occur on cooler sections of the water wall. Deposits begin as a thin layer of dry, powdery material. As mineral matter continues to accumulate, fingers of material are formed that extend out from the deposit in the direction of gas flow. These fingers continue to grow until they are sufficient to insulate the outer surface from the cooling effects of the waterwall tubes. At this point, ash begins to melt and slag deposits form. The chemical composition of the initial powdery material is different from the outer material. It is believed that the inner material is rich in sulfate material while the outer material is rich in iron.

### **3.3.14 Slagging Indices**

Several indices have been proposed that measure a coal's slagging potential. Table 9 lists several slagging indices that rank a coal's tendency to slag. All are based on the ASTM ash analysis and are therefore subject to inaccuracies. Some are used exclusively for bituminous- or lignite-type ash. One index is based on the base-to-acid ratio (for Western coals) and another is based on the base to acid ratio multiplied by the sulfur content (for Eastern coals). It should be noted that these indices, when used together, do not always predict the same results.

### **3.3.15 Fouling**

Fouling occurs when the minerals  $\text{Na}_2\text{SO}_4$  and  $\text{CaSO}_4 + \text{Na}_2\text{SO}_4$  condense on flyash particles or boiler surfaces. Fouling is not a function of ash fusion temperatures, but is dependent on the sodium content of the coal. In general, the greater the sodium content, the greater the chances of fouling. Fouling begins with ash deposits high in sulfates of calcium, potassium, and sodium sulfate. The next layers are composed of sintered layers of discrete flyash particles. The outer layers, which form the bulk of the fouling material, are ordinary flyash.

Table 9. Slagging indices.

| Parameter  | Slagging Tendency |             |             |        |      |      |      |      |      |      |      |
|--|-------------------|-------------|-------------|--------|------|------|------|------|------|------|------|
|  | Low               | Medium      | High        | Severe |      |      |      |      |      |      |      |
| $T_{250}$ of Ash, °F<br>(Eastern and Western Coals)  | >2375             | 2550 - 2100 | 2275 - 2050 | <2200  |      |      |      |      |      |      |      |
| $R_{BA}$ in Ash<br>(Western Coals)   | <0.5              | 0.5 - 1.0   | 1.0 - 1.75  |        |      |      |      |      |      |      |      |
| Sulfur Slagging Index (15)<br>$R_{BA} \times (\% \text{ Sulfur, Dry Coal})$<br>(Eastern Coals)   | <0.6              | 0.6 - 2.0   | 2.0 - 2.6   | >2.6   |      |      |      |      |      |      |      |
| $Fe_2O_3/CaO$ in Ash<br>(Western Coal)   | <0.3<br>>3.0      | 0.3 to 3.0  |             | ≈ 1.0  |      |      |      |      |      |      |      |
| Fusion Slagging Index (16)<br>$R_{VS} = \frac{(\text{Max HT}) + 4 (\text{Min IDT})}{5}$  |                   | 2450 - 2250 | 2250 - 2100 | <2100  |      |      |      |      |      |      |      |
| Viscosity Slagging Index (15)<br>$R_{VS} = \frac{T_{250}(\text{OX}) - T_{10,000}(\text{RED})}{975 F_s}$<br>(Bituminous and Lignite Coals)  |                   | 0.5 - 0.99  | 1.0 - 1.99  | >2.0   |      |      |      |      |      |      |      |
| <div>Note: <math>R_{BA}</math> = Base-to-Acid Ratio</div> <div>Note: Max HT = highest reducing or oxidizing hemispherical temperature (°F)</div> <div>Min IDT = lowest reducing or oxidizing initial deformation temperature (°F)</div> <div><math>T_{250}(\text{OX})</math> = temperature at 250 poise slag viscosity in an oxidizing atmosphere (°F)</div> <div><math>T_{10,000}(\text{RED})</math> = temperature at 10,000 poise slag viscosity in a reducing atmosphere (°F)</div> <div><math>F_s</math> = slagging factor</div> |                   |             |             |        |      |      |      |      |      |      |      |
| Temperature (°F)   | 1900              | 2000        | 2100        | 2200   | 2300 | 2400 | 2500 | 2600 | 2700 | 2800 | 2900 |
| $F_s$  | 1.0               | 1.25        | 1.6         | 2.0    | 2.6  | 3.25 | 4.1  | 5.2  | 6.55 | 8.3  | 11.0 |

### 3.3.16 Fouling Indices

A number of fouling indices have been developed to indicate the fouling tendencies of coal (Table 10). They are not absolute values and can only be used to predict a coal's relative fouling potential. Based on the premise that fouling is caused by sodium compounds, these indices are closely tied to the  $Na_2O$  content of the ash as determined by the ASTM Test Methods D 2795 and D 3682. Due to vaporization of sodium and potassium compounds during testing, these methods tend to understate the amount of sodium in the mineral matter.

### 3.3.17 Porosity

Coal is a porous substance. That allows air and water to reach a coal's inner surface. Porosity is the term used to describe pore size. In terms of combustion, it

Table 10. Fouling indices.

|   | Fouling Tendency |                     |                  |         |
|---|------------------|---------------------|------------------|---------|
|   | Low              | Medium              | High             | Severe  |
| 1. % Na <sub>2</sub> O in Ash<br>(Western Subbituminous Coals)  | <1               | 1-2                 | 2-3              | >3      |
| Modifier *<br>% CaO in Ash  | > 25<br>(Lower)  | 15 - 25<br>(Medium) | < 15<br>(Higher) |         |
| 2. % Ash in Dry Coal<br>(Western Subbituminous Coals)   |                  |                     |                  |         |
| When Ash contains:  |                  |                     |                  |         |
| a. <1% Na <sub>2</sub> O  | <15              | 12-20               | >2               | 0       |
| b. 1 - 3% Na <sub>2</sub> O   | <10              | 8-15                | >1               | 5       |
| c. >3% Na <sub>2</sub> O  | < 7              | 6-10                | >                | 9       |
| 3. R <sub>BA</sub> x (% Na <sub>2</sub> O in Ash)<br>(Eastern Coals)  | <0.2             | 0.2 - 0.5           | 0.5 - 1.0        | >1.0    |
| 4. Strength of Sintered Fly Ash, Psi<br>(Eastern Coals)   | <1000            | 1000-5000           | 5000-16,000      | >16,000 |
| 5. Na <sub>2</sub> O + K <sub>2</sub> O in Dry Coal<br>Expressed in Equivalent<br>% Na <sub>2</sub> O (Eastern Coals) | <0.3             | 0.3 - 0.4           | 0.4 - 0.5        | >0.5    |
| 6. % of Chlorine in Dry Coal<br>(Eastern Coals)   | <0.3             | 0.3 - 0.5           |                  | >5.0    |
| * Use modifier in a relative sense for various coals or for borderline cases of the preceding parameter.              |                  |                     |                  |         |

is desirable for pores to be large (i.e., that there be high porosity) so that oxygen can reach the inner surfaces of the coal. Coals with larger pores can have a higher combustion rate and greater carbon burnout. Unfortunately, coals with larger pores are also able to carry more moisture into the furnace.

### 3.3.18 Standard for Measuring Porosity

The ASTM Test Method D 167 outlines a procedure for determining the porosity of a coal sample, which is expressed as a percentage of the coal's volume. Values typically range from 0.02 to 0.2 percent.

### 3.3.19 Ash Resistivity

Ash resistivity refers to the ability of flyash to hold an electric charge. This ability is important when an ESP is used to control particulates. If the ash resists holding a charge (i.e., has a high resistivity), then it cannot be removed from the gas stream. Hence, when using an ESP, it is desirable for the ash to have a low resistivity.

Flyash is high in carbon (usually because of inefficient combustion) and has a very high resistivity. Carbon has a resistance greater than 100 times that of iron, sodium, or calcium. The presence of sulfur lowers ash resistivity and is necessary for proper ESP operation.

### ***3.3.20 Standard for Measuring Ash Resistivity***

The resistivity index is based on the chemical index (B/A). As the index increases, the resistivity decreases.

### ***3.3.21 Density***

The density of coal depends primarily on the types of mineral matter in the coal. Density can be a useful value for coal cleaning, storage, and combustion calculations.

### ***3.3.22 Standard for Measuring Density***

The ASTM Test Method D 291 outlines a procedure for determining the density of a sample of coal.

### ***3.3.23 Plasticity***

The melting and swelling characteristics of coal as defined by plasticity vary with the carbon content of the coal. Although an important requirement for coking coals, the melting and swelling of coal can form deposits on the combustion grates or coal nozzles used in combustion equipment. Coals with a carbon content between 80 and 90 percent (dry, ash-free) will typically exhibit melting and swelling.

## **3.4 Reporting of Test Results**

The results of coal tests can be reported according to various bases. Table 11 lists four standard methods of evaluating coal. Conversion formulas have been developed for converting test results from one basis to another. The equations apply to heating values and the results of ultimate and proximate analyses (Table 12). Table 13 lists the conversion formulas (specified by ASTM D 3180). Table 14 illustrates the results of a proximate analysis and lists them for each of the four bases.

### 3.5 Coal Analysis Reliability

Test results are not perfect; two identical coal samples tested using the same procedure at the same laboratory are likely to yield different results. The tendency for these results to deviate is termed the test's "repeatability." Likewise, two identical coal samples tested using the same procedure at different laboratories will yield varying results. This tendency is known as the test's "reproducibility." Both the repeatability and reproducibility for a given test can be expressed numerically. These values indicate the difference between a pair of test results that is exceeded only 5 percent of the time. Table 15 lists the repeatability and reproducibility for many significant ASTM test methods.

**Table 11. Bases for evaluating coal.**

| Base                | Description   |
|---------------------|---|
| As determined (ad)  | Refers to results that are obtained when the coal sample is air dried before testing. The purpose of air drying is to bring the moisture content of the coal into equilibrium with the laboratory atmosphere so that moisture changes during testing are minimized.   |
| As received (ar)    | Refers to results that are obtained when the coal sample is tested after arriving at the laboratory.  |
| Dry (d)             | Refers to results that are obtained when the coal sample is stripped of all moisture (both surface moisture and bed moisture).  |
| Dry, ash-free (daf) | Refers to results that are expressed such that moisture and ash are excluded. "Dry, ash-free" should not be confused with "Dry, mineral-matter-free." Mineral matter is contained in the coal before combustion. Ash is produced during combustion and contains mineral matter as well as other elements drawn from the atmosphere. Also, some of the mineral matter leaves as exhaust gas. Hence, these two bases do not equally represent the constituents of the coal. |

**Table 12. Parameters for which conversion formulas apply.**

|                       |                  |
|-----------------------|------------------|
| Gross Calorific Value | Hydrogen         |
| Fixed Carbon          | Oxygen           |
| Volatile Matter       | Chlorine         |
| Ash                   | Sulfur (organic) |
| Total Carbon          | Sulfur (pyritic) |
| Carbon Dioxide        | Sulfur (sulfate) |
| Nitrogen              | Total Sulfur     |

Table 13. Conversion formulas.

| Bases for Evaluation |                     | Formula                             |
|----------------------|---------------------|-------------------------------------|
| As received (ar)     | As determined (ad)  | $\frac{100 - M_{ad}}{100 - M_{ar}}$ |
|                      | Dry (d)             | $\frac{100}{100 - M_{ar}}$          |
|                      | Dry, ash-free (daf) | $\frac{100}{100 - M_{ar} - A_{ar}}$ |
| As determined (ad)   | As received (ar)    | $\frac{100 - M_{ar}}{100 - M_{ad}}$ |
|                      | Dry (d)             | $\frac{100}{100 - M_{ad}}$          |
|                      | Dry, ash-free (daf) | $\frac{100}{100 - M_{ad} - A_{ad}}$ |
| Dry (d)              | As received (ar)    | $\frac{100 - M_{ar}}{100}$          |
|                      | As determined (ad)  | $\frac{100 - M_{ad}}{100}$          |
|                      | Dry, ash-free (daf) | $\frac{100}{100 - A_d}$             |
| Dry, ash-free (daf)  | As received (ar)    | $\frac{100 - M_{ar} - A_{ar}}{100}$ |
|                      | As determined (ad)  | $\frac{100 - M_{ad} - A_{ad}}{100}$ |
|                      | Dry (d)             | $\frac{100 - A_d}{100}$             |

M = weight percentage of moisture  
 A = weight percentage of ash  
 Note: These conversions apply for hydrogen and oxygen content only when these values do not include the hydrogen and oxygen of associated moisture.

Table 14. Sample proximate analysis.

| Basis for Determination | Moisture | Ash   | Volatiles | Fixed Carbon |
|-------------------------|----------|-------|-----------|--------------|
| As Received             | 23.24%   | 3.73% | 33.50%    | 39.53%       |
| As Determined           | 8.23%    | 4.46% | 40.05%    | 47.26%       |
| Dry                     | —        | 4.86% | 43.64%    | 51.50%       |
| Dry, Ash-Free           | —        | —     | 45.87%    | 54.13%       |

Air-dry loss in accordance with Method D 2013 = 16.36%.

Table 15. Test precision.

| Calorific Value<br>Hardgrove Grindability Index |  | Repeatability<br>50 Btu/lb<br>2 Index Points | Reproducibility<br>100 Btu/lb<br>3 Index Points |
|---|--|--|---|
| Ash Fusibility                                  | Reducing atmosphere  | 50 °F  | 125 °F  |
|   | -IT  | 50 °F  | 100 °F  |
|   | -ST  | 50 °F  | 100 °F  |
|   | -HT  | 50 °F  | 100 °F  |
|   | -FT  |  |   |
|   | Oxidizing atmosphere   | 50 °F  | 100 °F  |
|   | -IT  | 50 °F  | 100 °F  |
|   | -ST  | 50 °F  | 100 °F  |
|   | -HT  | 50 °F  | 100 °F  |
|   | -FT  |  |   |
|   |  | Repeatability<br>(% by weight)               | Reproducibility<br>(% by weight)                |
| Proximate Analysis                              | Moisture   | 0.20   | 0.30  |
|   | -Less than 5%  | 0.30   | 0.50  |
|   | -Greater than 5%   |  |   |
|   | Ash  | 0.20   | 0.30  |
|   | -No carbonates present   | 0.30   | 0.50  |
|   | -Carbonates present  | 0.50   | 1.00  |
|   | -Coals with more than 12% ash<br>containing carbonate and pyrite |  |   |
|   | Volatile Matter  | 0.20   | 0.40  |
|   | -High temperature coke   | 0.30   | 0.60  |
|   | -Anthracite  | 0.50   | 1.00  |
|   | -Semianthracite, bituminous,<br>low-temperature coke and<br>char | 0.70<br>1.00                                 | 1.40<br>2.00                                    |
|   | -Subbituminous<br>-Lignite                                       |  |   |
| Forms of Sulfur                                 | Sulfate  | 0.02   | 0.04  |
|   | Pyritic, less than 2%  | 0.05   | 0.30  |
|   | Pyritic, equal to or greater than 2%                             | 0.10   | 0.40  |
| Carbon Dioxide                                  | Under 1% carbon dioxide  | 0.05   | 0.10  |
|   | Over 1% carbon dioxide   | 0.10   | 0.20  |

Table 15. (Cont'd.)

|                   |   | Repeatability<br>(% by weight) | Reproducibility<br>(% by weight) |
|-------------------|---|--------------------------------|----------------------------------|
| Ultimate Analysis | Carbon  | 0.3                            | —                                |
|                   | Hydrogen                                      | 0.07                           | —                                |
|                   | Sulfur by Eschka or bomb-wash-<br>ing method  | 0.05<br>0.10                   | 0.15<br>0.25                     |
|                   | -Less than 2% sulfur<br>-≥ 2% sulfur<br>-Coke | 0.03                           | 0.15                             |
|                   | Nitrogen                                      | 0.05                           | —                                |
| Ash Analysis      | SiO <sub>2</sub>                              | 1.00                           | 2.00                             |
|                   | Al <sub>2</sub> O <sub>3</sub>                | 0.70                           | 2.00                             |
|                   | Fe <sub>2</sub> O <sub>3</sub>                | 0.30                           | 0.70                             |
|                   | TiO <sub>2</sub>                              | 0.10                           | 0.25                             |
|                   | CaO   | 0.20                           | 0.40                             |
|                   | MgO   | 0.30                           | 0.50                             |
|                   | Na <sub>2</sub> O                             | 0.10                           | 0.30                             |
|                   | K <sub>2</sub> O                              | 0.10                           | 0.30                             |
|                   | P <sub>2</sub> O <sub>5</sub>                 | 0.05                           | 0.15                             |



## 4 Coal Preparation

The introduction of more mechanized mining techniques that do not differentiate between coal and surrounding impurities has made coal preparation and cleaning increasingly important. Many of the larger coal mines have adjoining preparation plants where the coal is mechanically cleaned and screened to conform to the required size specifications.

### 4.1 Cleaning

Nearly two thirds of all the coal mined in the United States is mechanically cleaned. Coal cleaning (also known as “beneficiation”) removes noncombustible minerals and other impurities (such as sulfur) from coal. (When fired, noncombustible minerals become ash, and sulfur reacts to form environmentally hazardous gases.) Coal cleaning is normally done at the mining site or at a central cleaning plant before the coal is delivered to the power plant. Coal cleaning offers a number of benefits:

- The quality of coal delivered to the plant improves.
- The quantity of noncombustible materials shipped along with the coal is reduced. This can lower shipping costs by reducing the weight of the coal.
- The quantity of ash left in the furnace is reduced, thus lowering the cost of ash handling and disposal.
- The performance of boilers and auxiliary equipment is improved, as slagging, fouling and corrosion-related problems are reduced.
- The cost of removing sulfur from the flue gases is reduced

Coal cleaning presents the following disadvantages:

- Surface moisture may increase shipping costs by increasing the weight of the coal.
- Surface moisture due to coal cleaning can cause freeze-control problems during winter.
- Removal of sulfur through coal cleaning can increase the resistivity of flyash making it more difficult to collect with an ESP.

## **4.2 Sizing Coal With Crushers**

Crushing is usually done for sizing purposes. It is recommended that coal be sized at the mine or at a separate coal preparation site. Crushing coal on site creates dust and other hazards. Also, the practice of crushing already sized coal to break large lumps is a poor practice since the process will also break small coal, moving it out of the required specifications.

## **4.3 Mixing**

To achieve certain specifications, coals are sometimes mixed. Boilers need a good distribution of sizes to burn efficiently.

## 5 Coal Handling

Coal handling refers to the movement and storage of coal from the time it arrives at the plant until the time it enters the furnace. Figure 15 illustrates the flow of coal through a plant. Attention to coal handling practices can greatly reduce operating problems and costs. Ironically, good handling techniques demand little more time and effort than poor handling techniques.

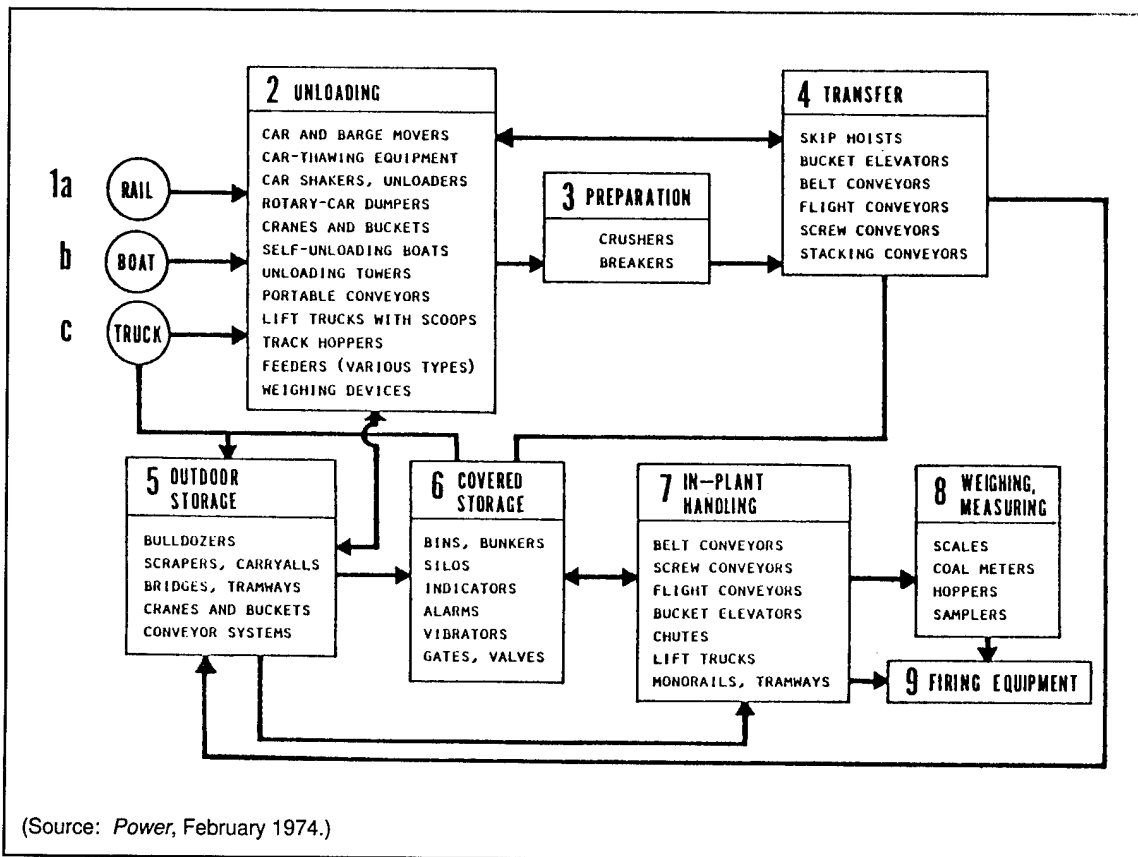


Figure 15. Flow of coal through plant.

## 5.1 Problems

Problems related to coal handling fall into five categories:

1. *Oxidation.* Coal is valuable because of its ability to oxidize (burn). Unfortunately, this oxidation can occur outside the furnace. For instance, during storage and handling, coal oxidizes in the presence of air. This process reduces the heating value of the coal from 1 to 3 percent in the first year. Furthermore, if the heat generated by this slow oxidation is unable to escape, the coal can ignite.
2. *Segregation.* Segregation is the grouping of coal based on the size that occurs during storage and handling. For example, in making a coal pile, large pieces roll down the sides while small pieces sift down through the center (Figure 16).

Coal that segregates highly in storage is more likely to oxidize and ignite because larger coal particles allow air to flow through the pile, while finer coal traps heat. In addition, segregated coal may plug coal handling and storage equipment. Segregated coal that reaches the furnace can cause an uneven distribution of coal on the grate, thereby lowering combustion efficiency.

3. *Breakage (Size Degradation).* Coal handling tends to break coal into smaller pieces. Typically, each handling operation increases the amount of fines by as much as 5 percent. This breakage encourages segregation and increases the presence of coal dust. Most importantly, breakage can produce coal that does not meet size specifications. Such situations lower boiler efficiency and create operating problems.
4. *Moisture.* Moisture that accompanies coal causes several problems. Wet coal can freeze during winter transport and storage and water run-off from coal storage is polluted, so that it poses a waste disposal problem. In addition, steam generated by oxidation during storage creates air passages through the coal, which intensify the oxidation process. Wet coal can clog equipment, and moisture accompanying coal into the furnace lowers combustion efficiency.
5. *Air Pollution.* Coal dust that becomes airborne during handling and

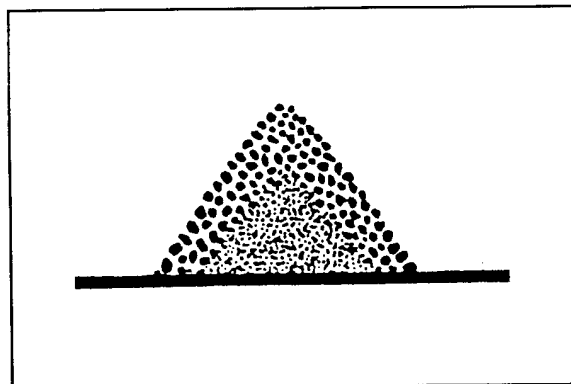


Figure 16. Segregation.

storage is air pollution and can be explosive. Note: Because coal yard operations expose personnel to numerous potential hazards, safety considerations should receive priority during all coal-handling procedures. Only qualified and authorized personnel should be allowed to operate coal-handling equipment. All safety equipment including guards and shields should be kept intact and all equipment should be operated in a professional and safe manner. Unsafe actions or equipment should be stopped immediately and reported to the plant supervisor for corrective measures.

The remainder of this chapter describes coal-handling procedures that minimize the occurrences of these problems.

## **5.2 Delivery to the Plant**

Before methods of coal delivery are discussed, note that all incoming coal should be weighed. This practice allows the plant to check contractor weigh-bills and may help personnel in spotting coal quality problems. For example, if a load is heavier than expected, there may be excess moisture or perhaps a high percentage of fines in the load.

Coal is delivered to the plant by truck, railroad, or barge. Even though truck and railroad deliveries are most common, each plant should choose the most economical method compatible with timely delivery and the plant's unloading equipment. Only experienced and qualified personnel who are familiar with facility unloading practices and procedures should be given the responsibility of receiving coal. All training and certification should be kept up to date, and clear procedures should be made available to all personnel responsible for unloading coal.

### **5.2.1 Transportation**

**5.2.1.1 Truck.** Truck delivery offers several advantages over other forms of coal transport. For instance, trucks can use roads, whereas railroads and barges are limited to tracks and waterways. This makes truck transportation faster and more accessible in most situations. Truck delivery is best suited for delivery ranges of 5 to 400 miles for a plant that consumes between 25 and 200,000 tons of coal per year. A single truck can hold approximately 30 tons. For this transport range, delivery time varies from 1 to 10 hours including loading and unloading. Because most trucks are equipped with hydraulic dump beds, it is easy to unload coal onto the ground or into underground hoppers. Trucks should be unloaded on solid, level ground that is clear of power lines and overhead equipment.

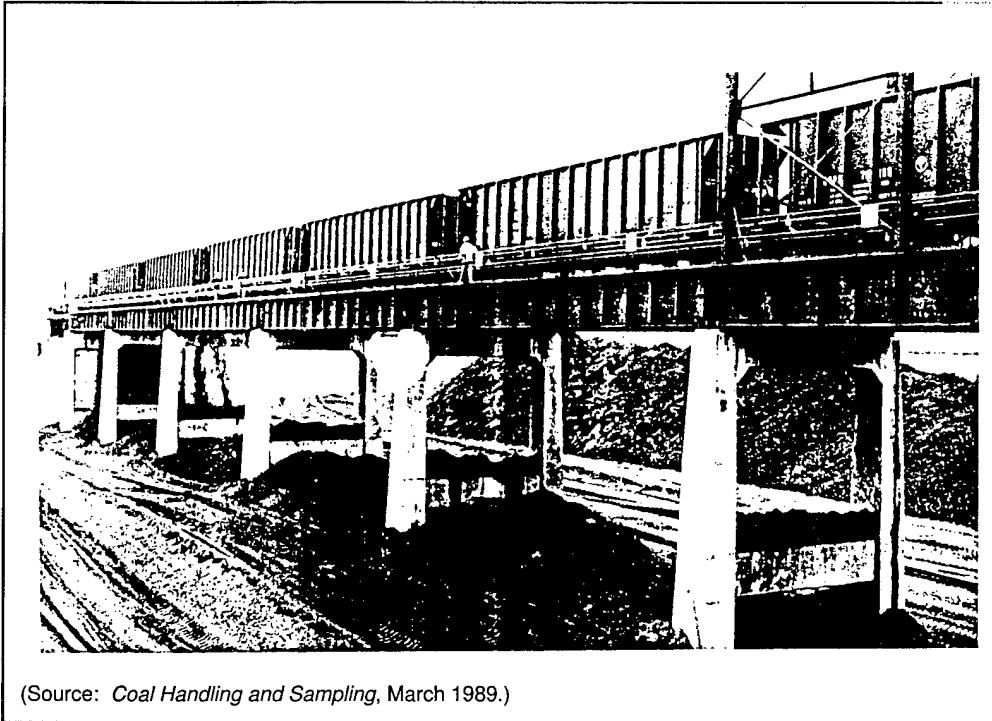
**5.2.1.2 Railroad.** Railroad transport is economical for distances of 10 to 2000 miles, especially when rail service is available directly from the mine (or preparation facility) to the plant. Railroads best serve plants that consume from 50 to 4 million tons of coal per year. One railcar can hold around 100 tons. Delivery can take anywhere from a day to a month, including loading and unloading time. When the coal arrives at the plant, there are several methods for unloading railcars. The most common method is "gravity discharge." Some plants use a crane, but a crane is undesirable because it increases breakage and encourages segregation of the coal.

"Gravity discharge" can be done two ways. Coal can flow out the bottom of the railcar or it can be dumped by overturning the entire railcar. Cars emptied from the bottom can be discharged at ground level into an underground hopper or from an elevated bridge (or trestle) into a pile, hopper, or truck (Figure 17). To make emptying easier, the railcars have sloped bottoms (Figure 18). Unfortunately, these sloped bottoms do not prevent wet or frozen coal from sticking to the car. For these situations, a car shaker (Figure 19), or car hoe (Figure 20 ) can dislodge the coal.

A rotary car dumper is valuable for a plant where large quantities of coal must be unloaded quickly (Figure 21). Rotary car dumpers are economical when significant demurrage charges (fines paid by the plant for holding a freight car beyond its scheduled departure time) result from a slow turnaround of railcars.

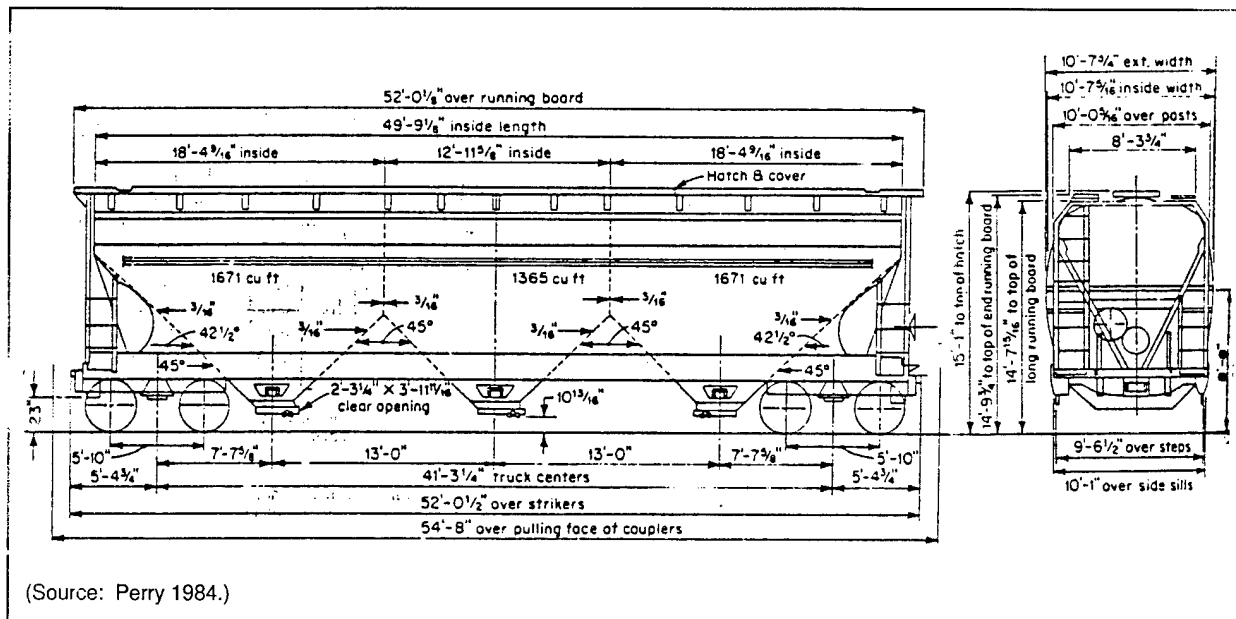
For unloading frozen coal, a thawing shed may be necessary. The purpose of a thawing shed is not to thaw an entire load, but to break the bonds between the coal and the sides of the railcar. A typical thawing shed employs infrared heaters that heat the railcar to loosen the coal that has frozen to its sides (Figure 22). For potentially explosive conditions (such as those of a munitions plant) steam can be used. Caution should be exercised as use of an open flame is never safe.

**5.2.1.3 Barge.** River barge delivery is practical for distances of 10 to 1000 miles, especially when water transportation is near both the mine (or preparation facility) and the boiler plant. Barge transportation is best for plants that consume more than 50,000 tons of coal per year. One barge can carry anywhere from 600 to 3000 tons. Delivery can take anywhere from a day to a month. At the plant, barges are unloaded by a bucket elevator system or by crane. Sometimes barges even carry their own crane.



(Source: *Coal Handling and Sampling*, March 1989.)

Figure 17. Trestle.



(Source: Perry 1984.)

Figure 18. Typical coal car.

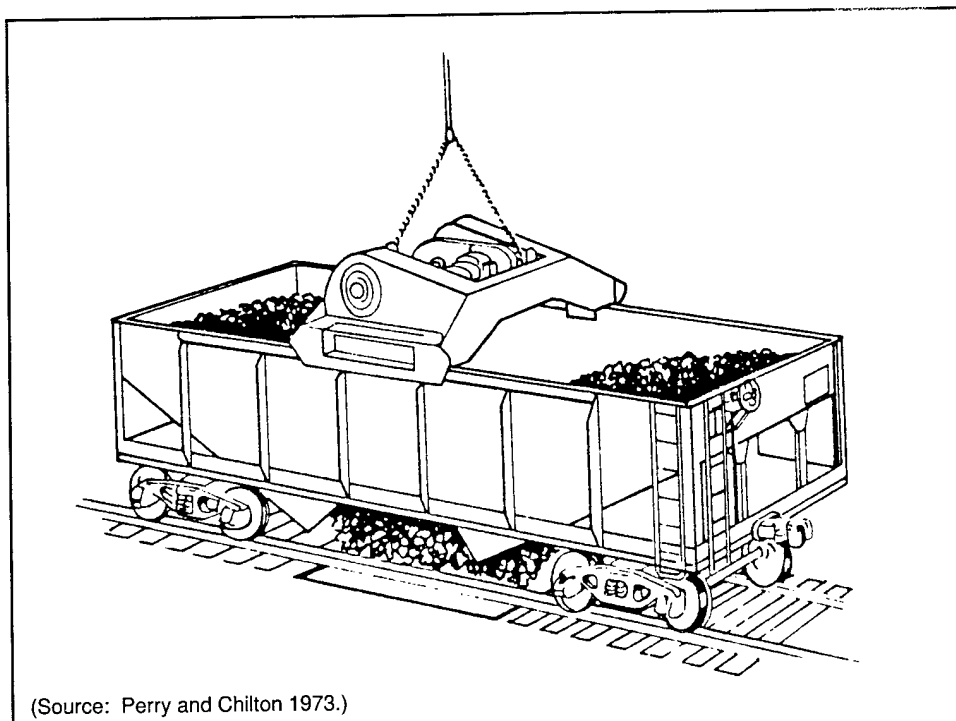


Figure 19. Rail car shaker.

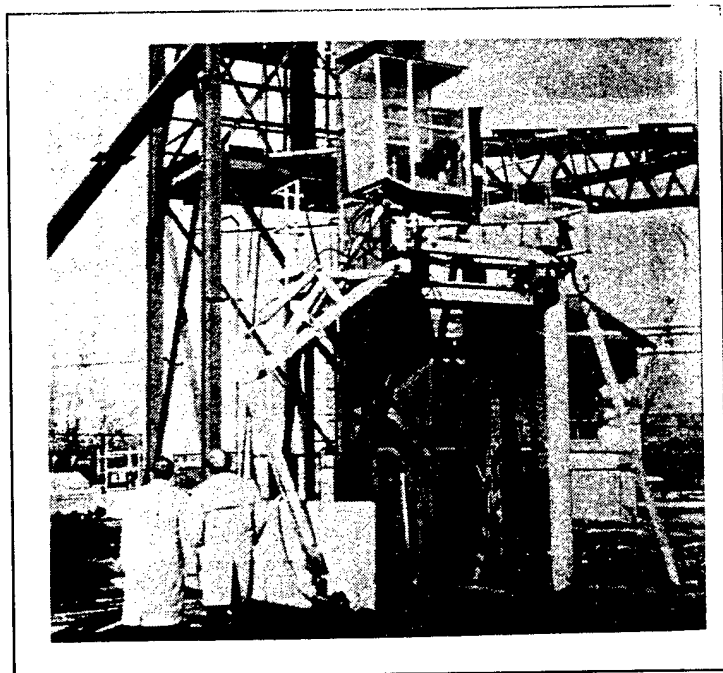


Figure 20. Rail car hoe.



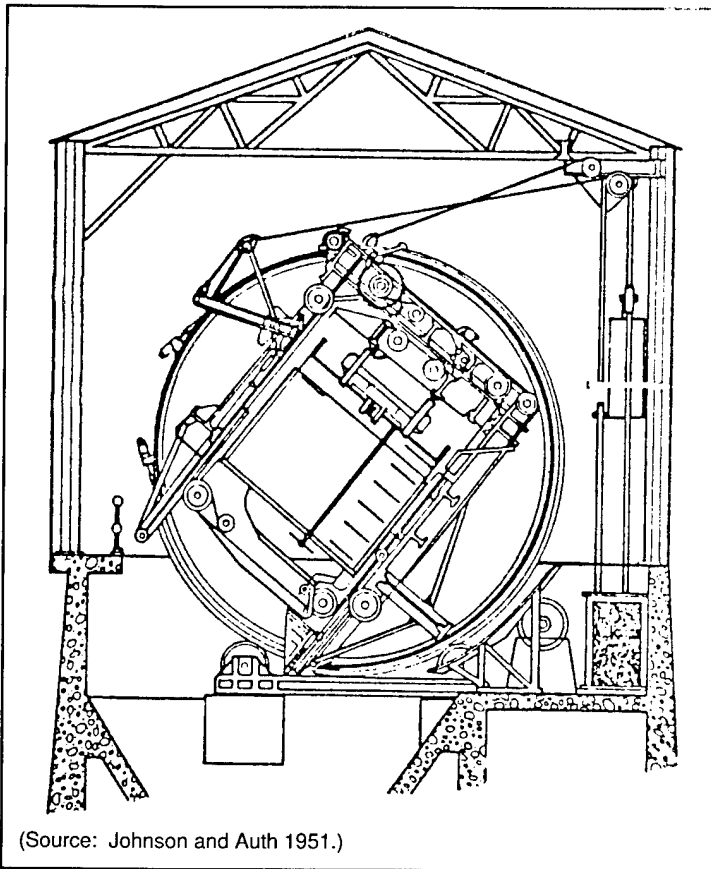


Figure 21. Rotary rail car dumper.

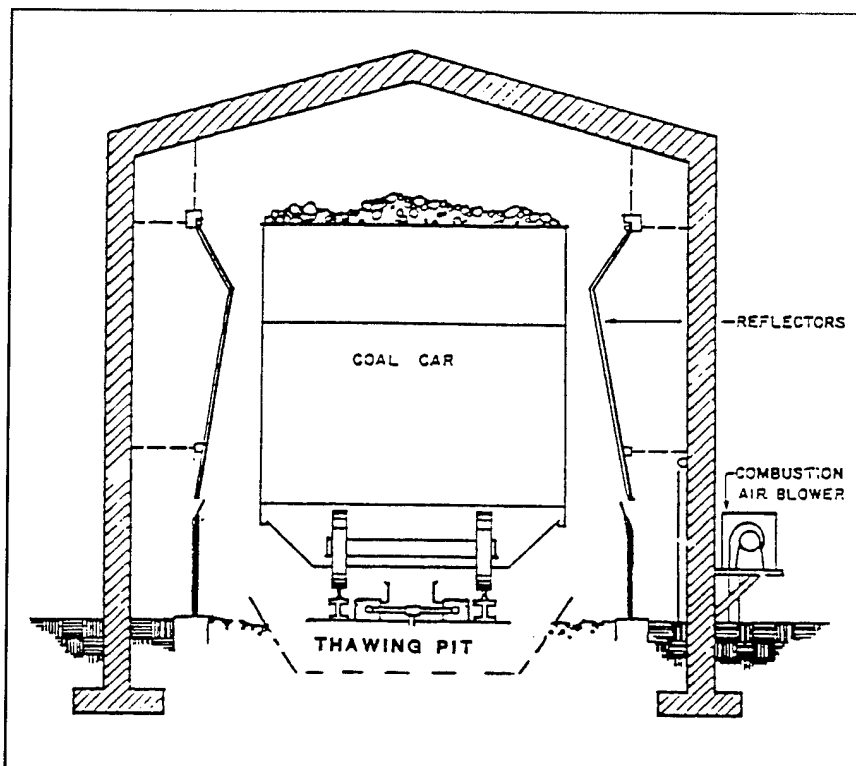


Figure 22. Thawing shed.

Lake and ocean vessels are another means of water transportation. Some of these vessels can carry up to 50,000 tons of coal. Delivery time generally falls between 1 and 5 weeks.

**5.2.1.4 Other Methods.** Coal can be transported by conveyors to the plant. However, this technique is not practical unless the plant is within a few miles of the mine (or preparation facility). Also, coal can be transported by suspending it in water and pumping it through a pipeline (called a slurry flow pipeline). Once at the plant, this coal must be dried. The use of such pipelines is rare and primarily experimental.

### **5.2.2 Scheduling**

In most cases, a plant should receive coal as it is needed for normal operations. Although there may be certain situations when the plant must replenish its long-term storage, a plant should have a routine delivery schedule. Some exceptions arise in areas where winter delivery is uneconomical or impossible. For these installations, a plant must receive its annual supply of coal over the summer. By scheduling these deliveries to match a plant's unloading capacity, the installation can reduce the possibility of demurrage charges.

## **5.3 Moving Equipment**

### **5.3.1 Cranes**

A clamshell (or grab bucket) crane can be used for unloading trains and barges and removing hot spots in a coal pile (Figure 23). A crane provides the only practical means for unloading barges, but gravity discharge is the preferred method for unloading trains.

### **5.3.2 Tractors**

Tractors are used to move coal around the yard as well as for pile management. The following sections compare these three tractor types:

- track-type dozer
- wheel-type dozer
- wheel-type loader (or front-end loader).

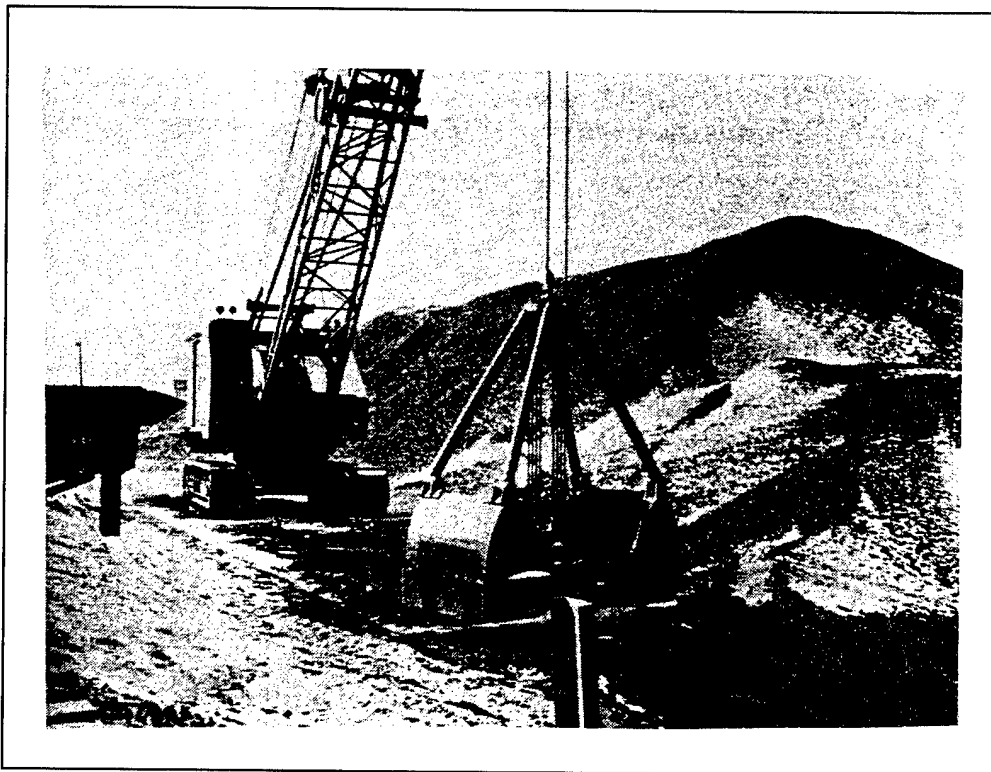


Figure 23. Crane with clamshell bucket.

**5.3.2.1 Track-Type Dozer.** Track-type dozers have excellent traction and can push large amounts of coal (Figure 24). Unfortunately, the grinding action of its treads degrades (breaks) coal. For this reason, the track-type dozer is not recommended.

**5.3.2.2 Wheel-Type Dozer.** Although the wheeled dozer has less traction than its tracked counterpart, it offers several advantages (Figure 24). First, a wheeled

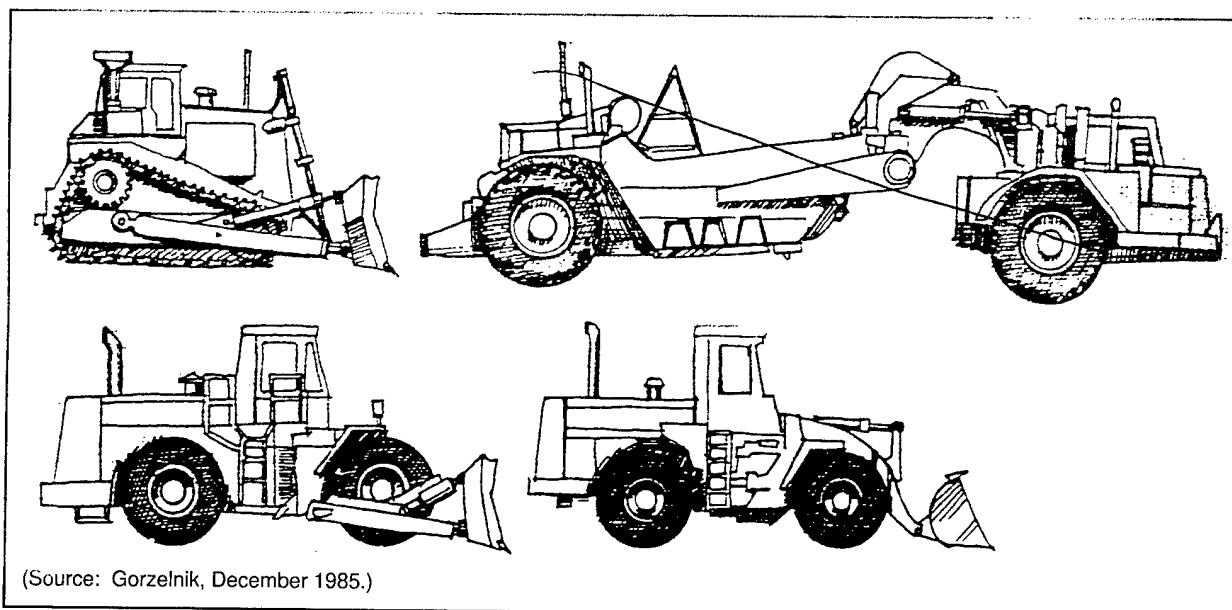


Figure 24. Tractor types.

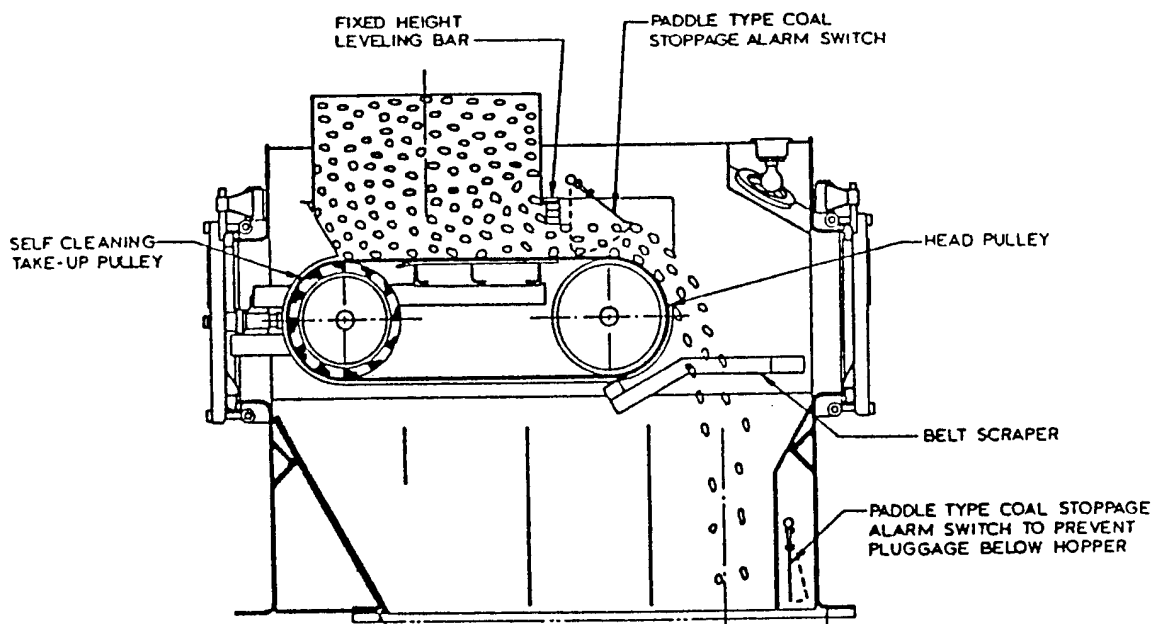
tractor travels faster and is less damaging to coal. Second, the wheeled vehicle has a smaller area of contact with the ground giving it three times the compaction pressure of the tracked vehicle. This compaction pressure is helpful for managing stored coal, as compacting is a method for reducing the oxidation.

**5.3.2.3 Wheel-Type Loader (Front-End Loader).** The wheel-type vehicle offers the same advantages as the wheel-type dozer (Figure 24). However, the loader surpasses the dozer in versatility by carrying instead of pushing its load. The wheeled loader (or front-end loader) is the preferred tractor type for most coal yard operations.

### 5.3.3 Feeders

Feeders are responsible for transferring coal from storage to the conveyor system (or to a pulverizer). Their primary function is to control the flow of coal. There are two basic types of feeders: volumetric and gravimetric. A volumetric feeder controls the flow of coal by volume, while a gravimetric feeder controls the flow by weight.

**5.3.3.1 Belt Feeder.** A volumetric belt feeder is probably the most accurate volumetric feeder. The coal rides on a belt under a fixed gate called a leveling bar. The flow of coal is controlled by varying the speed of the belt (Figure 25).



(Source: Schmidt Associates, Inc., July 1986.)

Figure 25. Volumetric belt feeder.

A gravimetric belt feeder maintains a constant belt speed. The flow is controlled by using the weight of the coal to adjust the leveling bar. The height of the leveling bar determines the thickness of the coal on the belt (Figure 26). Belt conveyors used as feeders are short and have closely spaced idlers. These idlers support the belt as coal is dropped from the hopper.

**5.3.3.2 Bar-Flight Feeder (or Drag Feeder).** A bar-flight feeder is a volumetric feeder that uses chain driven paddles to drag coal along a channel. The flow of coal is controlled by varying the speed of the chains. The bar-flight feeder is good for handling small quantities of coal (Figure 27).

**5.3.3.3 Apron Feeder (or Pan Feeder).** An apron feeder is a volumetric feeder that carries coal on overlapping steel pans driven by chains. The flow of coal is controlled by varying the speed of the chains. This slower type of feeder is common for removing coal from an under-the-track hopper. The apron feeder requires significant maintenance and does not operate efficiently at inclines steeper than 25 degrees (Figure 28).

**5.3.3.4 Screw Feeder.** A screw feeder is a volumetric feeder that uses a rotating auger to advance coal along a U-shaped trough. The flow of coal is controlled by varying the speed of rotation. Screw feeders are best suited for small plants that receive coal by truck (Figure 29).

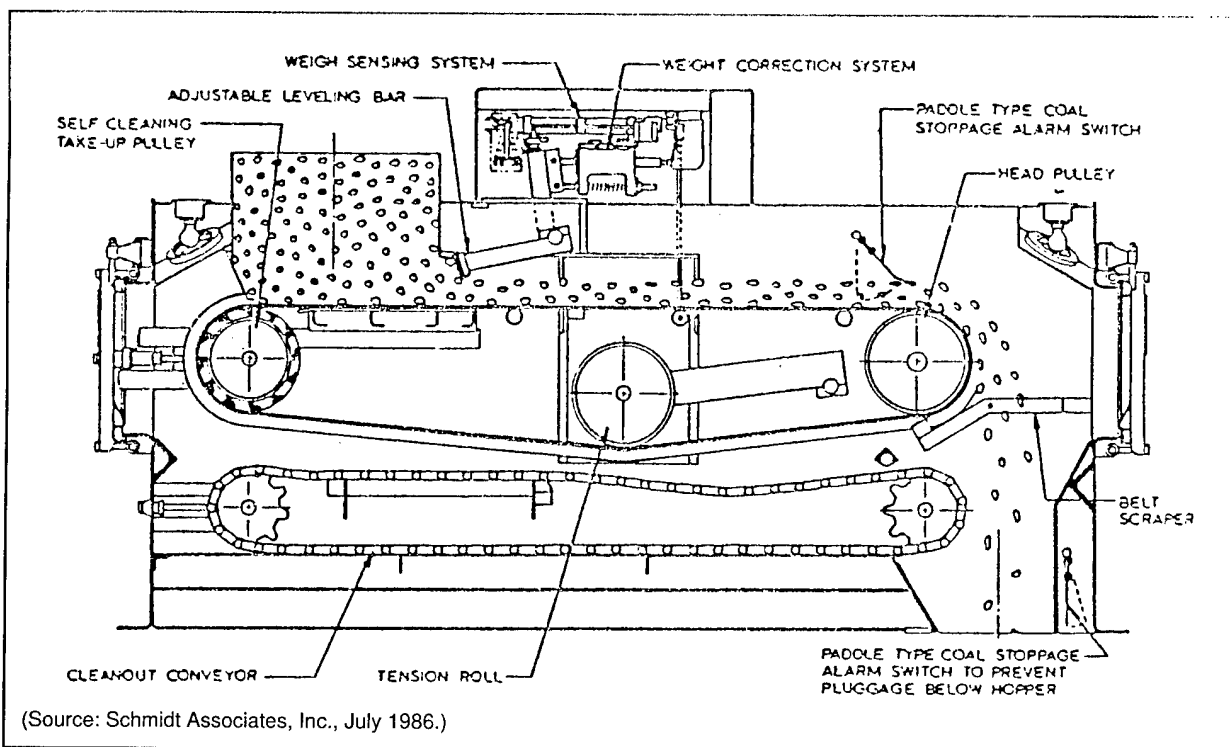


Figure 26. Gravimetric belt feeder.

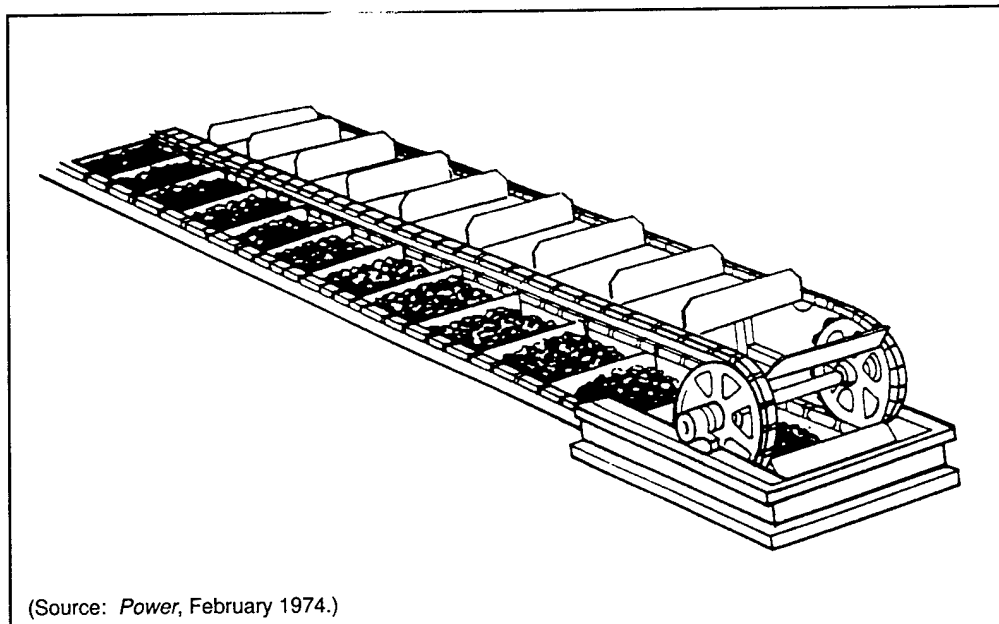


Figure 27. Bar-flight feeder.

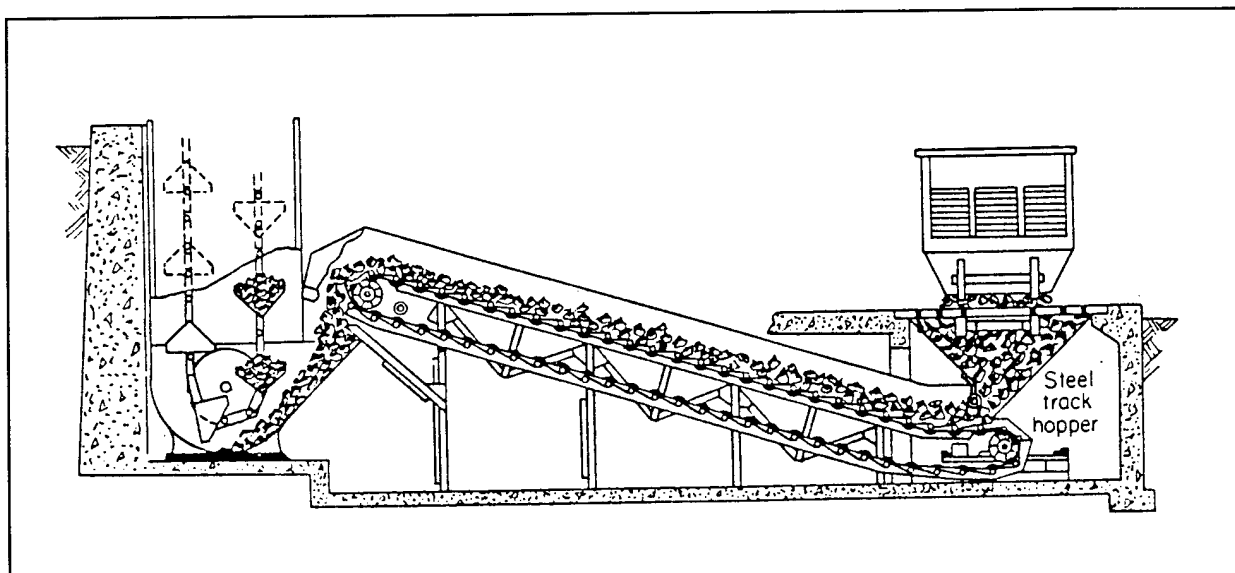
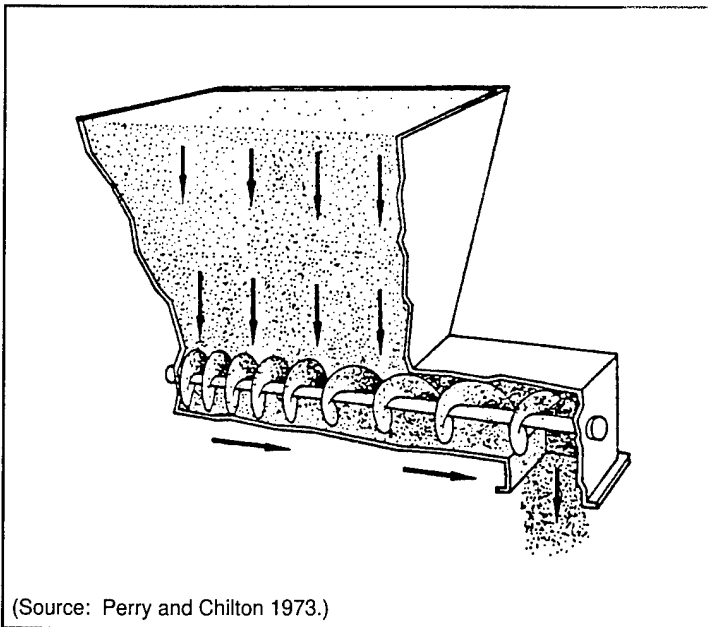


Figure 28. Apron feeder delivering coal from a track hopper to a bucket elevator.

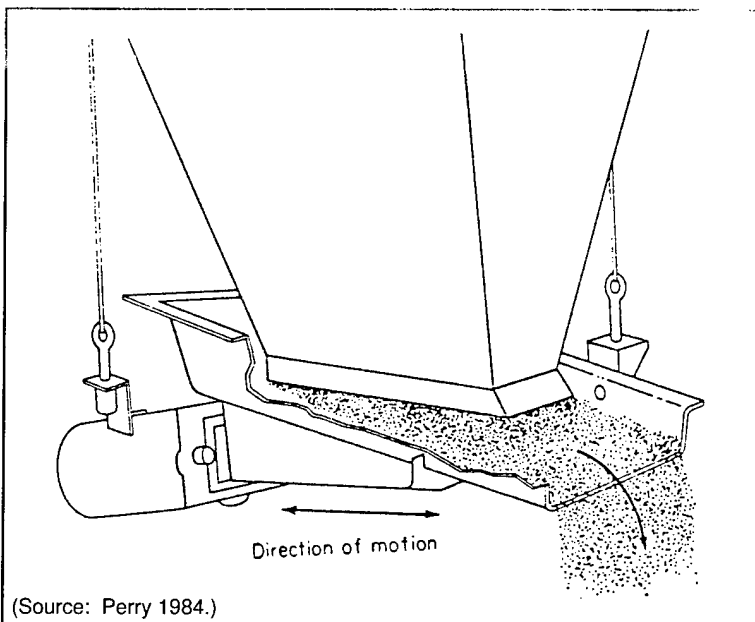


(Source: Perry and Chilton 1973.)

Figure 29. Screw feeder.

**5.3.3.5 Vibrating Feeder.** A vibrating feeder is a volumetric feeder that uses agitation to move coal along a pan. As the pan vibrates, coal flows steadily uphill or downhill. The flow of coal is controlled by varying the intensity of vibration. Vibrating feeders require little maintenance (Figure 30).

**5.3.3.6 Reciprocating Feeder.** A reciprocating feeder is a volumetric feeder that uses oscillation to move coal along a pan. As the full pan moves backward, coal hits a stationary plate, which slides the coal off the far end. During the forward stroke, the cleared portion of the pan moves beneath the hopper and fills with coal; the flow is controlled by varying the stroke length of the pan (Figure 31).



(Source: Perry 1984.)

Figure 30. Vibrating feeder.

### 5.3.4 Conveyor Systems

If coal storage were unnecessary, a plant would need only a front-end loader to move coal from the unloading point to the stoker hoppers. However, most plants maintain live and reserve coal storage. Conveyor systems move coal to and from these areas. In addition to managing storage with conveyors, there are several advantages to having conveyors under the bunkers. For instance, when the stoker hoppers cannot be fed by a chute, conveyors may provide the only practical way to deliver coal from the bunkers. Conveyors can also empty sections of the bunker to prevent fires, make repairs, or reclaim coal from dead spots in the bunker.

Conversely, conveyor systems can aggravate segregation. During the discharge of a conveyor, finer coal tends to accumulate directly beneath the conveyor, while larger pieces tumble down the outside of the pile being formed. The result is a "cylinder" of fines down the center, with the coal gradually increasing in size toward the outside of the storage area. Unfortunately, this segregation is not reversed when the coal is removed from the storage area. The larger pieces tend to flow more easily, leaving steep banks of fines. When these banks are undercut sufficiently, they collapse, allowing a large quantity of fine coal to flow at once.

Most conveyor systems lift coal as well as move it around the plant. While some systems are better for lifting, others are better for horizontal or slightly inclined runs.

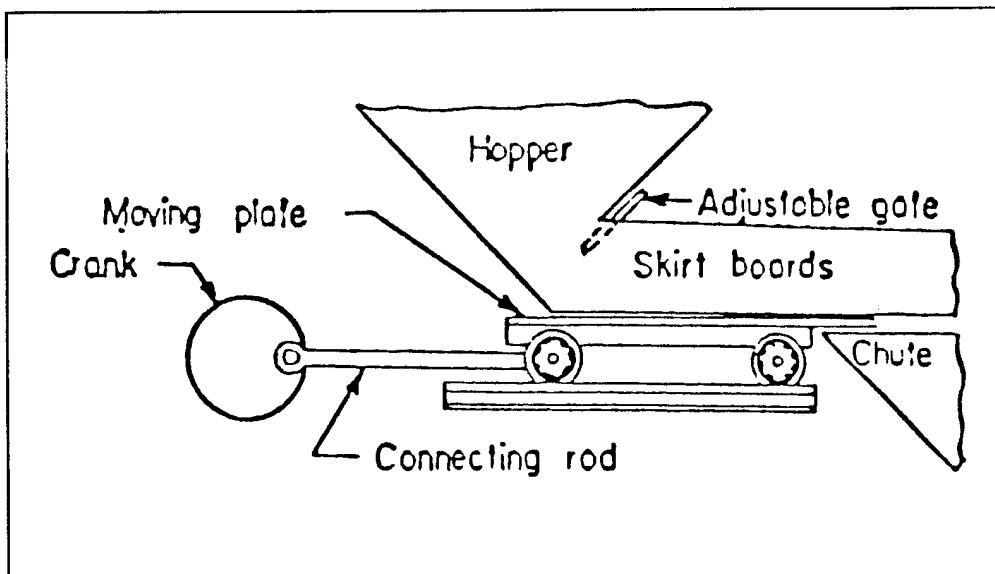
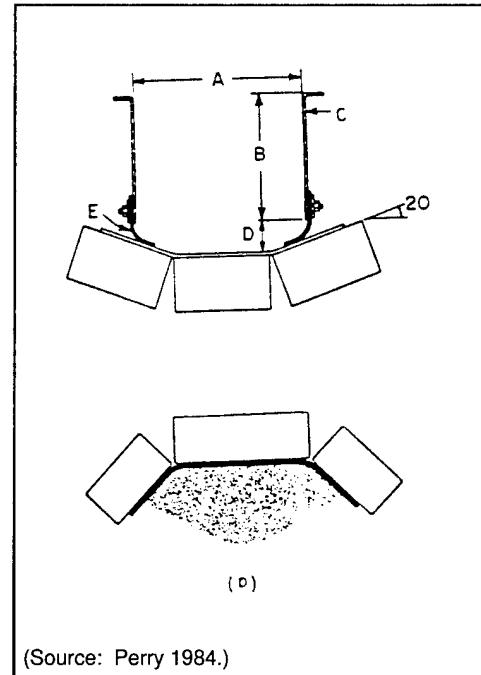


Figure 31. Reciprocating feeder.



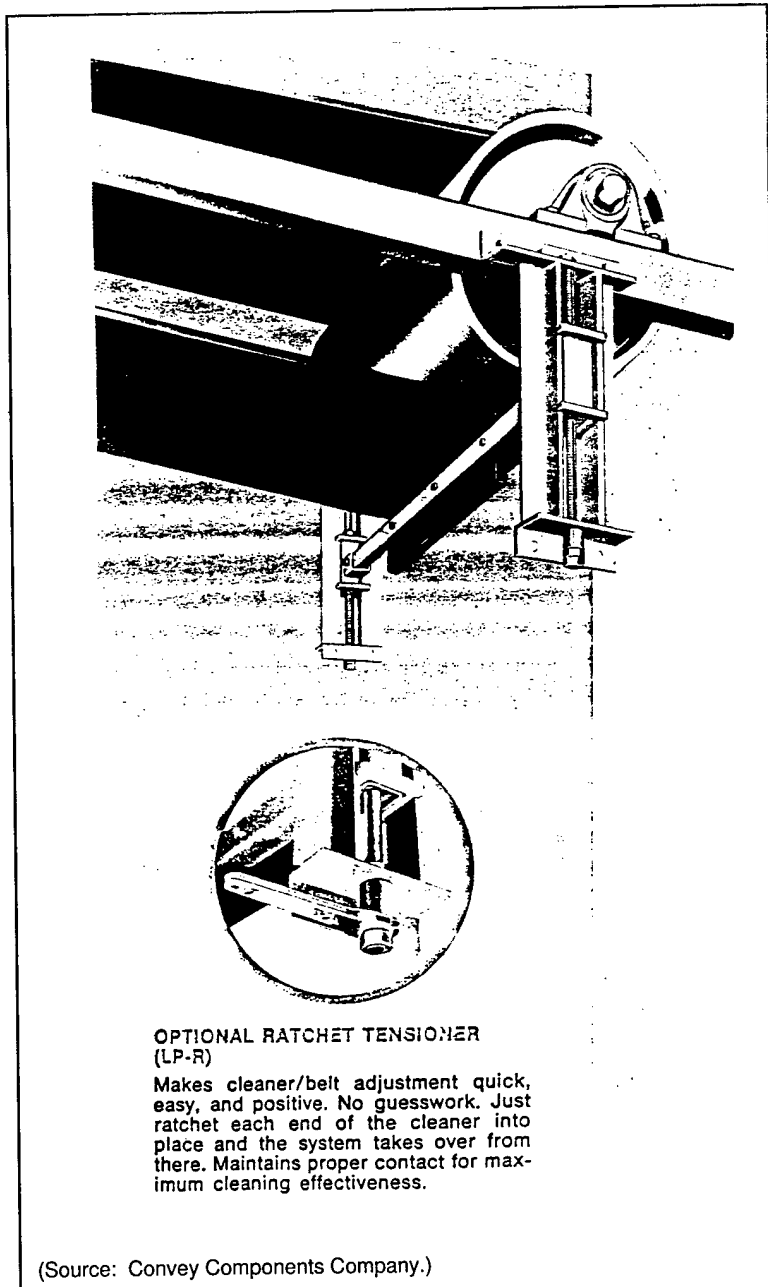
**5.3.4.1 Belt Conveyor.** The belt conveyor is popular because it has few moving parts and requires little power to operate. The belt conveyor performs well horizontally or at inclines of up to 20 degrees. (In warmer climates, the maximum incline is a few degrees less.) Some important aspects of belt conveyors are:

- Belt conveyors used outside should be covered to protect coal from the weather and to limit dust emissions.
- Belt idlers should be properly maintained and lubricated to avoid belt damage, seizing and fire (Figure 32).
- Skirtboards are required where coal is loaded. Each skirtboard should be approximately two-thirds the belt width, and long enough to prevent coal spillage (Figure 32).
- Belt take-ups are necessary to provide proper belt tension. Gravity-type take-ups are preferred; however, screw-type take-ups are satisfactory for conveyors less than 40 ft long. The screw-type take-up is typically part of the tail pulley.
- Belt sag should be adjusted to 2 percent. To determine belt sag, unload and turn off the conveyor. (Switches should be locked off and notices posted.) Using a straight edge and scale, two measurements should be taken. First, measure the distance between two neighboring rollers (X). Second, with the straight edge placed on the belt across the two rollers, measure the distance from the belt to the straight edge (Y). The percentage of belt sag is (Y/X) multiplied by 100 percent.
- Primary and secondary belt cleaners discharge coal that has stuck to the belt at the head pulley. Belt cleaners must also clear the clean side of the belt before it reaches the belt take-ups and the tail pulleys. Counterweighted type cleaning devices are not recommended because they become ineffective very quickly (Figure 33).



(Source: Perry 1984.)

**Figure 32. Skirtboard.**



**Figure 33. Belt cleaners.**

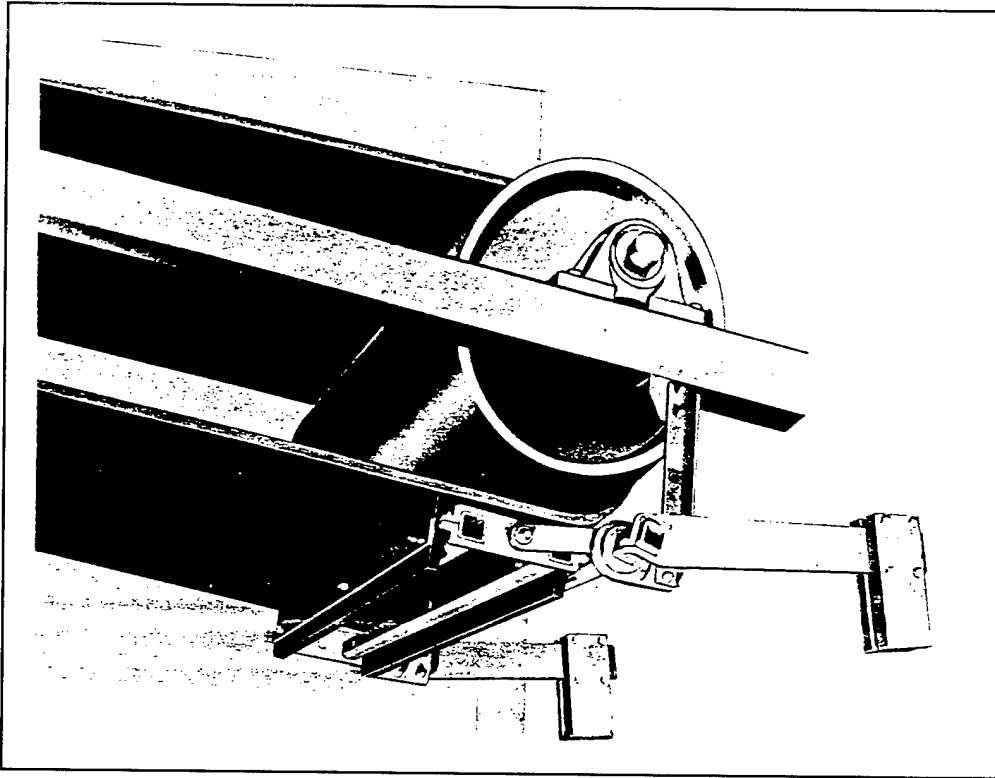


Figure 33. (Continued).

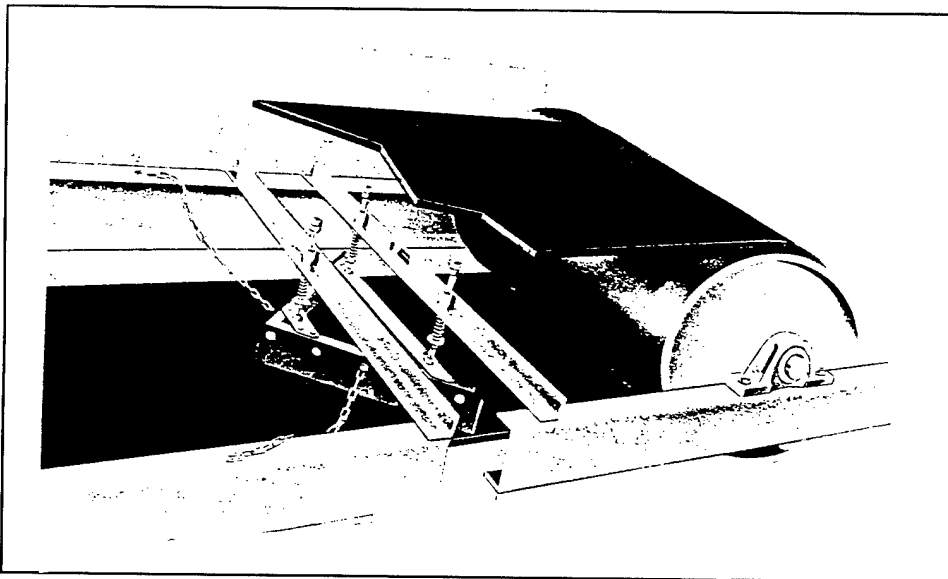


Figure 33. (Continued).

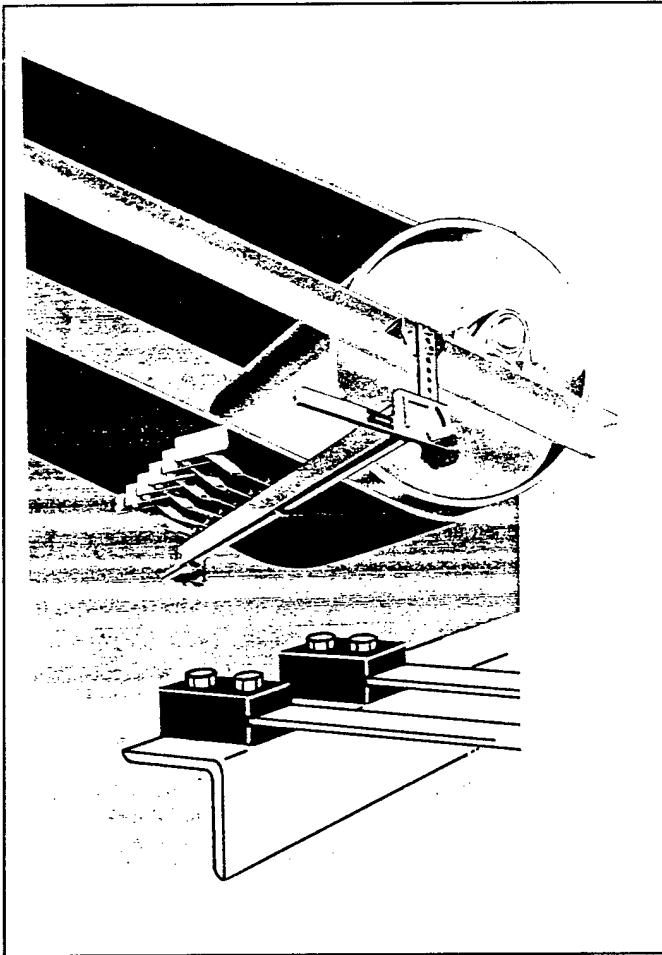


Figure 33. (Continued).

- Most belt conveyors use magnets to remove tramp iron from coal. One such system employs a magnetic head pulley to redirect tramp iron from the coal spout to a collection bin.
- The two ends of the belt are connected to form a loop. If this loop breaks, it should be repaired using a vulcanized or metal lace splice. Vulcanized splices are more dependable. Spare parts and extra belt lengths should be kept at the plant. Most belt suppliers provide quick repair service to minimize equipment down time.

The simplest way to unload a belt conveyor is to let the coal fall off the end. However, it is frequently desirable to unload coal in specific locations along the belt. Plows and trippers make this possible.

- A plow is an angled blade that forces coal from one or both sides of the conveyor belt. The plow can be fixed or movable. Plows are simple

mechanisms requiring little maintenance, but a poorly adjusted plow can cause belt damage.

- A tripper dumps coal by overturning the belt. One type of tripper uses special guide rollers to flip the belt. Another type redirects the belt down and back so that coal falls off the end. This coal falls into a chute that diverts it past the now empty belt passing underneath. Both types of trippers can be fixed or mobile. Mobile trippers (also known as “tripper cars”) run on tracks over the bunker. Tripper cars can be used to layer coal in the bunker by moving the car back and forth over the bunker. This technique limits coal segregation in the bunker.

**5.3.4.2 Bar-Flight Conveyor (or Drag Conveyor).** The bar-flight conveyor uses chain driven paddles to drag coal along a channel (Figure 34). This conveyor system works well horizontally and at inclines of up to 40 degrees. Each degree of incline over 30 degrees reduces the conveyor capacity by approximately 1 percent. The drag conveyor is noisy and requires a lot of maintenance. Due to the abrasive nature of coal, wear is most severe along the conveyor’s bottom. Maintenance is much simpler when the bottom plates of the trough can be replaced without disturbing the flights or side plates. Bar-flight conveyors can be fitted with drops and gates to distribute coal to the bunkers.

**5.3.4.3 Skeletal-Flight Conveyor (En Masse Conveyor).** The skeletal-flight conveyor, also known as the en masse conveyor, is similar to the bar-flight conveyor in that chains move flights through a channel, yet there are differences in the flights



Figure 34. Bar-flight conveyor.

and the channel (see Figure 35). For instance, the paddles of the skeletal-flight conveyor are not as solid as are those of the bar-type. Also, the channel of the skeletal-flight conveyor is completely enclosed whereas that of the bar-flight conveyor is open on top. In particular, the enclosed channel of the skeletal-flight gives it some unique abilities:

- The completely enclosed channel gives the skeletal-flight conveyor the ability to move coal vertically, horizontally, and on an incline. Furthermore, this conveyor system can change directions without transferring the coal to a new conveyor.
- The skeletal-flight conveyor can be loaded to as high as 90 percent of its cross-sectional area.
- The completely enclosed channel provides excellent dust control.
- Discharges from the conveyor do not required complicated chutework.
- The skeletal-flight conveyor is somewhat quieter than the bar-flight conveyor.
- The skeletal-flight conveyor requires approximately twice the horsepower of a standard belt conveyor.
- The skeletal-flight conveyor is more susceptible to damage from foreign material than the belt conveyor. Special care should be taken to limit damage to the housing.

**5.3.4.4 Screw Conveyor.** The screw conveyor uses a rotating auger to advance coal through a tube or along a U-shaped trough. This conveyor type is economical for loads less than 50 tons per hour. However, the conveyor should not be loaded beyond 30 percent of the trough's cross-sectional area, even if excess power is available. Furthermore, as the screw conveyor is inclined, its carrying capacity decreases.

**5.3.4.5 Bucket Elevator.** The bucket elevator is used to lift coal. Because it requires a great deal of maintenance, the facility should carry an inventory of spare parts and follow a program for routine maintenance. Two types of bucket elevator are commonly used in coal handling: the centrifugal discharge elevator and the continuous discharge elevator.

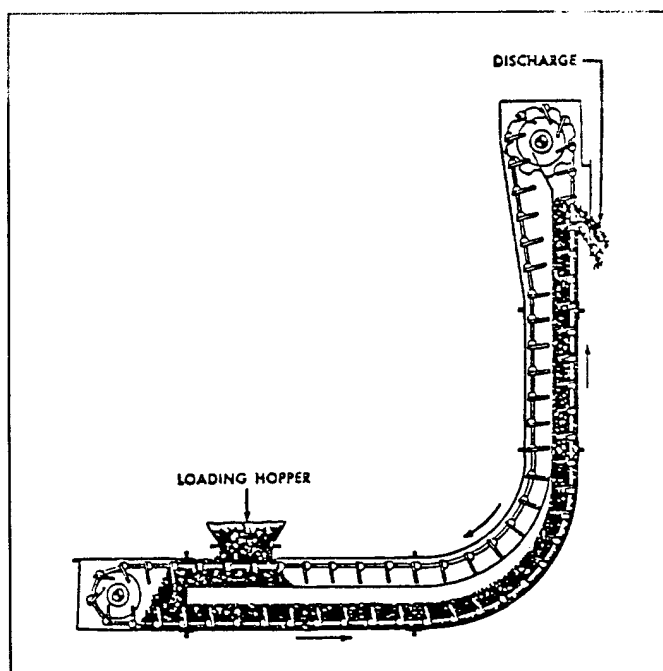


Figure 35. Skeletal-flight conveyor.

The centrifugal discharge elevator is best suited for fine or small lump coals (Figure 36). It is fast moving and can transfer 5 to 80 tons of coal per hour. It is this speed that flings the coal from the buckets as they round the top pulley of the elevator. At the tail pulley, coal is poured into the buckets. Coal that misses the buckets is scooped up from the bottom of the elevator by buckets passing around the tail pulley.

The continuous discharge elevator serves best when large quantities of coal must be moved (Figure 36). Although it is slower moving than the centrifugal discharge elevator, it can transfer 15 to 300 tons of coal per hour. As each bucket passes over the top pulley, the coal falls out and hits the back of the bucket ahead of it. In this way, the back of each bucket acts as a chute directing the flow of coal. The elevator's slower speed and less violent method of discharge minimizes breakage of the more fragile coals. The buckets of this elevator do not scoop coal, but require a loading leg to raise coal from the bottom of the pit.

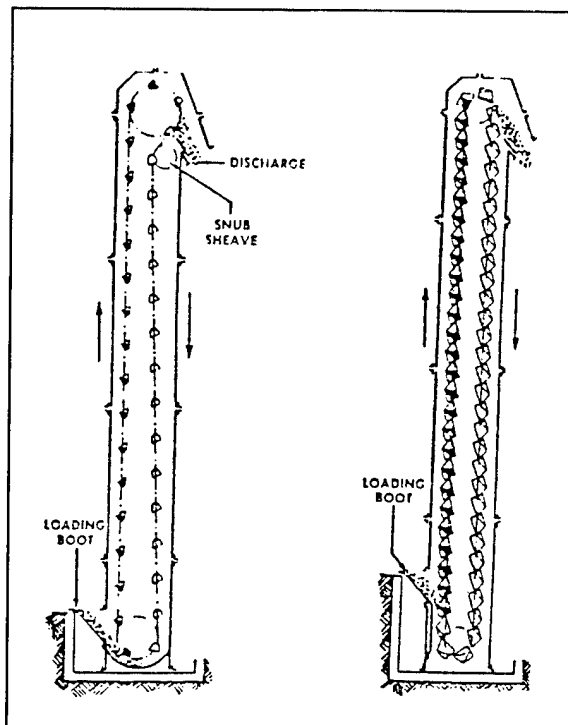


Figure 36. Bucket elevators.

**5.3.4.6 Pneumatic Conveyor.** The pneumatic conveyor uses compressed air to force coal through a pipeline. It is particularly economical for loads less than 50 tons per hour. Its advantages are that the pneumatic conveyor requires little maintenance; consumes less space than the belt conveyor, and can convey coal in any direction. Also, it is completely enclosed, which eliminates spillage and fugitive dust.

The main disadvantages of the pneumatic conveyor are that: (1) it is more expensive to operate than the belt conveyor, (2) it is limited in the maximum coal size it can pass, and (3) the quantity of fines is restricted because those in excess of 40 percent can plug the pipeline. Another disadvantage stems from the conveyor's ability to move coal in any direction. Directional changes in the

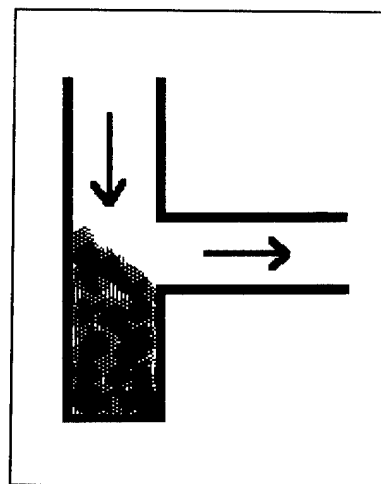


Figure 37. Dead-head intersection within a pneumatic conveyor pipeline.

pipeline increase erosion at these elbows. This erosion can be reduced using elbows with large radii or by employing "dead head" intersections. In a "dead head" intersection, coal covers the piping at the point where the flow turns (Figure 37). Coal exits the pneumatic conveyor quickly. To limit breakage, the coal should be allowed to flow over a pan or spreader before entering storage.

**5.3.4.7 Chute.** The chute is typically used to deliver coal from the bunkers to the stoker hoppers (Figure 38). Chutes, also called "downspouts," work best when they are vertical, however, an incline is workable.

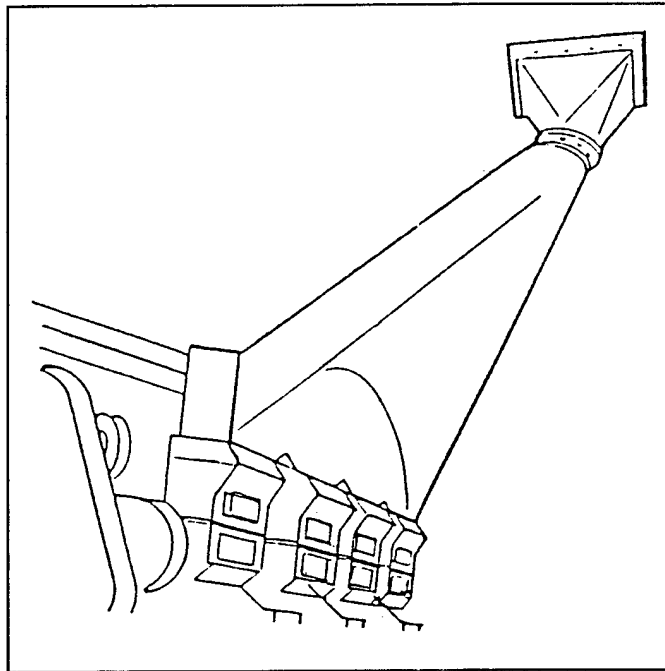


Figure 38. Conical nonsegregating distribution chute.

## 5.4 Storage

### 5.4.1 Short-Term

Short-term storage provides coal for day-to-day heating plant operations. A military plant should carry anywhere from a few days to several weeks worth of coal in short-term storage. Short-term storage is classified as either "active" (live) or "inactive" (dead). Live storage refers to coal that can be fed directly into the furnace without being transferred through other storage areas. The coal can be fed by chute, conveyor, or tractor. Dead storage refers to coal that must pass through another storage area before it can be fed to the furnace. Dead storage is transferred to live storage areas by conveyor, tractor, or both. If dead storage is located far from the plant, it may be necessary to transfer the coal to the plant using train cars or trucks. For these cases, just-in-time delivery is especially attractive.



### 5.4.2 Long-Term

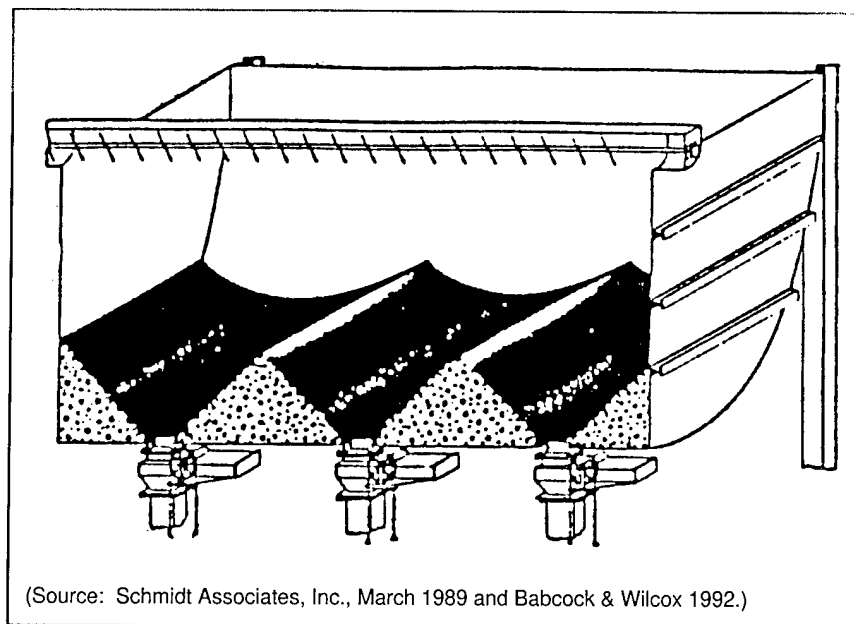
Long-term storage is dead storage that holds coal for emergencies or for those rare instances when the plant has exhausted its short-term supply. A military plant should carry a 90-day supply of coal in long-term storage.

### 5.4.3 Devices

There are many ways to store coal; each method has its advantages and drawbacks. The most expensive methods provide the best coal protection and allow for the simplest and cheapest recovery, while less expensive methods provide much less protection and require more costly, less convenient recovery. In addition, enclosed storage reduces air and water pollution while making the plant site look cleaner.

**5.4.3.1 Bunkers.** Bunkers provide live storage. They are usually situated above the plant floor so that coal can be fed directly to the furnace by chute. To accommodate unloading, bunkers have sloped bottoms to funnel the flow of coal.

**5.4.3.2** Many of these sloped bottoms are shaped like cones or inverted pyramids. The angle of slope is very important to the performance of the bunker. For instance, coal will collect in any region that is not sloped steeply enough. These “dead” areas can lead to plugging or bunker fires.



(Source: Schmidt Associates, Inc., March 1989 and Babcock & Wilcox 1992.)

Figure 39. Common bunker types.

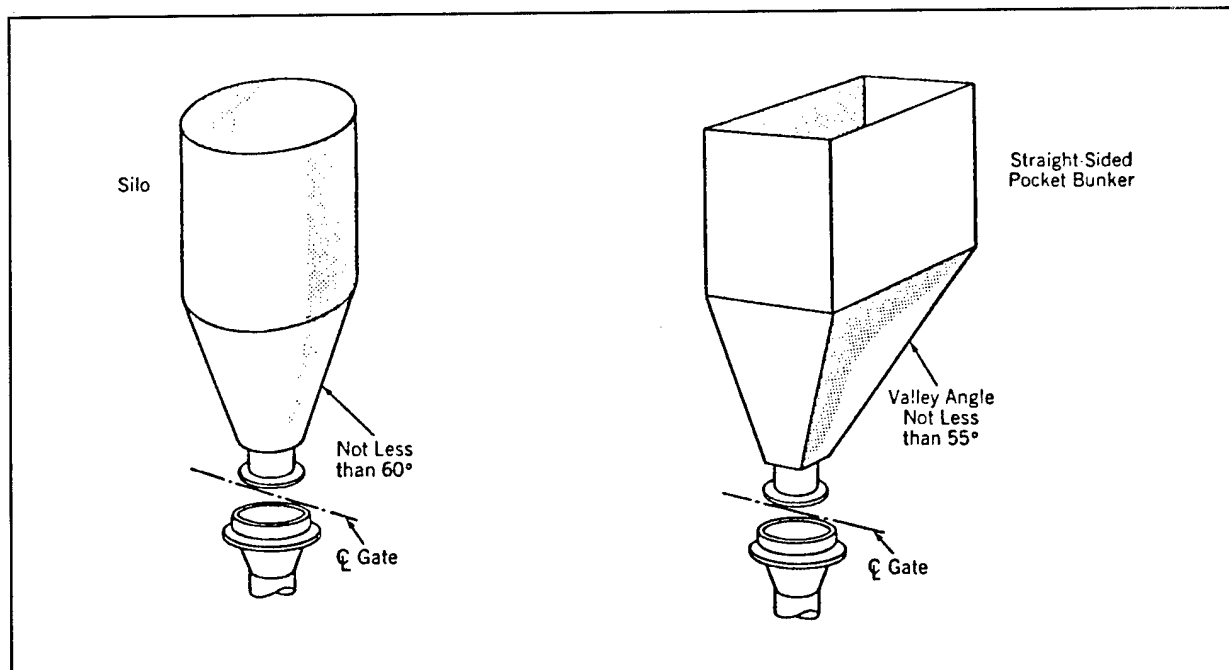


Figure 39. (Continued).

- The square bunker shown in Figure 39 is a common design that makes efficient use of space while eliminating the creation of dead spots. To prevent dead spots, hopper sides should be at least 55 degrees above the horizontal to prevent dead spots.)
- The parabolic (or catenary) shaped bunker shown in Figure 39 also makes efficient use of space. However, it allows dead spots to form between the outlets and along the sides of the bunker.
- The cylindrical bunker shown in Figure 39 does not use space as efficiently as the other two bunker types. It does, however, have good coal flow characteristics.

An uneven flow of coal over bunker surfaces can lead to segregation and the formation of dead spots.

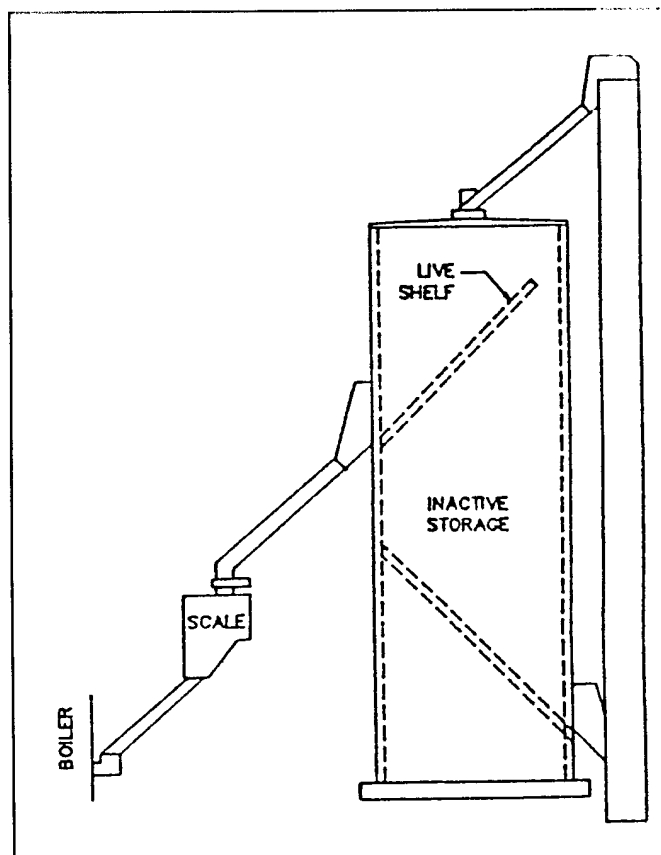


Figure 40. Silo with live and dead storage.

To limit segregation, the stream of coal entering the bunker should be split into several streams. If dead spots persist, the bunker should be periodically unloaded and cleaned. To help coal slide more evenly, the bunker can be fitted with slicker surfaces.

**5.4.3.3 Silos.** Silos provide both live and dead storage (Figure 40). Live storage is maintained on a "live shelf" located midway up the silo. This shelf is sloped towards an outlet on the side of the silo. When the live shelf is filled, excess coal becomes dead storage and spills over onto a lower shelf. Coal in dead storage can be reclaimed by a conveyor and returned to the live shelf. The shelves should be inclined at least 55 degrees above the horizontal to facilitate the flow of coal.

Silos provide excellent protection because they are completely enclosed. They shield against the weather and limit air circulation through the coal. In addition, silos are convenient and economical to unload. Unfortunately, these benefits are frequently offset by their large initial cost.

**5.4.3.4 Sheds.** A shed is a roofed building that protects live or dead storage from the weather. It can hold much more coal than a silo and is less expensive to build. However, it cannot offer the same protection or convenience of a silo. For example, a shed does not adequately limit air flow through loose coal. Therefore, coal maintained in a shed as long-term dead storage must be compacted. This compaction is difficult to achieve near posts and walls where noncompacted coal can act as a chimney for spontaneous combustion. In addition, compacting becomes difficult when the shed is nearly full. In terms of convenience, sheds are less efficient to unload because coal must be carried by tractor to a conveyor or hopper.

**5.4.3.5 Outside Bins.** An outside bin is a roofless, three-sided structure that can hold live or dead storage. Besides offering some protection from wind erosion, it serves primarily as a retainer for a coal pile. Because of its many similarities to the coal pile, handling and maintenance techniques for both storage methods are the same. However, the outside bin presents a drawback over the open pile because it is difficult to compact the coal along the bin walls.

**5.4.3.6 Piles.** A coal pile is generally used for long-term storage. It offers the least protection of all the storage methods, however, it requires the least capital investment. Due to the military requirement to keep 90 days of coal on hand, a coal pile is frequently the most economical means of storing this much coal.

The coal pile should be built on a paved surface. However, if concrete or asphalt is not available, the base can be constructed of heavily compacted coal. Regardless of

the material, the base must allow for proper drainage of the pile so the pile can be accessed during all weather conditions. In addition, proper drainage helps maintain coal quality as it helps the plant control water pollution.

## 5.5 Order of Use

When coal arrives at the plant, the best place for it to go is “straight to the furnace”—for several reasons. First, recently-delivered coal has had less time to oxidize and therefore delivers more energy per ton than stored coal. In addition, because coal headed directly to the furnace is not stored, less storage and handling is required. Finally, if the arriving coal is just enough to supply the plant, then all reserve coal can remain untouched, thereby reducing coal storage costs.

The practice of burning newly-delivered coal before stored coal is termed “last-in, first-out” (the newest coal is the first to reach the furnace). This method is far superior to its alternate method called “first-in, first-out.” With first-in, first-out, the plant burns its oldest coal and stores its new coal. By the time the new coal reaches the furnace, it is the oldest coal. Besides the extra handling required in rotating the coal stock, the loss of heating value suffered by the aged coal introduces many subtle costs.

For instance, the plant must now burn more coal to meet its load since the old coal has a lower heating value. This means extra wear on the plant equipment. The coal may also no longer meet specifications. For these reasons, the plant should employ the last-in, first-out method. Delivered coal should be arranged so it is the first to be burned, while long-term storage should remain untouched until an emergency.

The practice of receiving just enough coal to supply the plant's needs is termed “just-in-time delivery.” Besides saving storage and handling costs, just-in-time delivery improves the quality of coal reaching the furnace. As the following example illustrates, maintaining coal quality saves money, too.

Suppose that 1 percent of the heating value is lost from a 90-day stockpile of coal. If the plant had employed just-in-time delivery it would not have lost that heating value. Assume the stockpile contains 10,000 tons of 13,000 Btu/lb coal at \$35/ton. To meet the plant's load, the plant must burn an additional 100 tons, costing \$3,500, excluding the costs of extra coal and ash handling, as well as extra wear on equipment.

## 5.6 Weighing

It is important to weigh the coal just before it is fired for two reasons. First, it is helpful to know how much coal is burned each day to keep a running estimate of fuel on hand. Second, the coal usage information at each individual boiler allows the efficiency to be calculated. This is a good method of measuring equipment and operator performance.

One method of weighing the coal input to each boiler is to use an incline scale. This type of scale can be mechanical or electronic, and perform continual or batch measurements. A continual-type might be a belt scale with an integrating reader, while a batch-type might be a dump scale set to discharge every 200 lb. Either type can be used successfully to monitor coal usage.

Another method for weighing coal is the weigh larry (Figure 41). A weigh larry is a bucket set on tracks that receives coal from live storage and delivers it to the furnaces. It is a batch-type scale. The weigh larry can be used to calculate total coal usage over a given period. Or with slightly more effort, the scale can be used to calculate individual boiler efficiencies.

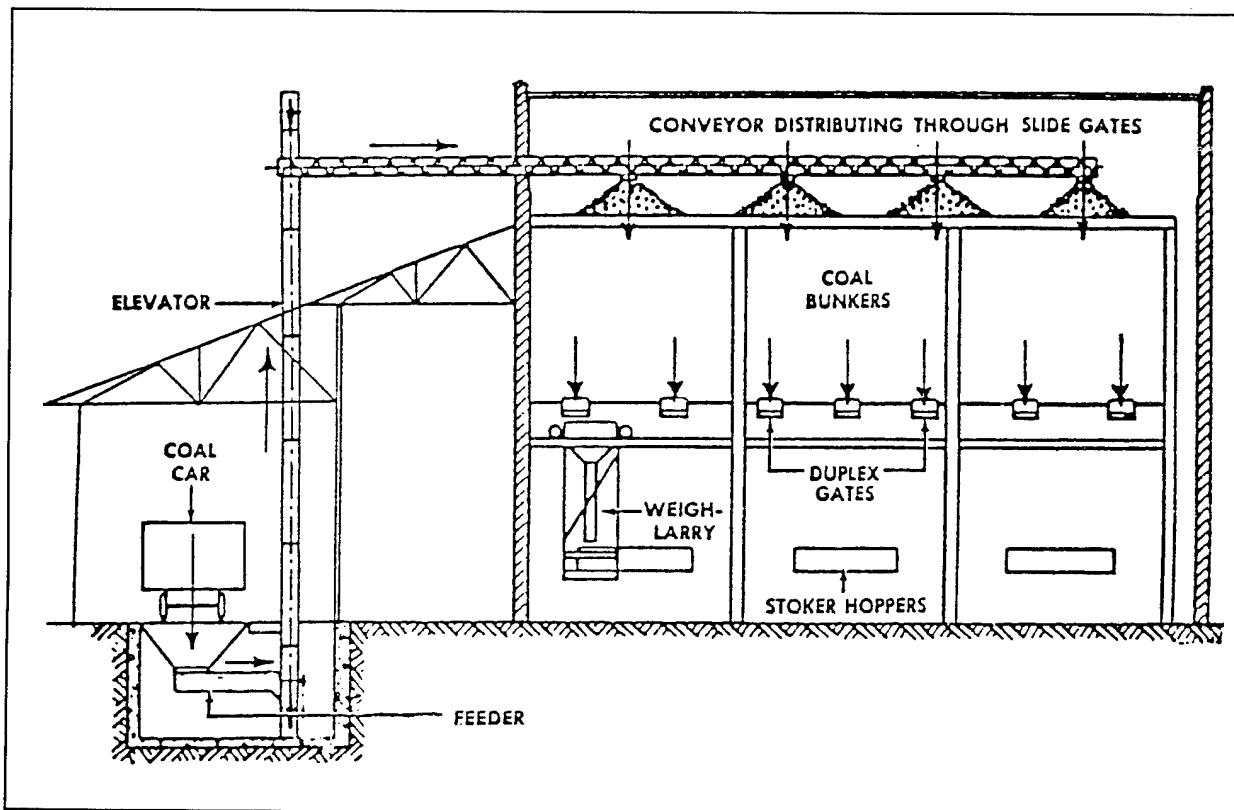


Figure 41. Weigh larry.

## 5.7 Controlling Oxidation

Higher-ranked coals, those low in sulfur, and coals washed before delivery to the plant are less prone to oxidation. Hence, these types of coal should be purchased when economical. In general, however, the plant can limit oxidation and the potential for spontaneous combustion by protecting its coal from air, moisture, and heat. The following is a list of some practical guidelines.

- Short-term live storage should be used within 7 days to minimize its exposure to air and water.
- Short-term dead storage (except for that contained in a silo) should be compacted to reduce exposure to air and water. A silo provides adequate protection because it is completely enclosed.
- Long-term storage (except for that contained in a silo) should be compacted and sealed.
- Coal should not surround vertical structures whenever possible. Such situations offer chimney-type air passages that encourage air flow through the pile.
- Coal should not be stored near sources of heat such as steam lines, hot water tanks, and smokestacks.
- Stored coal should be kept free of foreign objects such as rags, straw, paper, or wood. Such materials ignite at lower temperatures and could induce spontaneous combustion.

### 5.7.1 Piles

There are many ways to protect a long-term coal pile from air circulation, moisture infiltration, and wind erosion.

- The coal pile should be rounded on top and sloped to the ground so that water can run to the ground. This shaping can be done by dragging the tractor blade or bucket across the pile.
- The pile should be compacted to limit air circulation through the coal as well as to enhance drainage. Wheeled tractors are recommended over tracked vehicles for compacting the pile. First, wheels do not break the coal. Second, wheeled tractors exert three times the pressure of tracked vehicles. The

tractor should be used to compact 1-ft thick layers of coal under approximately 70 pounds per square foot of pressure.

- The side slopes of the compacted pile should be no steeper than 30 degrees to limit erosion and to aid handling.
- Adjacent piles should be at least 20 ft apart. This separation forms a fire break and allows equipment to access the piles.
- Once built, the pile should be sealed. Plastic or fabric tarps offer the most effective protection. Tarps should be opaque and light in color so light does not pass through to the coal, and so the cover itself does not get hot. The pile can also be sealed with a 6-in. layer of fine coal topped by a layer of coarser coal for anchorage. In addition, chemicals can be used to seal the pile.
- Once it is sealed, the long-term pile should not be disturbed except for weekly temperature checks, or for emergency coal shortages. When coal is removed, the pile should be repaired immediately. If the pile is used often, the quantity of the short-term storage should be increased to avoid continued disturbance and reshaping of the long-term pile.

To determine the presence of hot spots within a coal pile, visual inspection should be made daily. A hot spot is easy to recognize during wet weather because the hot spot dries quickly, giving the coal a lighter color. In cold or humid weather, vapors and the odor of gas may be detected. In addition, the temperature of the pile should be checked weekly for hot spots. A probe mounted with a thermometer or thermocouple should be used to test areas of the pile on 10- to 20-ft centers. If such a probe is unavailable, an iron rod may be thrust into the pile, withdrawn, and checked to see if it can be held by hand. When the temperature exceeds 150 °F, a hot spot is at that location.

### **5.7.2 Hot Spots and Fires**

If a hot spot goes untreated, it is likely to become a fire. Hot spots should be dug out and sent to the furnace immediately. When a fire has developed, there are several techniques for extinguishing it:

- For a coal pile, heavy plastic placed around the base of the pile can reduce air flow to the fire.
- For a loose coal pile, the hot spot can be compressed to reduce air flow.

- The hot spot can be removed (usually by crane) and spread out on the ground.
- For a shallow fire, dry ice can be buried just above the hot spot. Or, for a deeper fire, a pipe can be inserted into the pile to deliver the dry ice. As the dry ice vaporizes, it releases carbon dioxide gas, which extinguishes the fire by depriving it of oxygen.

Note that *water should not be used to extinguish coal fires except as a last resort*. Water near the hot spot turns to steam, which, during its escape, opens air channels through the coal.

After a coal fire has been extinguished, the damaged coal should not be reincorporated into storage. It should either be disposed of or blended with undamaged coal and fired in the boilers. Use of this blended coal should be coordinated with boiler operators because the coal's heating value will vary.

### **5.7.3 Segregation**

Coal that is highly segregated in storage is more likely to oxidize and ignite. Larger coal particles grouped together allow air to circulate through the pile, while pockets of finer coal trap heat.

### **5.7.4 Moisture**

Steam generated by oxidation creates passages through stored coal. These passages intensify the oxidation process by allowing more air into the coal.

## **5.8 Controlling Segregation**

Segregation adversely affects storage and boiler performance, and is a problem that perpetuates itself during coal handling.

### **5.8.1 Transportation**

Segregation begins during transport when finer coal sifts down through the coal. There is nothing the plant can do to prevent such segregation.



### 5.8.2 Cranes

When using a crane to make a pile or to fill an outside bin, coal should be deposited in small piles scattered around the storage area. These small piles are highly segregated (Figure 16), with fines in the center and larger pieces at the sides. As more coal is added, these small piles become one large pile, which is much less segregated than one constructed as a single pile. A popular technique for constructing a pile is to release coal from the bucket "on the run," or without stopping the circular motion of the crane. Although this technique reduces unloading time, it creates a kidney-shaped pile that is highly segregated.

### 5.8.3 Conveyor Systems

When unloading coal from a conveyor, segregation can be reduced by positioning a splitter at the point of discharge. For example, the pyramid-shaped splitter shown in Figure 42 shows the division of the flow of coal into four streams, which creates four small segregated piles instead of one large segregated pile. Figure 43 illustrates how segregation is reduced in a bunker by dividing the flow of coal.

## 5.9 Controlling Breakage

### 5.9.1 Cranes

To limit breakage caused by using a crane, coal should not be dropped long distances, and the clamshell should not be allowed to swing into the coal.

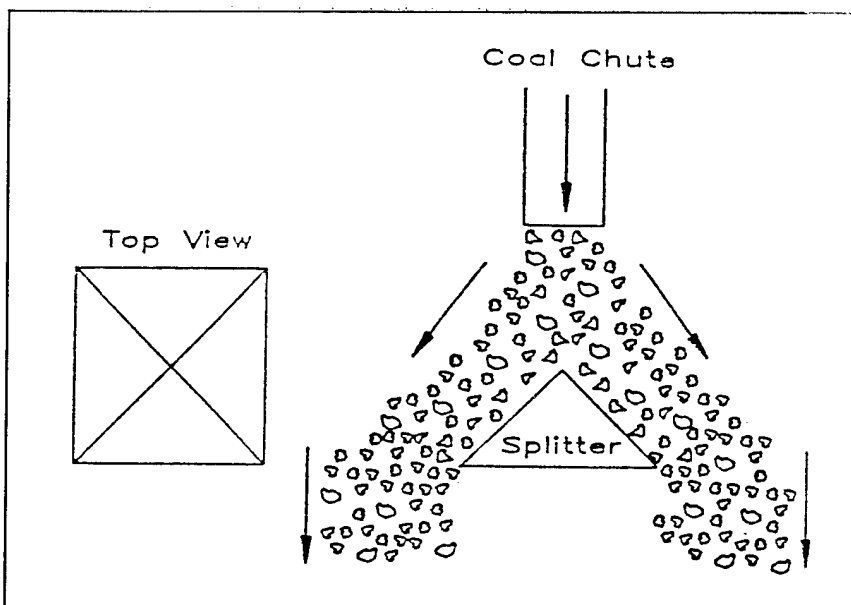


Figure 42. Pyramid splitter.

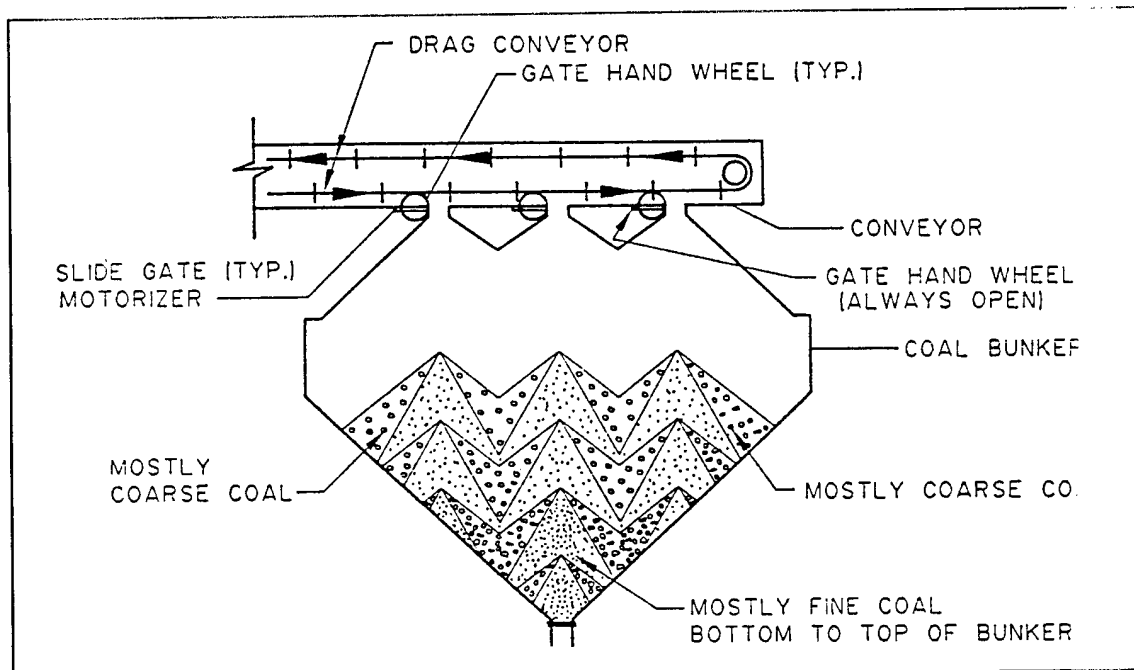


Figure 43. Segregation within the bunker.

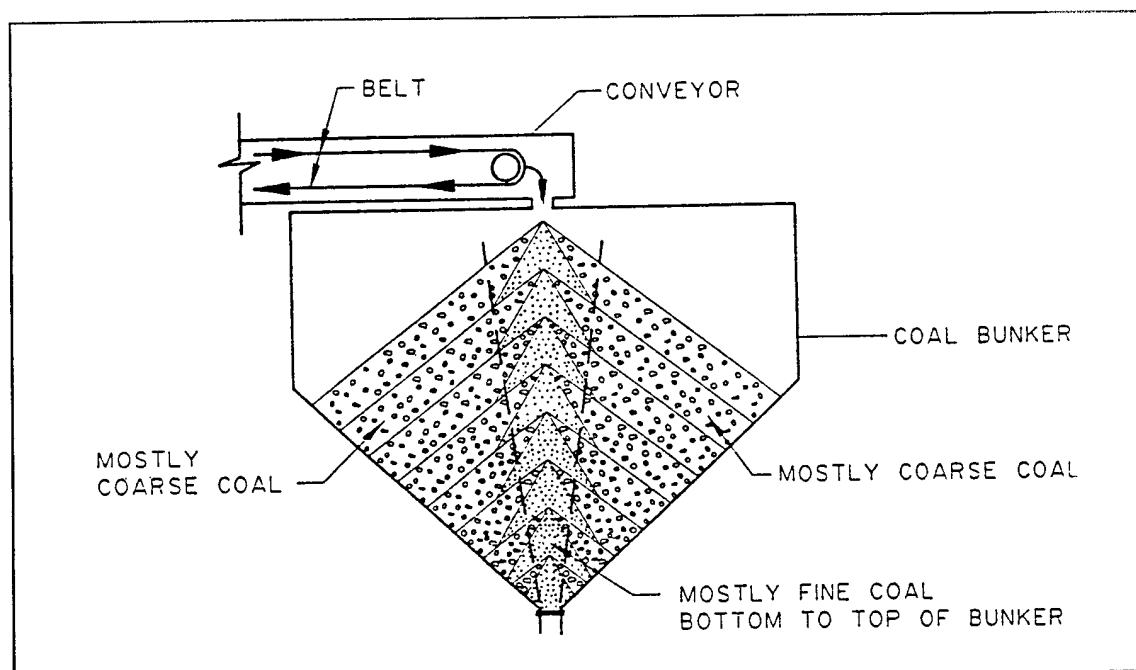


Figure 43. (Continued).

### **5.9.3 Conveyor Systems**

Coal should not be dropped long distances during crane or conveyor unloading.

### **5.9.4 Piles, Outside Bins, and Sheds**

Degradation is reduced by compacting coal. However, compacting lower rank coals with a high friability is not recommended. Long-term storage of this type of coal is more difficult and should be avoided.

### **5.9.5 Oxidation**

Coals tend to break apart as they oxidize. This tendency is known as slacking.

### **5.9.6 Moisture**

Certain lower rank coals begin to crumble as they lose moisture. This tendency is known as friability.

## **5.10 Controlling Moisture**

Wet coal can aggravate oxidation during storage, plug handling equipment, and lower boiler efficiency. In addition, frozen coal can obstruct coal handling, while water run-off from coal storage is polluted. The plant should protect its coal from moisture during the entire handling process. Where possible, the plant should employ covered storage and handling.

### **5.10.1 Frozen Coal**

During winter deliveries, coal that remains frozen to the sides of railcars is paid for, but not received by the plant, hence raising costs. To ease this problem, coal mines, carriers and users have devised several solutions. Some plants use railcar shakers to loosen frozen coal. However, shakers are only effective when the frozen coal is less than 12 in. deep along the perimeter of the railcar. Coal frozen deeper than this is considered "severely frozen." Severely frozen coal is practically impossible to remove without first thawing the coal or injecting it with calcium chloride. Because these techniques are very expensive, it is best to prevent the coal from severely freezing in the first place.

There are two techniques for preventing severe freezing: freeze-proofing chemicals that prevent coal from freezing, and freeze-conditioning chemicals that weaken the structure of frozen coal, although a car shaker may still be required.

Freeze-proofing agents consist of such chemicals as sodium chloride, calcium chloride, and some alcohols. Unfortunately, these treatments also have several drawbacks. For instance, these chemicals may lower the heating value of the coal and increase slagging in the boiler; they are prone to washing off the coal, and they can be ineffective in extremely coal climates.

Freeze-conditioning additives fall into two general categories: oil-based and glycol-based. Oil-based chemicals offer the best results because they tend to resist being washed off the coal. Unfortunately, these agents also deteriorate belt materials on feeders and conveyors. Also, they are more polluting than their glycol-based counterparts. On the other hand, glycol-based chemicals do not damage conveying equipment. However, it is believed that they are more prone to washing away.

#### **5.10.2 Water Pollution**

Water pollution is a significant consideration when coal is stored uncovered. Drainage from outside storage should be collected. This polluted water is usually sent to a settling pond where some of the contaminants fall to the bottom and some of the water evaporates. The remaining water is then filtered, treated, and released. The shape of the pile and the construction of the foundation should be designed to facilitate drainage.

Wastewater at a coal storage and handling site results from rain falling around and sweeping through the storage pile. Runoff outside the pile contains dust and similar particles from the air and ground surface. The leachate that results from water flowing through a pile is highly acidic and contains metallic sulfites in solution. To collect the on-site wastewater, a retention pond should be provided.

Improper long-term storage of coal represents a possible water pollution problem. Water that has entered a coal pile (rain or runoff) can leach out contaminants. The runoff from a coal pile can lead to surface water pollution problems and leachate from a coal pile can contaminate groundwater if not properly controlled. Properly seal coal storage piles to prevent groundwater contamination and collect runoff from coal piles in culverts, ponds, or other basins. If runoff is conveyed by pipe or other means to a waterway, obtain a National Pollutant Discharge Elimination System (NPDES) permit.

Accumulation of coal dust in coal handling and preparation areas can also pose a possible water pollution problem. Water in these areas should be controlled in the same manner as in coal storage areas.

## 6 Coal Combustion

### 6.1 Overview

Controlling the air/fuel ratio is critical for maintaining the efficiency of any boiler system. There are many different systems available for coal combustion control. This section will discuss some of these systems. This section will also provide a basic understanding of how to use control systems and give some insight into how to make decisions regarding the purchase of new or existing equipment.

#### 6.1.1 Combustion

Combustion is a process that produces heat through the rapid chemical combination of oxygen and combustible elements (carbon, hydrogen, sulfur) in fuel. Most of this heat comes from the combustion of carbon and hydrogen since sulfur is found in small quantities.

Oxygen is a key element in this combustion process. Some excess oxygen must be supplied to ensure complete combustion. However, the amount of excess oxygen should be kept at a minimum to maximize the combustion efficiency. Table 16 lists combustible elements found in coal and their corresponding reactions with oxygen. Table 17 shows the chemical analysis of coal.

Table 16. Coal combustibles and reactions with oxygen.

| Combustible Element                            | Reaction*                |
|--|--------------------------|
| Carbon (to CO <sub>2</sub> )                   | $C + O_2 + CO_2 + Q$     |
| Hydrogen                                       | $2H_2 + O_2 + 2H_2O + Q$ |
| Sulfur (to SO <sub>2</sub> )                   | $S + O_2 + SO_2 + Q$     |
| Sulfur (to SO <sub>3</sub> )                   | $2S + 3O_2 + 2SO_3 + Q$  |
| * Where Q = The heat of reaction on combustion |                          |

Table 17. Components of coal.

| Substance | Formula        | Heat of Combustion (Btu/lb) |        |
|-----------|----------------|-----------------------------|--------|
|           |                | Gross                       | Net    |
| Carbon    | C              | 14,093                      | 14,093 |
| Hydrogen  | H <sub>2</sub> | 61,100                      | 51,623 |
| Sulfur    | S              | 3,983                       | 3,983  |

### 6.1.2 Combustion Control Systems

Combustion control is primarily concerned with two functions:

- adjusting fuel supply to maintain constant steam pressure (or constant temperature in high-temperature hot-water generators) under varying loads
- maintaining the correct air/fuel ratio in the combustion chamber.

Because these two control functions are the most important with respect to energy conservation, only the controls needed to accomplish these two functions will be considered.

Many elements are common to the various types of combustion control systems. The terminology is explained below:

- *Sensor.* A device used to measure a property, such as an orifice plate that measures steam flow rates.
- *Setpoint.* A reference signal (either mechanical or electrical) representing the desired value of the measured variable. In other words, the point at which the boiler or system should be operating.
- *Feedback.* A measurement of the actual performance of the boiler used to change the control signal so the boiler operates closer to the setpoint. For example, the controller adjusts an air damper and the air flow feedback tells the controller the change in the air flow rate resulting from the air damper adjustment.
- *Controller.* The “brains” of the control system, it is a device that receives the feedback, compares it to the setpoints, and produces an output signal to the

control element that will cause the deviation between the measured quantity and the desired setpoint to diminish.

- *Actuator.* A device that receives the control signal from the controller and uses the signal to adjust the control element. Actuators can be electrical, mechanical, or pneumatic. They are the devices that open and close valves and dampers.
- *Control Element.* An apparatus, usually a valve or damper, that regulates the flow rate.

More complex control systems may contain other devices, but these elements are the most important and are sufficient to understand a combustion control system.

Control systems are classified as either "open-loop" or "closed-loop." In open-loop control of a boiler, the calibration curve of the fuel settings versus the steam demand could be used to set the firing rate. Measured steam output (feedback) is not used to adjust the firing rate. Closed-loop control adds the capability of feedback in which the monitoring of an output is used to make adjustments for the changes in calibration and other conditions. While open loops are simple and stable, they result in poor control because of calibration changes from wear, fouling, etc. Consequently, open-loop control systems are rarely used in boiler control.

Figure 44 shows the boiler control functions in a closed-loop system. In this configuration, the controller receives two types of signals: (1) the setpoint values for the desired steam pressure, flow, temperature, air flow, etc., and (2) feedback indicating the actual output values of the setpoint parameters. The function of the controller is to process these signals using programmed logic and produce an activating signal to set fuel and air flow. If all conditions were perfect, the activation would result in the optimal air/fuel ratio and firing rate.

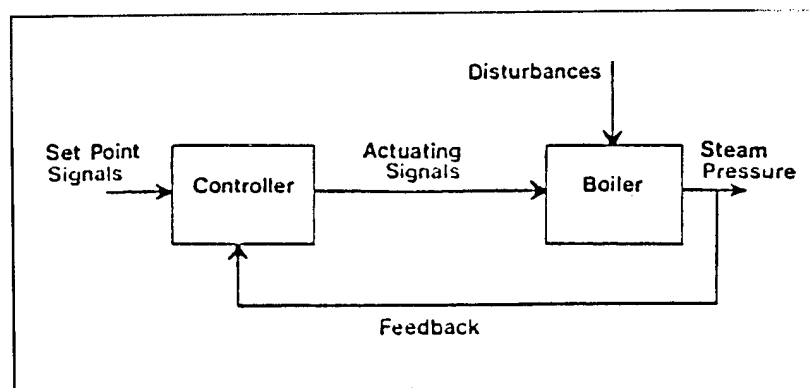


Figure 44. Boiler control functions.



Each activating signal produced by a controller in a closed-loop mode is obtained by comparing the setpoint and feedback signals. The following three basic controller modes, proportional, integral, and derivative, are used to process these signals and provide the desired output.

**6.1.2.1 Proportional.** The difference between the setpoint and feedback signals is called the “error signal.” The magnitude of the actuation or change made to the control element is proportional to the error signal. The error signal is magnified (or diminished) by an appropriate constant  $k$  (called the “gain”), which is used to bring the signal to zero more quickly, but at greater risk of dynamic instability. Figure 45 shows the response of a control system using different values of  $k$ , the proportional gain. With a gain of 2, there is cyclic variation in the pressure and valve position. This variation is the instability that can occur when a larger gain is used. Another point to notice in Figure 45 is that the proportional controller does not drive the error signal to zero. The difference between the setpoint and the output pressure is called the “offset.” Notice that the offset decreases as the gain,  $k$ , increases.

**6.1.2.2 Proportional and Integral.** The offset in the proportional control can be eliminated by adding an integral mode to the proportional controller. Integral control is based on the integration of the difference between the controlled variable and its set point over the time the difference occurs. Integral control is also called “reset” since the band of proportional control is shifted or reset so that the offset is removed. This condition is shown in Figure 46. The system may be less stable, however, because it takes longer to stabilize with the offset completely eliminated.

### **6.1.2.3 Proportional, Integral, and Derivative.**

The derivative action is the rate of change of the error signal with time as shown

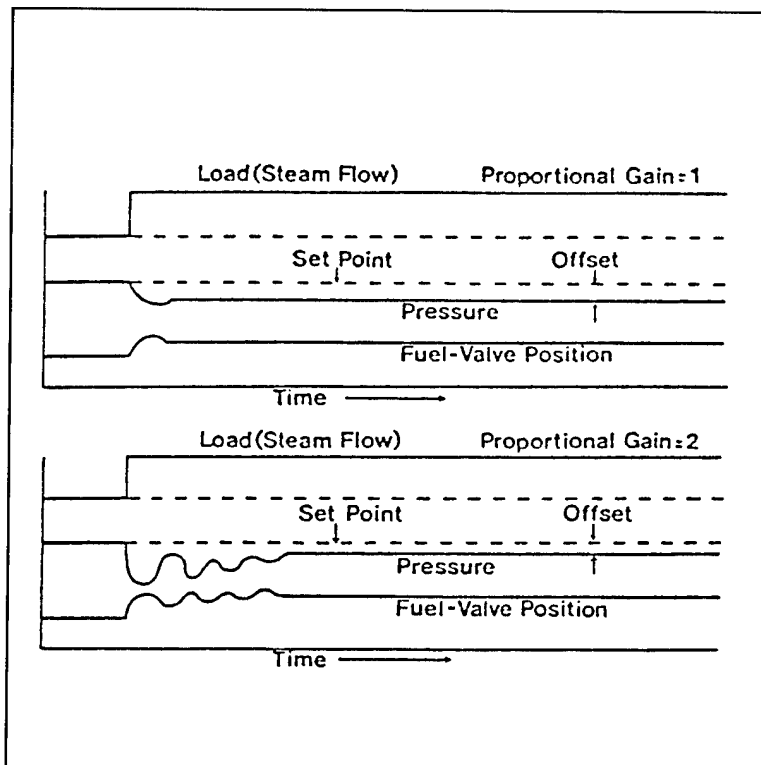


Figure 45. Proportional controller response with different gain values.

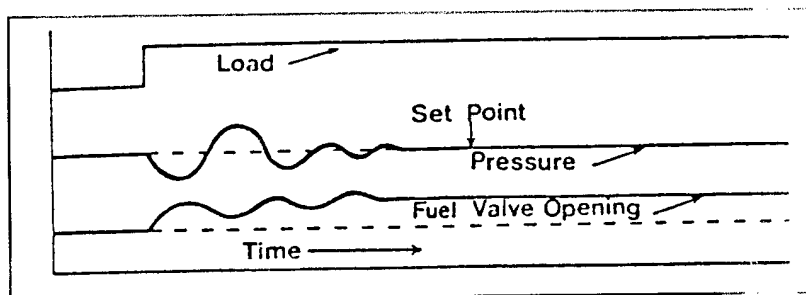


Figure 48. Typical response of proportional plus integral control.

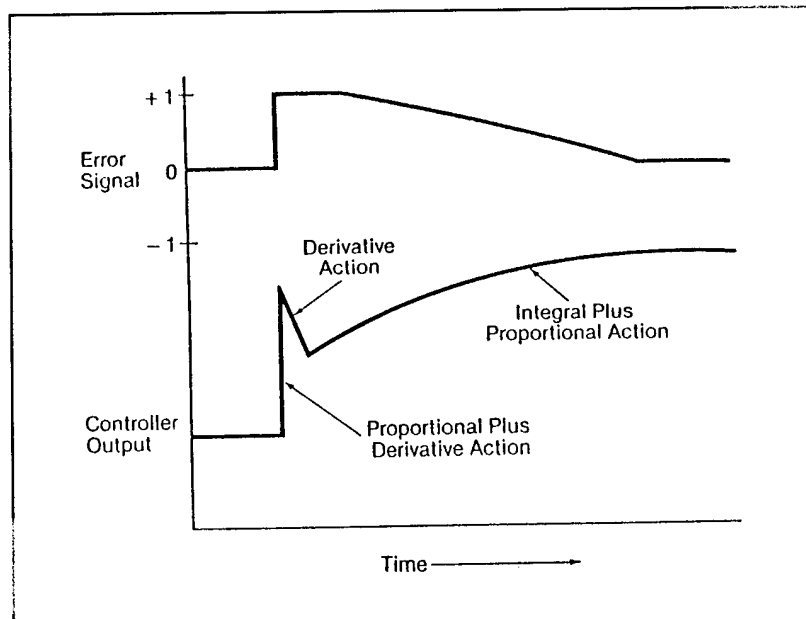


Figure 47. Typical response of proportional plus integral plus derivative control.

in Figure 47. This control action combines with the proportional and integral control to provide the most accurate control. It also reacts faster than the proportional and integral control. A drawback to adding turn-like derivative control is that improper tuning causes noisy signals and can cause instability and "hunting" in the control system.

## 6.2 Control Methods

Combustion control methods are divided into three major categories: series, parallel, and series/parallel. In series control, the deviation in steam pressure is used to set one variable, such as air shown in Figure 48. Fuel, the other variable, is set based on this controlled variable. Series control is suitable for situations in which the fuel has a relatively

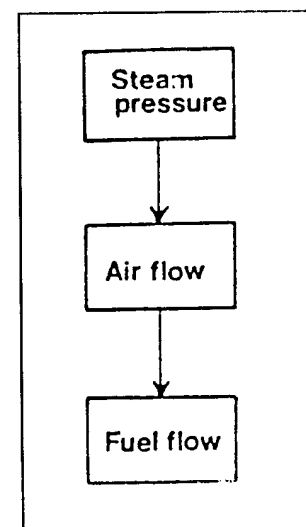


Figure 46. Series control.

constant heating value. Air should be the controlled variable in boilers required to increase their load rapidly and to shed it slowly. Fuel should be used in the opposite situation.

In parallel control, the deviation in steam pressure causes the air and fuel flow to be changed simultaneously (Figure 49).

In a series/parallel system, fuel and air flow are set simultaneously, hence the "parallel" nature of the control. However, steam pressure and flow are used to control fuel and air flow, respectively, hence the "series" nature of the control. Series/parallel control usually gives the tightest control over the air/fuel ratio. It is used when the heating value of the fuel is highly variable (Figure 50).

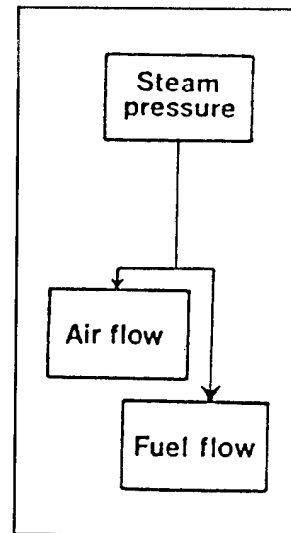


Figure 49. Parallel control.

### 6.3 Control Systems

Control systems can be further divided into three subcategories: positioning, semimetering, and metering. A positioning system is one in which the relative change in one input or output is used to control another. For example, settings for the air and fuel control are determined by the load and are varied continuously as shown in Figure 51. The linkage can be adjusted at one firing position.

A metering system is one in which an exact measurement of an input is used. The first input (either fuel or air) is controlled according to load. The flow of the other input is measured and controlled according to the flow of the first input. Figure 52 shows this system. A semi-metering system is one in which some inputs are measured and some are not. An advantage of this type of control is that it can be used in stoker-fired boilers where the fuel flow cannot be measured accurately, but where other factors, such as airflow, can.

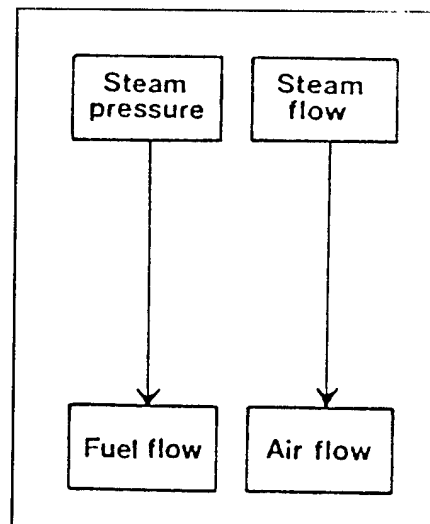


Figure 50. Series/parallel control.

### 6.4 Boiler Efficiency

The main concern with any system is how well it performs. For boilers, performance is measured by efficiency. Boiler efficiency is the ratio of the energy output of a

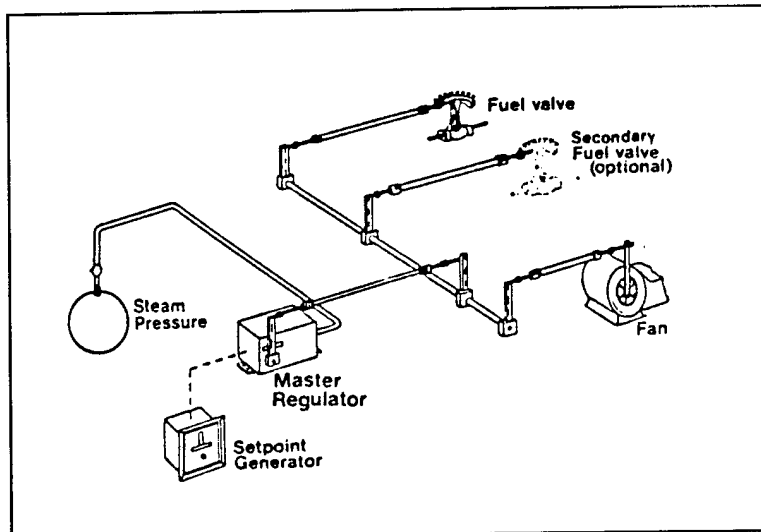


Figure 51. Positioning system.

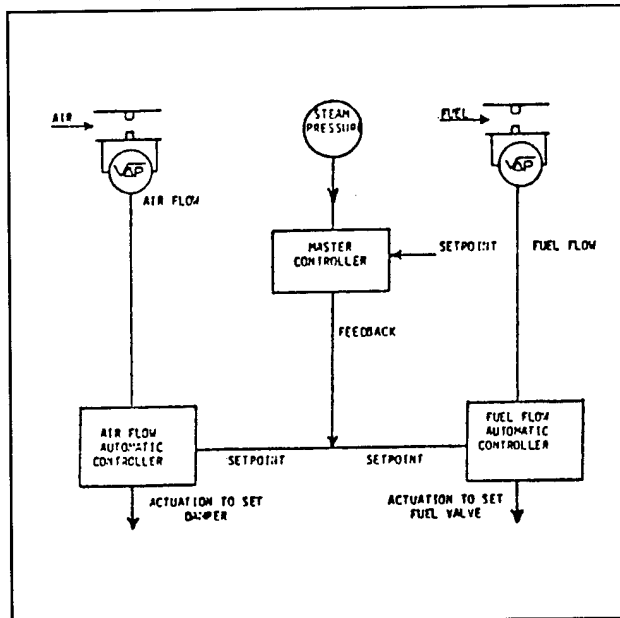


Figure 52. Metering system.

boiler to the energy input. The following graphs provide a simple method of estimating boiler efficiency based on the percentage of excess air being used.

To use these charts, first select the proper graph for the fuel being burned. These charts were developed for specific fuels but they can be used for other fuels by estimation (Figure 53).

**Low-sulfur coal****Ultimate analysis:**

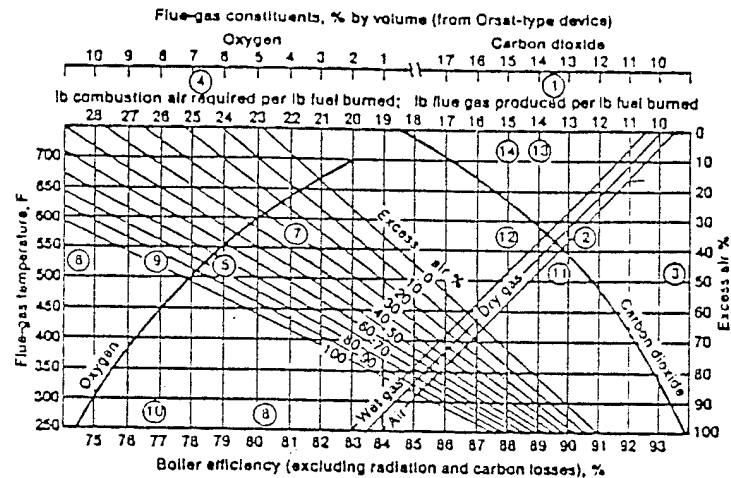
| constituent    | Amount, wt % |
|----------------|--------------|
| Carbon .....   | 71.487       |
| Hydrogen ..... | 4.708        |
| Oxygen .....   | 8.644        |
| Nitrogen ..... | 1.091        |
| Sulfur .....   | 0.715        |
| Chlorine ..... | 0.056        |
| Ash .....      | 9.275        |
| Water .....    | 6.024        |

**Proximate analysis:**

| Constituent     | Amount, wt % |
|-----------------|--------------|
| Carbon .....    | 51.18        |
| Volatiles ..... | 33.19        |
| Moisture .....  | 6.41         |
| Ash .....       | 9.24         |

**Other properties:**

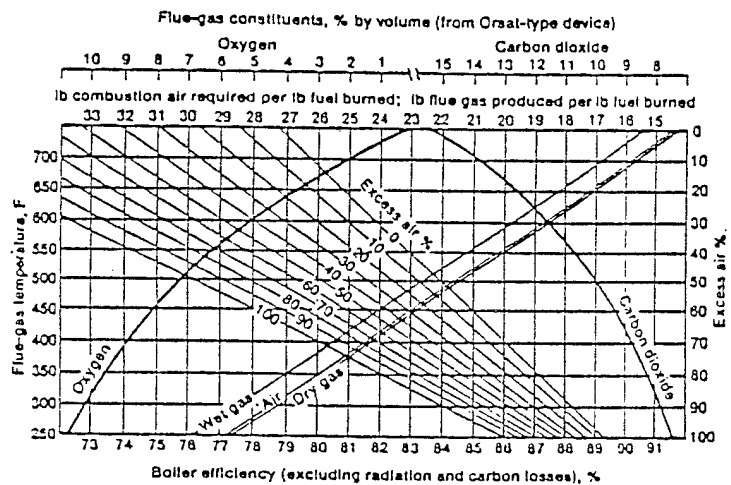
|                                  |        |
|----------------------------------|--------|
| Ash fusion temperature, F.....   | 2700   |
| Heating value (wet), Btu/lb..... | 12,808 |
| Heating value (dry), Btu/lb..... | 13,472 |

**Distillate (No. 2) oil**

| Constituent    | Amount, wt % |
|----------------|--------------|
| Carbon .....   | 86.63        |
| Hydrogen ..... | 12.97        |
| Sulfur .....   | 0.35         |
| Oxygen .....   | 0.04         |
| Nitrogen ..... | 0.01         |

**Other properties:**

|                             |         |
|-----------------------------|---------|
| Heating value, Btu/lb.....  | 19,458  |
| Heating value, Btu/gal..... | 138,697 |

**Natural gas**

| Constituent                          | Amount, wt % |
|--------------------------------------|--------------|
| Helium .....                         | 0.0085       |
| Hydrogen .....                       | 0.0005       |
| Nitrogen .....                       | 0.8295       |
| Methane .....                        | 90.7560      |
| Ethane .....                         | 4.8171       |
| Carbon dioxide .....                 | 2.4837       |
| Propane .....                        | 0.7499       |
| Butane .....                         | 0.3471       |
| C <sub>4</sub> H <sub>10</sub> ..... | 0.1364       |
| C <sub>5</sub> H <sub>12</sub> ..... | 0.0713       |

**Other properties:**

|                             |        |
|-----------------------------|--------|
| Heating value, Btu/lb.....  | 22,882 |
| Heating value, Btu/scf..... | 1029.4 |

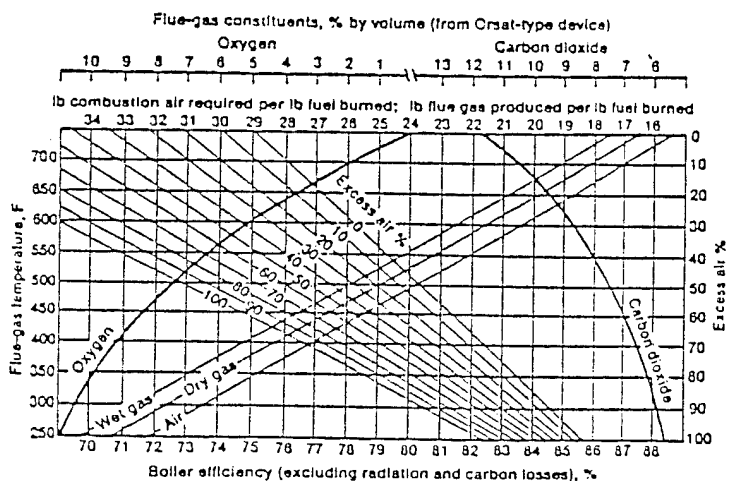


Figure 53. Boiler efficiency charts.

## Low-sulfur coal

## Ultimate analysis:

| Constituent    | Amount, wt % |
|----------------|--------------|
| Carbon .....   | 71.487       |
| Hydrogen ..... | 4.708        |
| Oxygen .....   | 8.844        |
| Nitrogen ..... | 1.091        |
| Sulfur .....   | 0.715        |
| Chlorine ..... | 0.056        |
| Ash .....      | 9.275        |
| Water .....    | 6.024        |

## Proximate analysis:

| Constituent     | Amount, wt % |
|-----------------|--------------|
| Carbon .....    | 51.18        |
| Volatiles ..... | 33.19        |
| Moisture .....  | 6.41         |
| Ash .....       | 9.24         |

## Other properties:

|                                   |        |
|-----------------------------------|--------|
| Ash fusion temperature, F.....    | 2700   |
| Heating value (wet), Btu/lb.....  | 12,608 |
| Heating value (dry), Btu/lb ..... | 13,472 |

## Distillate (No. 2) oil

## Constituent

## Amount, wt %

|                |       |
|----------------|-------|
| Carbon .....   | 86.83 |
| Hydrogen ..... | 12.97 |
| Sulfur .....   | 0.35  |
| Oxygen .....   | 0.04  |
| Nitrogen ..... | 0.01  |

## Other properties:

|                             |         |
|-----------------------------|---------|
| Heating value, Btu/lb.....  | 19,458  |
| Heating value, Btu/gal..... | 138,697 |

## Natural gas

## Constituent

## Amount, wt %

|                                      |         |
|--------------------------------------|---------|
| Helium .....                         | 0.0085  |
| Hydrogen .....                       | 0.0005  |
| Nitrogen .....                       | 0.8295  |
| Methane .....                        | 90.7580 |
| Elthane .....                        | 4.8171  |
| Carbon dioxide .....                 | 2.4837  |
| propane .....                        | 0.7499  |
| Butane .....                         | 0.3471  |
| C <sub>4</sub> H <sub>10</sub> ..... | 0.1364  |
| C <sub>4</sub> H <sub>8</sub> .....  | 0.0713  |

## Other properties:

|                              |        |
|------------------------------|--------|
| Heating value, Btu/lb .....  | 22,882 |
| Heating value, Btu/scf ..... | 1029.4 |

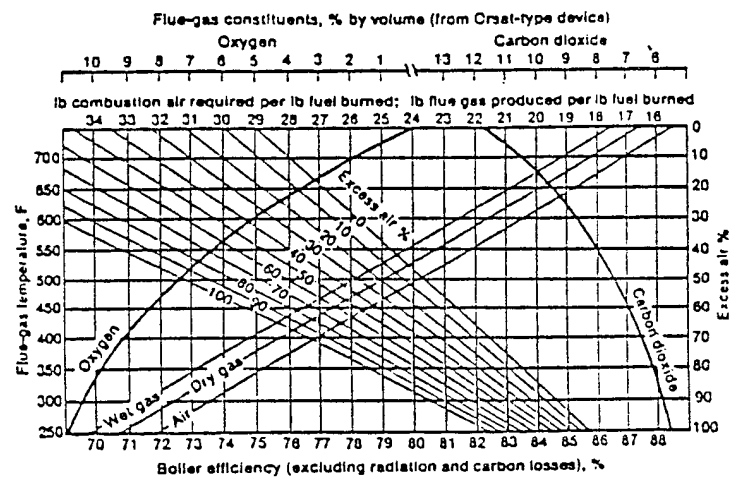
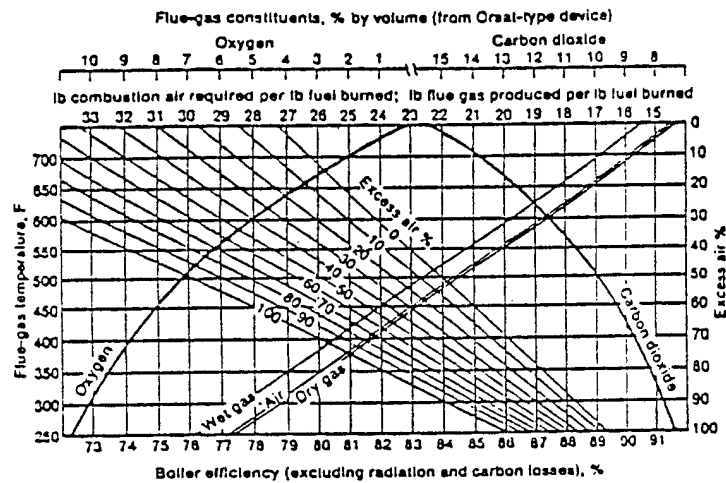
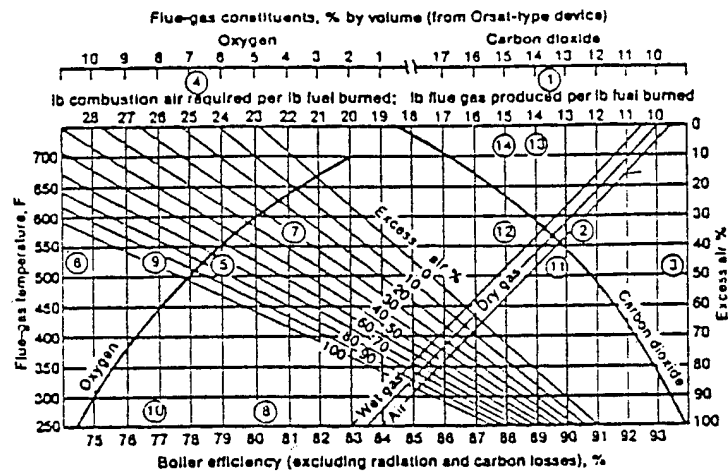


Figure 53. (Continued).

For example, assume that you are burning bituminous coal and your Orsat analysis indicates 13 percent carbon dioxide in the flue gas. From this point on, the carbon dioxide scale of the graph drops vertically until you intersect the CO<sub>2</sub> curve. At this point, draw a horizontal line to the right and read 42 percent excess air. Knowing the flue gas temperature, in this case 550 °F, draw a horizontal line from this point on the left hand axis to the 42 percent excess air curve, then drop vertically down and read the boiler efficiency off the bottom scale. This value is a good approximation of boiler efficiency.

## 6.5 Combustion Improvement

### 6.5.1 Optimizing Excess Air

The air/fuel ratio is one of the most important parameters in boiler control and is also an area where combustion can be improved. The goal is to burn fuel completely and safely using the minimum amount of excess air.

One of the simplest methods of improving combustion efficiency is to optimize the amount of excess air being used. This technique only requires the instruments for monitoring excess air and incomplete combustion. Optimal excess air is illustrated in Figure 54. As the excess air is reduced, the point is reached where sufficient air to complete the combustion process no longer exists. As a result, the amount of combustibles is increased, which can be seen in the opacity and carbon monoxide levels at the boiler outlet. The situation is accompanied by severe clinkering also. The excess air levels at which the opacity and CO begin to increase rapidly are called the "opacity limit" and the "CO limit." This point is the minimum excess air level and the most efficient place to operate. However, operating at this point can

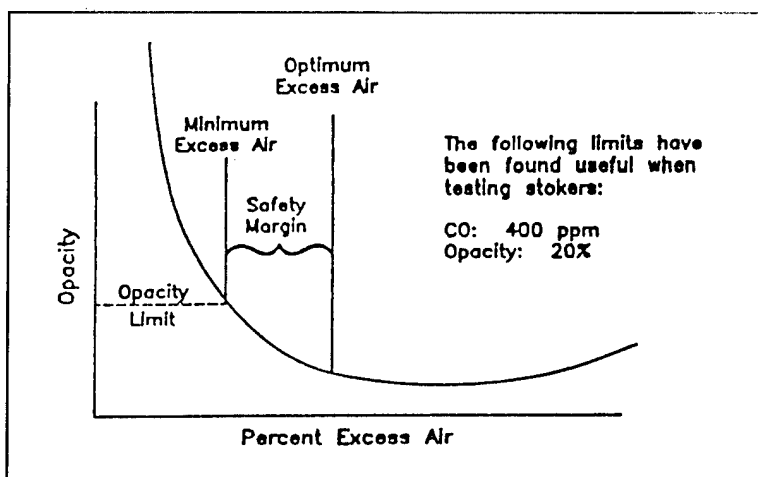


Figure 54. Excess air versus opacity.

have disastrous results. Changes in operation of fuel characteristics could cause the excess air level to be too low and place the boiler in a fuel-rich environment, leading to an explosion.

Therefore, the boiler operator must allow for a margin of safety in the excess air level to accommodate normal swings in the load and coal sizing or segregation. The size of the margin depends on load stability, fuel property variations, state of the control system, and the operator's motivation level. These margins typically range from 5 to 20 percent excess air. The optimal value is then set at this point. This optimum must be reestablished for different firing rates because different loads require different amounts of excess air. Table 18 lists some typical excess air values based on load.

Table 18. Typical excess air levels.

|                 | Load % |    |    |     |
|-----------------|--------|----|----|-----|
|                 | 40     | 60 | 80 | 100 |
| Stoker          | 100    | 80 | 40 | 30  |
| Pulverized Coal | 40     | 30 | 20 | 20  |

These values are only estimates and vary with boiler type and age. Excess air can be determined from Figure 55 if either the percentage of oxygen or carbon dioxide is known. In addition, portable electronic and chemical analyzers are available for making these measurements.

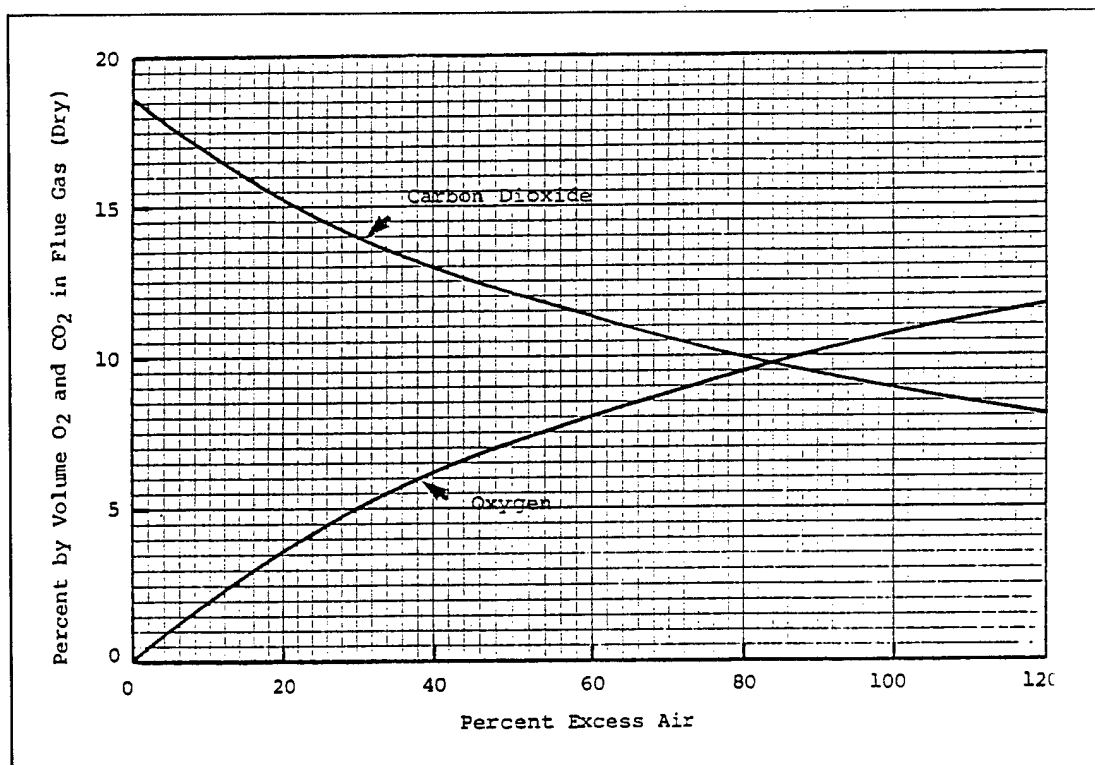


Figure 55. Excess air versus  $O_2$  and  $CO_2$ .



### **6.5.2     *Adjusting Overfire Air***

Overfire air serves two main purposes in stoker boiler operation. The primary purpose is to promote turbulence in the flame zone so volatile gases can mix with air for better combustion. The second purpose is to hold the flames away from the walls and prevent premature cooling or quenching of the flames. Tests have shown that use of overfire air can also reduce particulate emissions.

At high boiler loads, overfire air should be set at a high level. Overfire air pressure should be reduced with low boiler loads. If in doubt as to how much overfire air to use, it is better to use more than less. When the overfire air pressure is increased, allow the undergrate air to decrease so that excess air level remains low.

When unacceptable levels of opacity are measured at the boiler outlet, try increasing overfire air pressure. This step will sometimes solve the problem and allow you to operate at a lower, more efficient excess air level. With some stokers, there may be a problem with high overfire air pressures if the resulting turbulence is lifting particulate matter off the grate. This is very rarely a problem, but when it happens, the overfire air pressure should be reduced.

### **6.5.3     *Step-by-Step Procedure for Minimizing Excess Air***

1. Bring boiler to the desired test firing rate and turn the controls on manual. Make sure all safety interlocks are functioning properly.
2. Once the boiler is stable, observe and record flame conditions, oxygen levels, opacity, and flue gas temperature readings.
3. Increase air flow by about 1 percent. After allowing time for conditions to stabilize, take another set of readings.
4. Reduce airflow in small steps while observing stack and flame conditions and recording data. Adjust the overfire air if necessary. Allow the boiler to stabilize after each change.
5. Continue to reduce air flow until a minimum excess air level is reached as indicated by opacity or other visible deterioration in conditions.
6. Establish a safety margin in the excess air level above the minimum, resting controls to this optimal level.
7. Develop an opacity vs. excess air characteristic curve using the data obtained in this test.
8. Compare the minimum excess air level predicted by the manufacturers. High excess air levels should be investigated.

9. Repeat steps 1 through 8 for each boiler load considered and develop an  $O_2$ /load curve. You may need to consider excess air settings since control adjustments at one firing rate may affect others.
10. After completing steps 1 through 9, verify the settings by observing normal load swings. If you find undesirable conditions, increase the safety margin.

If the boiler is found to be operating in a fuel-rich condition, the combustion air flow should not be increased rapidly. A sudden increase of combustion air flow into a fuel-rich combustion chamber can cause very rapid combustion of the excess fuel. This phenomenon could increase combustion chamber pressures enough to cause a boiler explosion.

If the optimal excess air level determined by this procedure is higher than the manufacturer's recommended level, the boiler should be examined. Tables 19 and 20 list some of the operation and maintenance changes for stokers and pulverized coal boilers, respectively, that can help improve combustion so that recommended excess air levels can be achieved.

It is easy to demonstrate optimal boiler efficiency during a test. It is much harder to maintain optimal efficiency day after day. Once this optimum is determined, maintaining it requires a conscientious effort by the boiler operators. Special attention should be given to problems with clinkering, opacity, and slag buildup. The percentages of oxygen and opacity and the flue gas temperature exiting the boiler should be checked regularly. Boiler maintenance requirements should be addressed. Corrective action should be taken whenever a problem is discovered.

**Table 19. Stoker adjustments.**

|  |
|--|
| Adjust zone dampers                      |
| Adjust overfire air                      |
| Adjust coal feeders                      |
| Adjust furnace pressure                  |
| Check coal size and quality              |
| Adjust bed thickness                     |
| Reduce tramp air                         |
| Minimize coal segregation                |
| Repair controls and dampers              |
| Rebuild refractory                       |
| Clean grate holes and overfire air ports |

**Table 20. PC adjustments.**

|  |
|--|
| Adjust burner position                 |
| Adjust swirl at burner inlet           |
| Adjust primary air temperature         |
| Adjust velocity of primary air         |
| Change number of burners in service    |
| Adjust location of burners             |
| Balance fuel supply from burner in use |
| Replace burner tips                    |
| Maintain pulverizer                    |

## 7 Air Pollution Control Systems

### 7.1 Systems Overview

The boiler plant operator must always consider efficiency, reliability, and safety in the operation of air pollution control (APC) equipment. In this case, however, the efficiency does not focus on fuel or energy savings. Instead, the focus is on the removal of pollutants from flue gas. Poor air pollution control efficiency can cause pollution emissions that exceed State or Federal standards. This situation could result in substantial fines or even plant shutdown.

In tuning or optimizing air pollution control systems, the emphasis is on techniques for reducing unscheduled maintenance work and overall operating costs. Table 21 lists the objectives for optimizing air pollution control systems. When these objectives are met, large savings will result in the form of improved equipment life and reliability. This will also lead to less personnel exposure to safety hazards by reducing the amount of internal maintenance work required.

**Table 21. Optimization program objectives.**

- |   |
|---|
| <ul style="list-style-type: none"><li>• Reduce risk of catastrophic damage</li><li>• Reduce operating cost</li><li>• Reduce energy consumption</li><li>• Ensure operator safety</li><li>• Maintain compliance</li></ul> |
|---|

Optimization techniques for APC devices have the following general aspects in common: (1) evaluation of changes in baseline operating conditions, (2) component failure analyses, and (3) annual internal inspections.

The shifts from baseline values are used for important operating variables that can be monitored with reasonable accuracy. These variables include, but are not limited to: gas temperatures, gas pressures, gas stream opacities, electrical equipment operating conditions, and gas stream oxygen concentrations. Changes in sets of operating conditions provide a sensitive indicator of emerging problems and a means of evaluating when optimal conditions have been reached.

Component failure records provide a complete long-term picture of the nonuniformities within the unit. Problems such as extreme gas temperature differences,

extreme air infiltration, and nonuniform gas flow can often be identified clearly from the failure patterns, even though the plant's instruments indicate nothing unusual or undesirable. Furthermore, the change in frequency of component failures can indicate the need for revised operation and maintenance (O&M) procedures.

Comprehensive annual inspection can identify all the subtle problems that escape detection by other means. Furthermore, fundamental operating problems can be identified by observing the internal conditions rather than drawing conclusions from records and tests.

To evaluate changes in the key operating variables properly, it is necessary to have some unit specific data taken at some time in the past. A stack test is an ideal time to record data since pollutant emission rates and gas stream flow rates are provided by the test crew. Such data will be useful in the future to determine the extent to which air pollution control system performance can change without approaching the regulatory limits. Furthermore, baseline data is necessary to document that the air pollution control system was operating in a representative manner during the test.

A complete set of baseline data should also be taken any time the stack opacity (or sulfur dioxide emissions) is especially high or low. Information on the changes in a set of variables is useful at a later date in diagnosing the problems responsible for the change from normal operating conditions.

There is no strict format for baseline data and records. Each plant should adopt a reasonable approach that is appropriate for its installation.

## 7.2 Multicyclone Collectors

The conventional multicyclone consists of rows of 6 to 12-in. diameter tubes supported by a "dirty side" tube sheet in the approximate middle of the unit (Figure 56). A small outlet tube carries the treated gas stream from each cyclone tube upward through the clean gas tube sheet mounted on an angle across the side of the shell.

Vanes at the cyclone tube inlet force the gas to spin one or more times while passing through the tube (Figure 57). Because of inertia, the large-diameter flyash concentrates near the tube wall. The gas (with some small-diameter particles) turns 180 degrees and passes directly upward through the clean gas tube and larger particles drop downward into the hopper.

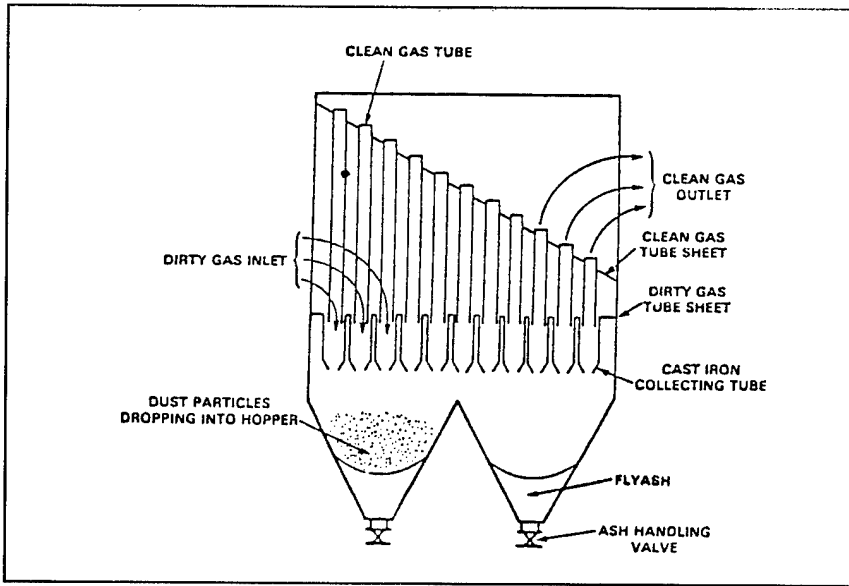


Figure 56. Multicyclone collector.

The efficiency of this system depends largely on particle size. Essentially 100 percent collection is achieved for particles larger than 10 microns, but efficiencies drop between 50 and 75 percent for 5 micron particles. At 0.1 to 2 microns, the collection efficiency is extremely low. Under good conditions, emissions from multicyclone collectors on coal-fired boilers can be from 0.15 to 0.20 lb/MBtu heat input. However, since current regulations require lower emissions for moderate to large boilers, the multicyclone collectors have primarily become a pre-cleaner for more efficient systems.

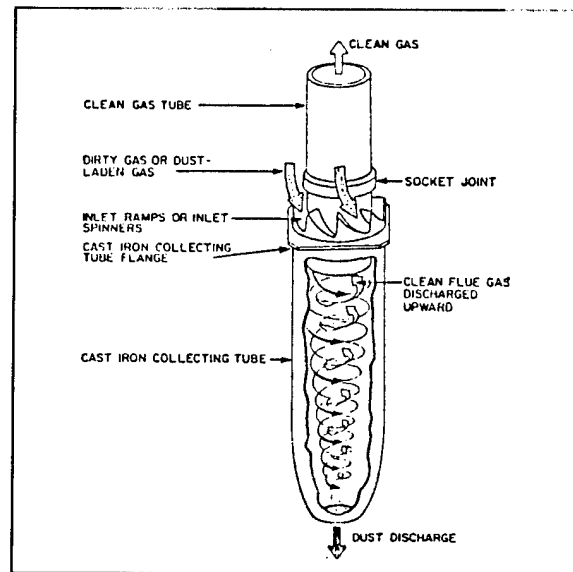


Figure 57. Single cyclone.

Table 22 lists the operating data that should be taken during a baseline period when the multicyclone collector is in good physical condition and coal-firing conditions are at least adequate. Problems developing within the collector can be indicated by lowered static pressure and gas temperature or by arising oxygen concentration.

Table 22. Baseline operating data.

- Inlet and outlet static pressures
- Inlet and outlet gas temperatures
- Inlet and outlet oxygen concentrations
- Stack opacity

The baseline data should be taken at various boiler loads since gas flow rate strongly influences the pressure drop. The gas temperatures and flue gas oxygen concentrations are also different at full loads than at low loads. The data should be prepared as a set of charts, with the boiler load data provided on the horizontal (x) axis, as shown in the opacity data (Figure 58).

Measurement ports and instruments located before and after the multicyclone collector are necessary to obtain the basic operating data outlined in Table 22. The collector inlet port should be at either location 4 or 5 on Figure 59. The outlet measurement port should be at either location 6 or 8. The choice of location is generally limited by accessibility to the inlet and outlet ductwork.

Air infiltration can be a serious problem with multicyclone collectors because of the thermal expansion and contraction that occurs during startups and shutdowns. In addition, the wear on solids discharge handling equipment affects air infiltration. Infiltration up through the hoppers causes the most serious impact on multicyclone performance (Figure 60). The rising air stream entrains some abrasive particulates from the hopper and then disrupts the vortices in many of the collector tubes. The combined effect of infiltration substantially increases flyash emissions.

The presence of significant air infiltration can be detected by comparing gas temperature drops or oxygen concentration increases across the multicyclone collectors. Normally, the gas temperature drops are in the range of 10 to 30 °F and oxygen concentration increases are in the range of 0.5 to 1.0 percent. Changes in these readings can clearly indicate air infiltration problems.

In a walk-around inspection to identify possible sites of air infiltration, the hopper area should be emphasized because of adverse impact of infiltration in this part of the collector. To the extent that the hopper area is safely accessible, operators should listen for air infiltration around the solids, discharge valves, access hatches, poke holes, flanges, and welds.

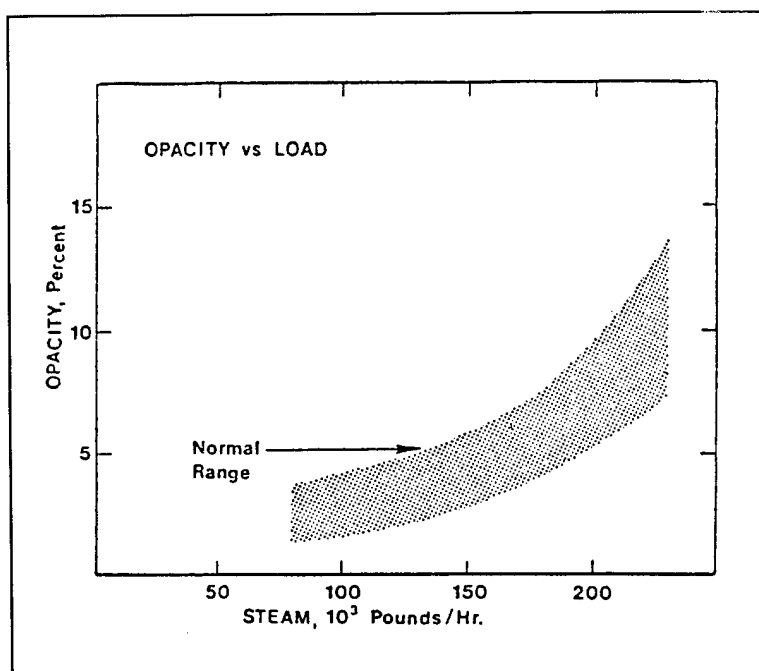


Figure 58. Opacity versus load.

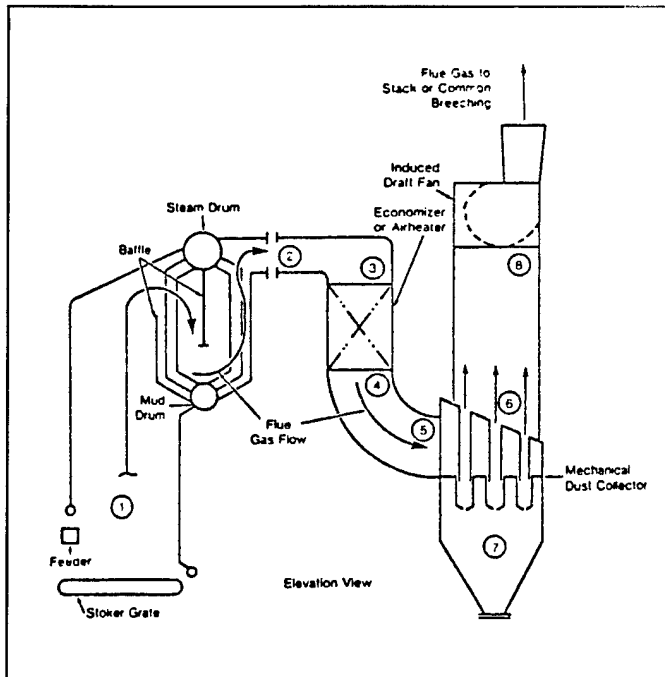


Figure 59. Measurement port locations.

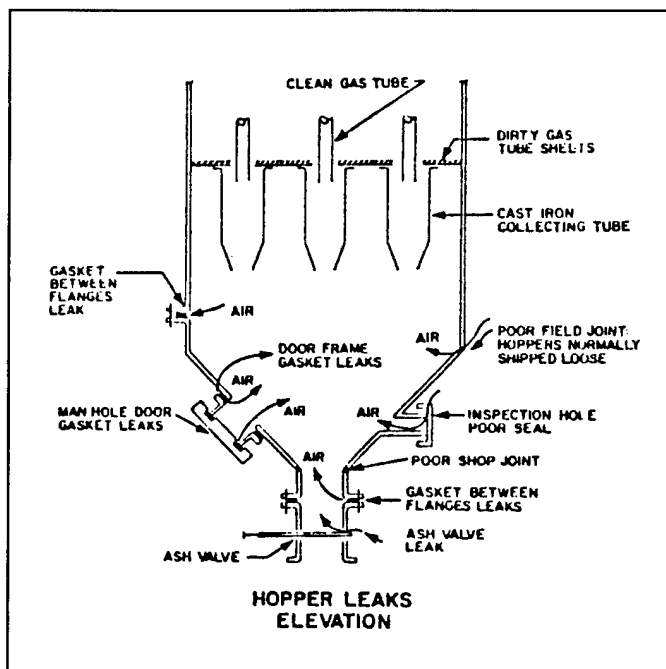


Figure 60. Air infiltration.

Plant noise levels and poor accessibility can limit the ability to locate infiltration sites. Also, small leaks can escape detection in any unit. To better identify and correct these problems, a smoke bomb test can be conducted during an extended outage of the boiler and multicyclone collector.

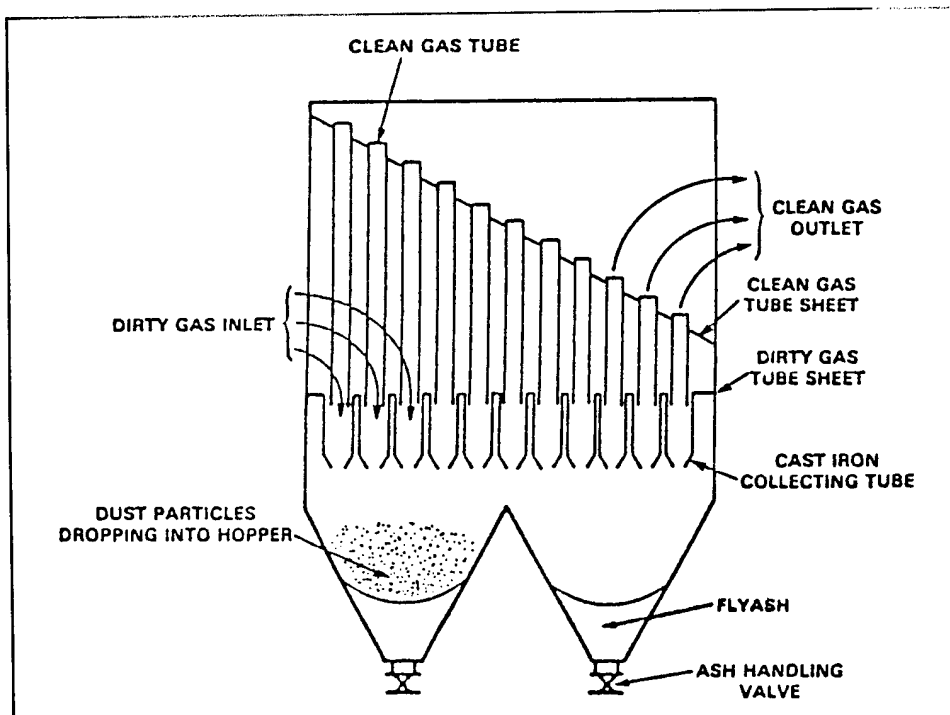
Several observations should be made during the annual internal inspection of the units, as shown in Table 23. The first four listed conditions can help confirm suspected problems because of observed shifts from baseline boiler load/operating parameter charts. Internal inspections are especially important with the last three listed items since these problems do not significantly affect measurable operating parameters, but can be found only during internal inspection.

**Table 23. Internal inspection observation.**

- Tube and inlet vane and outlet vane plugging
- Tube gasket and/or weld failure
- Corrosion
- Obvious air infiltration sites
- Tube outlet deposits
- Tube wall deposits
- Symptoms of cross hopper ventilation

Solids can accumulate within a hopper for several reasons. Even though the operator has successfully pulled the hopper, solid plugs of material can remain in the bottom of the multicyclone tubes. Since the flyash cannot be discharged, it is re-entrained and emitted from the tube. This condition increases the stack opacity with no significant effect on the unit's static pressure drop.

Figure 61 shows cross-hopper ventilation problems. The treated gas stream in the front rows of the collector can sometimes pass downward out of the tube instead of up the appropriate outlet gas tubes. This gas stream passes across the hopper to the back rows of tubes that have relatively short outlet gas tubes with low resistance to



**Figure 61. Cross-hopper ventilation.**



the flow. By passing upward in this back row of tubes, the cross hopper gas disrupts the vortices in the tubes and lessens the particle collection efficiency. If the hopper levels are moderately high, this cross-hopper gas also contributes to re-entrainment emissions.

The presence of cross-hopper flow is indicated by unusual gas stream scouring patterns in the front and back rows of tubes and across any obstructions or sidewalls at the tops of the hoppers. It is relatively difficult to identify. One possible way to minimize cross-hopper flow is to construct a solid partition that divides hoppers serving the front and back sections.

Another option for minimizing the effects of cross-hopper flow is to add a "side stream" baghouse (Figure 62). This device is a small baghouse that pulls 10 to 25 percent of the total flue gas from various points near the tops of the hoppers. Any cross-hopper flow is collected by this system. It also helps collect any rising ambient air that has entered the hopper area. In most cases, the filtered gas from the baghouse is then combined with the treated effluent from the multicyclone collector.

### 7.3 Electrostatic Precipitators

Figure 63 shows a schematic of an electrostatic precipitator. Inside the unit is a large number of electrodes that are hung from the top and stabilized at the bottom. These wires or electrodes are energized to voltages ranging from 15,000 to 45,000 kV. Large, grounded collection plates are hung between each row of the wires or electrodes.

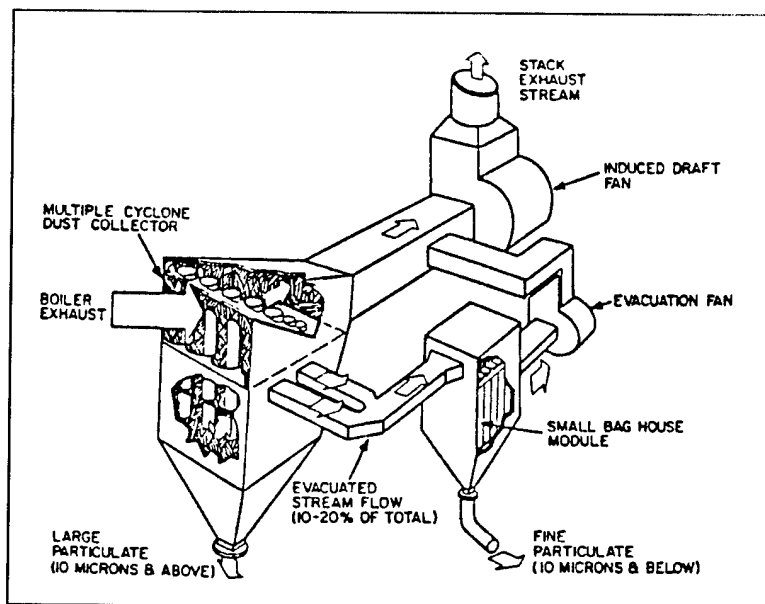


Figure 62. Hopper evacuation.

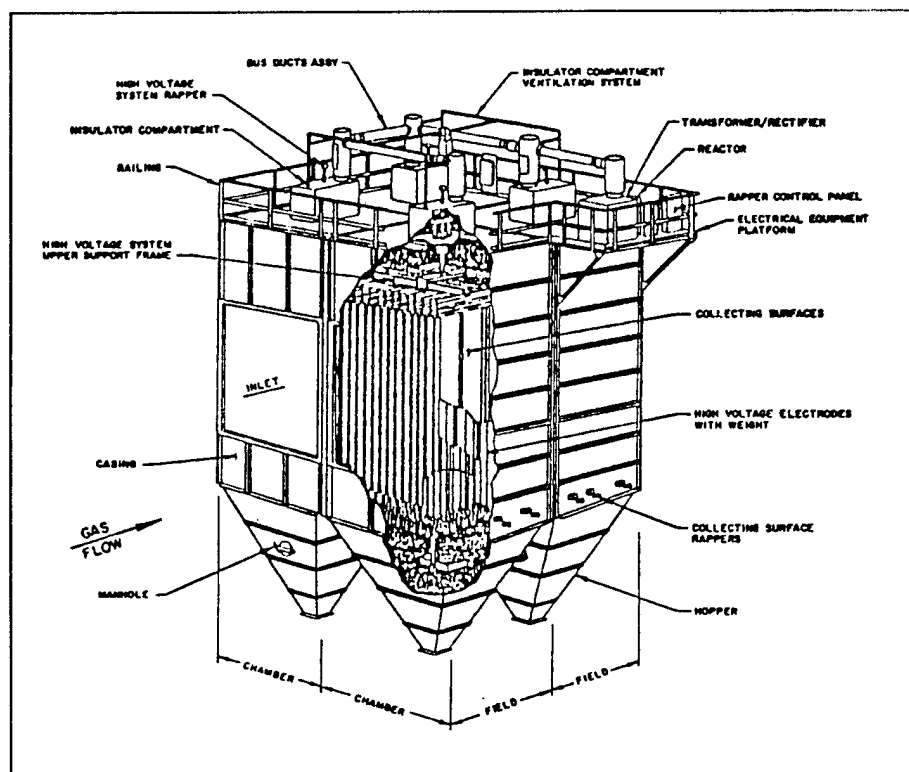


Figure 63. Electrostatic precipitator.

During passage through the precipitator, flyash particles are charged and driven primarily toward the collection plates. However, small amounts also accumulate on the electrodes. A set of "rappers," or electric vibrators, are used to routinely dislodge most of the accumulated solids on the collection plates and electrodes.

Negative ions generated by the high-voltage discharge electrodes attach to flyash particles passing through the precipitator. Once enough ions are clustered around a particle, it is driven to the grounded collection plate. The accumulated flyash must be removed occasionally to avoid suppressing performance of the field. As stated above, removal is done by the use of rappers. During routine operation, there should normally be 1/16 to 1/8 in. of dust on the plates. Too little or too much can indicate improper rapping.

The removal efficiency of electrostatic precipitators also depends on the flyash particle sizes. Unlike the multicyclone collectors, however, precipitators have modest efficiencies, even for particles that are difficult to collect in the range of 0.1 to 2 microns.

Particulate emissions from precipitators serving stoker coal-fired boilers are typically in the range of 0.02 to 0.05 lb/MBtu heat input. These systems can comply with essentially all current regulatory requirements. In addition, much has been

documented about precipitators on coal-fired boilers, since they have been used to control flyash for more than 40 years.

Opacity is a useful indicator of the precipitator's overall performance. High opacity means that the quality of flyash being emitted to the air is high. This condition can be determined simply by observing light coming through the plume at the stack-discharge. However, stack observations are difficult to perform during rainy periods and at night.

The transmissometer provides a more convenient method of determining opacity. This device generates a light beam that passes through the stack or breaching twice before it enters the detector. The fraction of light transmitted is then determined and converted to the opacity in a percentage. A completely invisible plume has an opacity of zero percent, while an entire opaque (black) plume has an opacity of 100 percent. In most areas, the opacity is limited to 20 percent by air quality regulations.

Flyash collection efficiency of precipitators is usually best at low boiler firing rates when the flue gas flow rates are low. As the load increases, the emissions generally increase. The opacity versus boiler load chart shows this important relationship (see Figure 58). The shape of this chart will differ for each boiler/electrostatic precipitator and can be developed by compiling opacity data at different boiler loads over a 1- to 12-month period. There will invariably be some scatter in these data due to the variations in flyash resistivity and other important operating conditions. Once compiled, this chart becomes part of the baseline information that is extremely useful in evaluating precipitator performance and optimizing the operating conditions.

Increases in the average opacity outside the previously established range at a given boiler load indicate decreased precipitator performance. Even slight increases of 2 to 5 percent above this normal range are significant. In addition, opacity levels that are of concern are below the 20 percent generally used by the regulatory agencies to indicate noncompliance. In other words, operators should be concerned about the performance of a unit long before noncompliance occurs.

The increase in opacity above the baseline range clearly indicates a precipitator problem. In most cases, one fundamental problem eventually generates additional problems, which, in turn, lead to further increases in the opacity. If the fundamental problem is not identified and corrected at an early stage, it can be difficult to diagnose accurately. Also, the repairs can be extremely expensive if problems are allowed to compound and intensify.

It is important at this point to realize that average opacity, and not the spiking pattern, will be used to evaluate precipitator performance. Many operators tend to focus on the short-term spikes because these are the periods of maximum stack opacity. Although events such as soot blowing and plate rapping can cause these spikes, they do not cause high average opacity readings. Furthermore, premature changes in boiler or precipitator operating conditions based solely on perceived spiking can be very counterproductive.

## 7.4 Fabric Filters (Baghouses)

Fabric filter flyash removal efficiencies can be very high and are not dependant on particle size. These systems can obtain emissions rates in the range of 0.01 to 0.05 lb/MBtu heat input.

There are two main types of fabric filters currently in use today. The pulse-jet fabric filter system (Figure 63) is one type. Fabric bags, usually made of fiberglass, are supported on metal cages that are suspended near the top of the collector. In this type, flue gas enters near the top of the hopper. Flyash then collects or cakes on the outside of the bags. Filtered air eventually passes through the bag and is collected in the top plenum.

Compressed air pulses, introduced at the top center of each bag, are used to avoid excessive dust caking. In the small units, bags are cleaned by working on one row while the others remain operating. On the other hand, the larger units are divided into compartments. This allows an individual compartment to be shut down and cleaned while the other compartments remain on line.

The second type of fabric filter is the reverse air baghouse (Figure 64). In this type of baghouse, the bags are hung from the top and secured to a tube sheet immediately above the hoppers. The gas stream enters near the top of the hoppers and passes up into the inside of each bag. The dust then cakes on the insides of the bags, allowing filtered gas to pass through. The bags are then cleaned by isolating a compartment and circulating a stream of filtered gas backwards through the bags. The dust cake then falls off the bags and into the hopper below.

Fabric filter optimization focuses on three areas: static pressure drop, bag cleaning, and bag life. High static pressure drops can lead to derating of the boiler. These pressure drops are often due to either coal firing problems or failures in portions of the baghouse cleaning equipment.

### 7.4.1 Static Pressure Drop.

Before discussing static pressure drop in detail, it is necessary to define the term "air-to-cloth ratio." This ratio is the volume of flue gas passing through a given filter area in 1 minute. It is normally expressed in terms of actual cubic feet of gas per square foot per minute. For pulsed-jet baghouses (Figure 65), the air-to-cloth ratio is normally 3 to 8 ft/min. For reverse air baghouses, it is in the range of 1 to 2.5 ft/min.

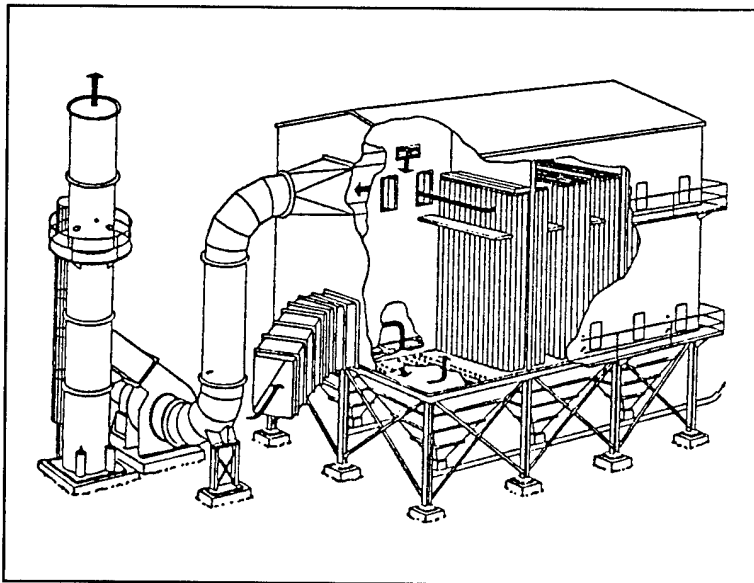


Figure 64. Reverse air baghouse.

There is a general relationship between the air-to-cloth ratios in the baghouse and the emissions of flyash. If the unit is undersized or cleaning problems reduce the filter surface area available for gas flow, the air-to-cloth ratios will increase. Substantial increases in emissions can occur as this happens. These emissions, however, occur even before the fabric is damaged and holes or tears develop. At high air-to-cloth ratio conditions, flyash can seep through the filter.

The static pressure drop should be monitored routinely using simple instruments such as a diaphragm gage and a water or oil-filled manometer. Portable static pressure gauges should be used occasionally, in addition to permanently mounted gages, to measure the overall baghouse static pressure.

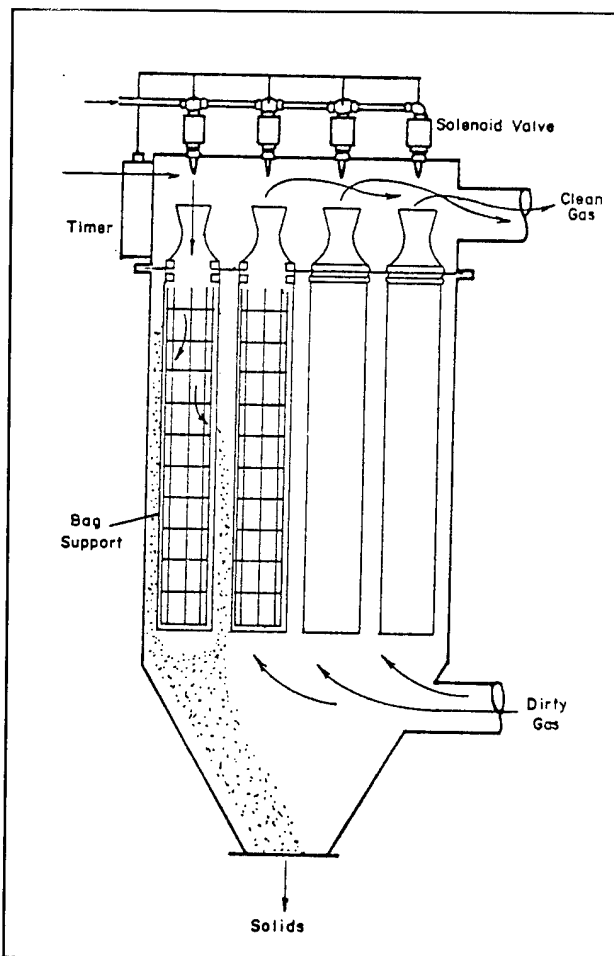


Figure 65. Pulse jet baghouse.

Once reliable static-pressure-drop data is available, the present pressure drop data should be compared to baseline data at the same boiler load. Slight shifts above baseline levels should be cause for concern. Long-term operation with either cleaning system problems or adverse flyash properties can lead to numerous bag failures and excessive emissions. Evaluation of high-pressure drop problems generally begins with a check of the cleaning system operation. The cleaning system is not at fault if the various components appear to be functioning properly and if the cleaning frequency and intensity are similar to baseline conditions.

Flyash appearance is one indicator of combustion problems. If the material is highly-carbonaceous or sticky, the high static pressures are probably related to coal-firing problems.

Excessive cleaning, "clean-side" air infiltration, and extreme bag failure are conditions that can decrease the overall static pressure drop at a given boiler load. Excessive cleaning intensities and frequencies are the most common cause. This practice leads directly to increased flyash emissions due to the temporary lack of dust cake filtration immediately after cleaning. The cleaning energies can also accelerate fabric wear and bag failure.

The overall baghouse static pressure drop is clearly an important operating parameter that should be monitored routinely. The most important aspects of pressure drop are:

- directly affects fan energy costs
- symptom of possible cleaning problems
- symptom of possible flyash emission problems.

#### **7.4.2 Bag Life Extension.**

A major objective of the baghouse O&M program is to extend bag life as much as possible. Frequent bag replacement is expensive and time consuming. Also, frequent shutdowns make the bags vulnerable to chemical attack. Furthermore, health and safety risks are involved with entry into confined spaces such as fabric filter compartments.

Fiberglass is the main type of fabric used in coal-fired boiler baghouses and is extremely sensitive to abrasion and flex. For this reason, it is especially important to install the bags properly and optimize cleaning practices. Each bag that has to be removed because of failure should be checked before it is discarded so the reason

for failure can be established. This will help operators to prevent the loss of other bags still on-line in the compartment.

Figure 66 shows a plan view of a baghouse compartment showing the locations of each bag. The first step in evaluating a failed bag is to mark the location from which it was removed. After several bags have been removed, a pattern of failed bags will develop that can provide an indication of the causal factors.

The date of bag replacement should be recorded to help create a bag failure frequency chart. The failures usually occur over three main time periods. Several bags fail during the time period immediately after all of the bags in a compartment have been replaced. These failures are due to bag fabrication faults or improper installation. Then there is a long time when few bag losses occur, followed by an increase in bag loss because of normal wear and tear on the bags or baghouse operating problems.

In this latter period, bag replacement and maintenance costs can be substantial. Further bag evaluation is very important during this time to determine if individual bags should be repaired or replaced or if the entire compartment should be rebagged.

Next the bag must be evaluated to determine if the bag failed because of localized abrasion/flex damage or fabric strength loss from chemical attack or high temperature damage. The rip test is a rough initial test that can be performed after the bag is removed.

|    | A | B | C |  | D | E | F |  | G | H | I |    |
|----|---|---|---|--|---|---|---|--|---|---|---|----|
| 14 | ○ | ○ | ○ |  | ○ | ○ | ○ |  | ○ | ○ | ○ | 14 |
| 13 | ○ | ○ | ○ |  | ○ | ○ | ○ |  | ○ | ○ | ○ | 13 |
| 12 | ○ | ○ | ○ |  | ○ | ○ | ○ |  | ○ | ○ | ○ | 12 |
| 11 | ○ | ○ | ○ |  | ○ | ○ | ○ |  | ○ | ○ | ○ | 11 |
| 10 | ○ | ○ | ○ |  | ○ | ○ | ○ |  | ○ | ○ | ○ | 10 |
| 9  | ○ | ○ | ○ |  | ○ | ○ | ○ |  | ○ | ○ | ○ | 9  |
| 8  | ○ | ○ | ○ |  | ○ | ○ | ○ |  | ○ | ○ | ○ | 8  |
| 7  | ○ | ○ | ○ |  | ○ | ○ | ○ |  | ○ | ○ | ○ | 7  |
| 6  | ○ | ○ | ○ |  | ○ | ○ | ○ |  | ○ | ○ | ○ | 6  |
| 5  | ○ | ○ | ○ |  | ○ | ○ | ○ |  | ○ | ○ | ○ | 5  |
| 4  | ○ | ○ | ○ |  | ○ | ○ | ○ |  | ○ | ○ | ○ | 4  |
| 3  | ○ | ○ | ○ |  | ○ | ○ | ○ |  | ○ | ○ | ○ | 3  |
| 2  | ○ | ○ | ○ |  | ○ | ○ | ○ |  | ○ | ○ | ○ | 2  |
| 1  | ○ | ○ | ○ |  | ○ | ○ | ○ |  | ○ | ○ | ○ | 1  |

ACCESS DOOR  
 MODULE NO. \_\_\_\_\_  
 DATE \_\_\_\_\_

REPLACE - R  
 PATCH - P

CAP-OFF - C  
 RETENSION - T

A screwdriver is inserted through the bag near the point of failure. If the bag can be ripped easily, then it has probably suffered chemical attack or high temperature damage. If this is the case, then all of the bags in the compartment have probably suffered this damage and the whole compartment should be rebagged. If the bag cannot be ripped easily, then the damage was probably caused by localized abrasion or flexing. In this case, the bag can be washed, patched, and reinstalled at a later date. With localized abrasion, the other bags in the compartment are generally not damaged.

Figure 66. Bag failure record.

If there are numerous bag failures, it is advisable to send fabric samples to a qualified laboratory to confirm the reasons for the failure. Two or three swatches from different elevations of failed bags should be submitted.

## 7.5 Wet and Dry Scrubbers

### 7.5.1 Wet Scrubbers.

Figure 67 shows a flow chart illustrating a common wet desulfurization (scrubber) system. In this system, sulfur dioxide is removed in a spray-tower absorber. A high-efficiency particulate device, such as an electrostatic precipitator, is often used upstream of the absorber to ensure compliance with particulate emission regulations. Lime is slaked to form calcium hydroxide and injected into the system at a rate necessary to maintain the proper pH and alkalinity in the recirculation loop. A purge stream is drawn from the recirculation tank for removal of accumulated calcium sulfate and calcium sulfite solids. Following the clarifier, the thickened slurry is vacuum-filtered or centrifuged.

The scrubber system has numerous variations. In some systems, limestone is used as the alkali rather than lime, which is more expensive. In earlier installations, a venturi scrubber was used for both sulfur dioxide absorption and particulate-matter collection. The lime/limestone units have been applied primarily to the moderate-to-large coal-fired boilers.

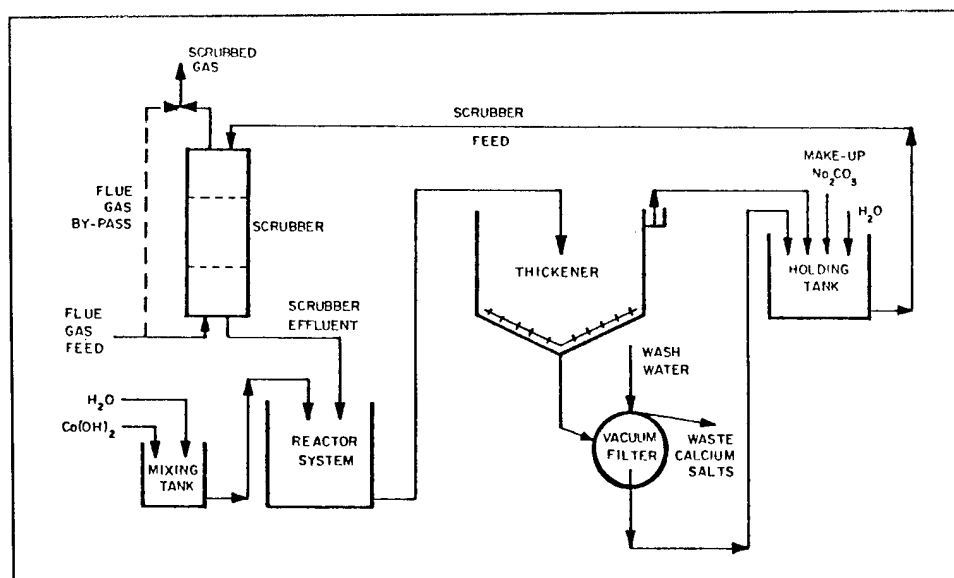


Figure 67. Wet scrubber schematic.



### 7.5.2 Dry Scrubbers

Figure 68 diagrams one common type of dry scrubber. After exiting the boiler and any pre-cleaners, the flue gas stream enters a large spray dryer absorber. A fine spray of calcium hydroxide slurry is generated in this chamber, using either a high-speed rotating disk atomizer or two fluid nozzles. Sulfur dioxide is absorbed as spray droplets evaporate within the chamber. The gas stream then passes to a particulate control device, such as a fabric filter or electrostatic precipitator, for removal of the flyash and calcium sulfate/calcium sulfite particles.

Another variation of a dry desulfurization system simply uses dry calcium hydroxide that is injected into the flue gas stream before entry to a fabric filter. Sulfur dioxide is absorbed while the gas stream passes through the calcium hydroxide on the bags. Although much higher quantities of calcium hydroxide are used in these type of systems, however, they are simpler and less expensive to build than many others.

The dry scrubber system has several claimed advantages over the wet scrubber system. Since the baghouse is part of the dry scrubber system, the system is able to extract particulates in addition to  $\text{SO}_2$ . The dry waste is easier to handle than the sludge from the wet scrubber. Also, for small boiler systems, the spray-dry scrubber is more reliable. Dry scrubbers do have one main disadvantage; slightly more lime is required for the dry system because of lowered efficiency in capturing  $\text{SO}_2$ .

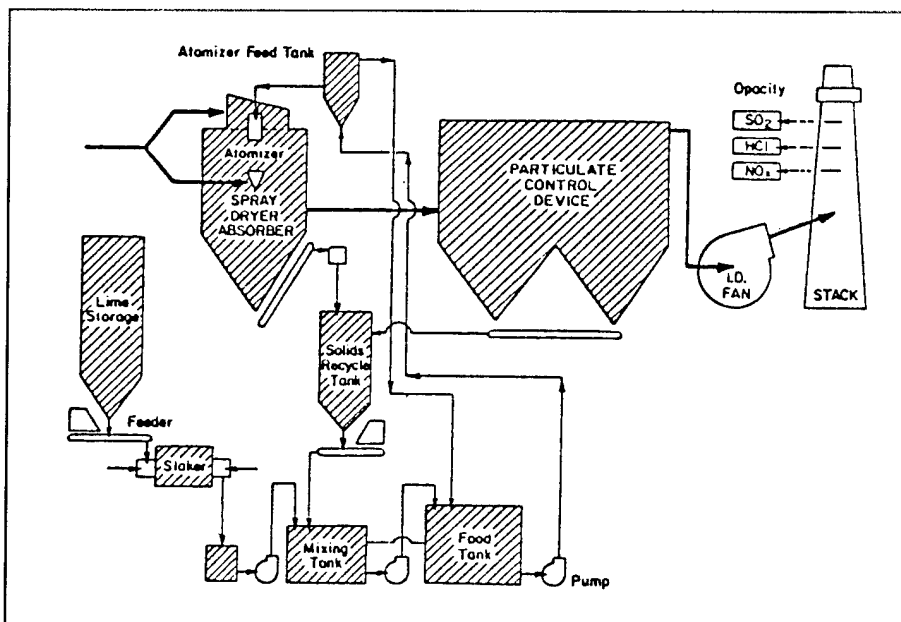


Figure 68. Dry scrubber schematic.

## 8 Coal-Fired Boiler Systems

### 8.1 Overfeed Stoker Boilers

#### 8.1.1 *System Descriptions*

An overfeed stoker admits coal to the furnace above the point of air admission to the fuel bed. There are three types of overfeed stokers:

- chain grate stokers
- traveling grate stokers
- vibrating grate stokers.

Overfeed stokers feed coal onto the grate from a coal hopper mounted on the front of the furnace. The depth of coal fed on the grate is regulated by raising and lowering a sliding coal gate at the hopper discharge (Figure 35). The coal burns during transportation across the furnace. The ash is continuously deposited off the rear of the grate into an ash pit.

Air for combustion enters through openings in the grate (undergrate air) and through overfire air jets. Undergrate air is manually controlled through individual air zones or compartments underneath the grate. Air from overfire air jets enters the furnace through the front arch—roofs over parts of the furnace used to direct the flame and to protect parts of the boiler from direct heat—or the front wall above the arch. Over-fire air and undergrate air, which passes through the fuel bed, provide turbulence (mixing of combustible gases) for rapid combustion. Overfire air jets can also be located at the rear wall to provide a counterflow of gases in the furnace, promoting increased turbulence and further reducing smoke emissions.

Flexible plates divide the space beneath the combustion grate into compartments. Individual supply ducts with dampers regulate air distributing through the coal-ash bed. Overfire air jets on the front wall mix volatile gases and air for more complete combustion.

When describing these types of stokers, a discussion of the firing arch, front, rear or combination is essential. The type of coal—anthracite, bituminous, subbituminous,

or lignite—as well as each coal's inherent chemical and physical properties dictate the type of arch required for the furnace.

Front arch furnaces were first designed for anthracite coal. These furnaces, however, provided inadequate combustion volume for the low volatile fuel. The furnaces also suffered from gas stratification and excess carbon loss. Carbon loss occurred when glowing carbon particles blown from the furnace were not swept back into the combustion zone by air turbulence. The front arch furnace was also used for bituminous coals. Although they operated at conservative combustion rates, these furnaces required a lot of maintenance. These furnaces were used where space constraints were present, but many have been replaced by the more popular combination arch.

The combination arch, as the name implies, has both a front and rear arch in the furnace. Figure 69 shows a typical combination arch furnace with a traveling grate stoker. This arrangement provided better flame stability and more complete combustion for the low volatile anthracite and made it possible to fire bituminous coals at a higher combustion rate. The combination arch provided less gas stratification and better carbon burnout. In many cases, however, the higher possible combustion rate caused unacceptable wear on the furnace refractory. This problem was resolved by the introduction of water-cooled walls for bituminous firing. This type of front and rear arrangement is still in use today for both anthracite and bituminous coals.

The rear arch furnace has proved the most functional, with slight variations, for different types of coal. For anthracite coal, the best rear arch design is a horizontal arch located from 2 to 4 feet above the grate that extends horizontally forward 70 to

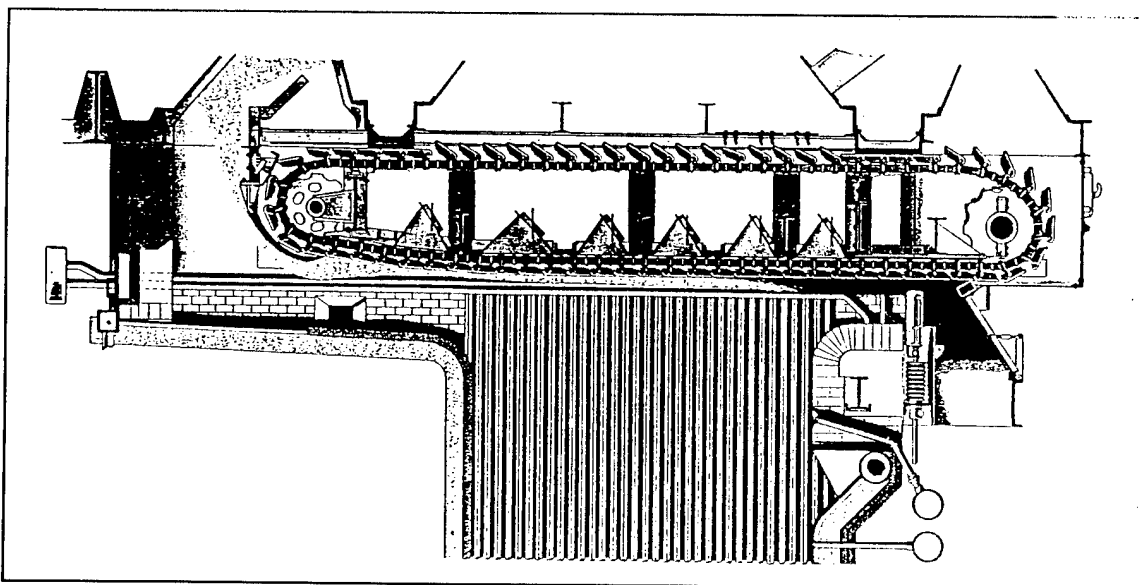


Figure 69. Combination arch furnace with traveling grate stoker.

75 percent of the stoker length or about 2 to 3 feet from the front wall. Air is added mostly toward the rear of the stoker. This promotes excellent mixing and decreases stratification. A low arch, practically horizontal, ensures an increasing air velocity towards the front end. It also picks up the incandescent fines and forces them toward the front of the boiler for better combustion.

With this design, between 50 and 60 percent of the fuel is burned under the arch. For anthracite coal, sometimes a small nose is added to the front of the furnace to aid ignition in the lower portion of the unit. For anthracite coal, neither the sidewalls nor the arch are water cooled. This type of arrangement provides the fastest and most stable combustion of anthracite coal, and allows for good heat radiation from the furnace refractories, which assist ignition of the incoming fuel. The rear arch is also used for bituminous coal. In this arrangement, however, water cooling is required to minimize wear on the furnace refractory.

Ash fusion temperature is particularly important to the traveling grate stokers because they have grate holes that can easily plug when the ash becomes liquid. The Free Swell Index is critical to these units. Because coal swells volumetrically when exposed to the heat of the furnace, the swelling can eliminate underfire air flow through the fuel bed.

**8.1.1.1 Chain Grate and Traveling Grate.** The distinction between chain grate and traveling grate, also known as bar-and-key grate stokers, is the configuration of the grates. The grate of a chain grate stoker is composed of a series of cast iron links connected by bars or pins, which form an endless chain. Chain grate stokers, because of their chain configuration, are capable of breaking up masses of fused coal and ash. The traveling grate stoker is comprised of a series of cast iron sections, or keys, mounted on carrier bars, which in turn are fastened to two or more drive chains to form an endless conveyor. Traveling grates are not as adapt at breaking up clinkers, but are easier to service because each grate section can be serviced individually, whereas the chain grate must be completely disassembled.

The traveling grate stoker is better suited to firing anthracite than the chain grate. The chain grate stoker allows the finely sized anthracite to fall between the links of the chain grate, which sends this unburned carbon to the ash pit, consequently decreasing efficiency.

The mechanism for ignition on a chain grate or traveling grate stoker is radiation that comes from arches, located either front, rear, or both, depending on the type of coal being fired. Once the surface layer begins to burn, the coal is heated beneath by contact. For a successful combustion to occur, proper air distribution is essential.

This is done through a series of zone dampers that allow the quantity of air supplied to different parts of the bed to vary.

***8.1.1.2 Vibrating Grate.*** The vibrating stoker uses vibration and gravity to move the coal-ash bed from coal feed to ash discharge. Coal that is gravity fed from a coal hopper onto the grate passes underneath a gate that controls the thickness of the coal bed on the grate. The grate is vibrated by a vibration generator that consists of two unbalanced weights rotating in opposite directions to impact the desired vibration to the grates. The vibration and inclination of the grate causes the coal bed to move through the furnace toward the ash pit.

### ***8.1.2 Coal Specifications***

Table 24 gives the baseline specifications for overfeed stoker systems. Table 25 gives recommended coal specifications for chain and traveling grate stoker systems. Figure 70 shows recommended limits of coal sizes for overfeed stoker boilers.

## **8.2 Spreader Stoker Boilers**

### ***8.2.1 System Description***

The name spreader stoker refers to the way coal is fed to a furnace. Instead of simply dropping coal directly from a hopper onto the furnace grate, it is dropped onto a spinning paddle called an “overthrow rotor” that hurls the coal into the furnace. The rate at which coal is fed into the furnace is easily controlled by a “reciprocating feed plate” (Figure 71), that slides back and forth beneath the outlet of the coal hopper. As it moves away from the furnace, coal falls in front of it on the spill plate. As it moves towards the furnace, it pushes coal off the end of the spill plate and onto the overthrow rotor. The speed and length of each stroke of the “reciprocating feed plate” determines the rate at which coal is fed to the furnace.

A second degree of control offered by the rotor is the ability to control how far the coal travels into the furnace. By adjusting the position of the end of the spill plate, coal can be forced to hit the rotor in different places. When the spill plate is slid back away from the furnace, coal hits the rotor blades sooner, casting the coal farther into the furnace. If the speed of the rotors is increased, coal will fly farther.

Table 24. Baseline specifications for overfeed stoker systems.

| Coal Quality Measure   | Bituminous Coal                                 | Subbituminous Coal                              | Lignite <sup>1</sup>                            |
|--|---|---|---|
| Low Moisture Content   | Below 5% by wt.                                 | Below 15% by wt.                                | Below 25% by wt.                                |
| High Moisture Content  | Above 15% by wt.                                | Above 30% by wt.                                | Above 45% by wt.                                |
| Low Ash Content  | Below 6% by wt.                                 | Below 6% by wt.                                 | Below 6% by wt.                                 |
| High Ash Content   | Above 20% by wt.                                | Above 30% by wt.                                | Above 20% by wt.                                |
| High Sulfur Content  | Regulation dependent                            | Regulation dependent                            | Regulation dependent                            |
| Low Heating Value  | Below 10,500<br>Btu/lb, dry                     | Below 8,300<br>Btu/lb, dry                      | Below 6,300<br>Btu/lb, dry                      |
| Low Volatile Matter  | Below 30% by wt.                                | Below 30% by wt.                                | Below 30% by wt.                                |
| High Volatile Matter   | Above 45% by wt.                                | Above 40% by wt.                                | Above 45% by wt.                                |
| Excess Coarse Coal Particles   | Above 5% by wt.<br>Over 1 in.                   | Above 5% by wt.<br>Over 1 in.                   | Above 5% by wt.<br>Over 1 in.                   |
| Excess Fine Coal Particles   | Above 5% by wt. Under<br>8 Mesh                 | Above 5% by wt. Under<br>0.025 in.              | Above 5% by wt.<br>Under 8 Mesh                 |
| High Free Swelling Index   | Above 5   | Above 5   | Above 5   |
| High Free Alkali <sup>2</sup>  | Above 50% by wt.                                | Above 50% by wt.                                | Above 50% by wt.                                |
| Low Fixed Carbon   | Below 40% by wt.                                | Below 30% by wt.                                | Below 40% by wt.                                |
| High Fixed Carbon  | Above 55% by wt.                                | Above 50% by wt.                                | Above 55% by wt.                                |
| Low Ash Fusion Temp <sup>3</sup><br>- Chain Grate Stoker<br>- Traveling Grate Stoker | Below 2,100°F<br>Below 2,200°F                  | Below 2,100°F<br>Below 2,200°F                  | Below 2,100°F<br>Below 2,200°F                  |
| High Relative Free Quartz <sup>4</sup>   | Undetermined                                    | Undetermined                                    | Undetermined                                    |
| High Abrasion Index <sup>5</sup>   | Undetermined                                    | Undetermined                                    | Undetermined                                    |
| High Flyash Erosivity <sup>6</sup>   | Undetermined                                    | Undetermined                                    | Undetermined                                    |
| High Chlorine Content  | Below 0.15%                                     | Below 0.15%                                     | Below 0.15%                                     |
| High Flyash Resistivity  | 2x10 <sup>9</sup> -2x10 <sup>10</sup><br>ohm-cm | 2x10 <sup>9</sup> -2x10 <sup>10</sup><br>ohm-cm | 2x10 <sup>9</sup> -2x10 <sup>10</sup><br>ohm-cm |
| High Hardgrove grindability Index  | NA  | NA  | NA  |

## Notes:

<sup>1</sup>Lignite firing assumes 450°F preheated combustion air and lignite design furnace.<sup>2</sup>Relative soluble alkali values estimated from limited pulverized coal fire boiler results.<sup>3</sup>Hemispherical ash fusion temperature under reducing conditions.<sup>4</sup>See Appendix A, see reference two.<sup>5</sup>See Appendix A, see reference three.<sup>6</sup>See Appendix A, see reference four.<sup>7</sup>See Appendix A, see reference five.

**Table 25. Recommended coal specifications for chain and traveling grate stoker systems.**

| Proximate Analysis  | Anthracite        | Bituminous                                    | Subbituminous | Lignite                                   |
|---|-------------------|---|---------------|---|
| Moisture (M)  | 1-12%             | 0-25%   | 10-35%        | 25-45%                                    |
| Volatile Matter (VM)  | 1-12%             | 30-45%  | 20-40%        | 22-32%                                    |
| Fixed Carbon (FC)   | 75-90%            | 40-55%  | 30-50%        | 22-32%                                    |
| Ash   | 8-20%             | 6-20%   | 6-20%         | 6-20%                                     |
| <b>Heating Value, Btu/lb</b>                                      |                   |   |               |   |
| 10,500 - 13,500 for Anthracite                                    |                   |   |               |   |
| 10,500 - 14,000 for Bituminous                                    |                   |   |               |   |
| 8,300 - 11,500 for Subbituminous                                  |                   |   |               |   |
| 5,800 - 7,500 for Lignite   |                   |   |               |   |
| <b>Hemispherical Ash Softening Temperature (H - ½ W Reducing)</b> |                   |   |               |   |
|   | <u>Anthracite</u> | <u>Bituminous, Subbituminous, and Lignite</u> |               |   |
| For Chain Grate Stokers:  | 2,300°F Minimum   | 2,100°F Minimum                               |               |   |
| For Traveling Grate Stokers:                                      | 2,300°F Minimum   | 2,200°F Minimum                               |               |   |
| <b>Free Swell Index:</b>  | 5 Maximum         |   |               |   |
| <b>Size:</b>  | Top Size = 1 inch |   |               |   |
| <b>Size Distribution:</b>   |                   |   |               |   |
| <u>Bituminous and Lignite</u>                                     |                   | <u>Subbituminous and Lignite</u>              |               | <u>Anthracite</u>                         |
| Top Size (TS)   | 5%                | Top Size (TS)                                 | 5%            | Buckwheat #2 & #3                         |
| TS x ½ - in.  | 30%               | TS x ¾ - in.                                  | 30%           | Buckwheat #2 = 5/16 x 3/16 - in. (Rice)   |
| ½ x ¼ - in.   | 35%               | ¾ x ½ - in.                                   | 35%           | Buckwheat #3 = 3/16 x 3/32 - in. (Barley) |
| ¼ x No. 8   | 25%               | ½ x ¼ - in.                                   | 25%           |   |
| Less than No. 8   | 5%                | Less than ¼ - in.                             | 5%            |   |

\* Lignite can only be fired with 450°F preheated combustion air and a large arch.

\*\* Sodium and Potassium must be less than 4% in ash analysis.

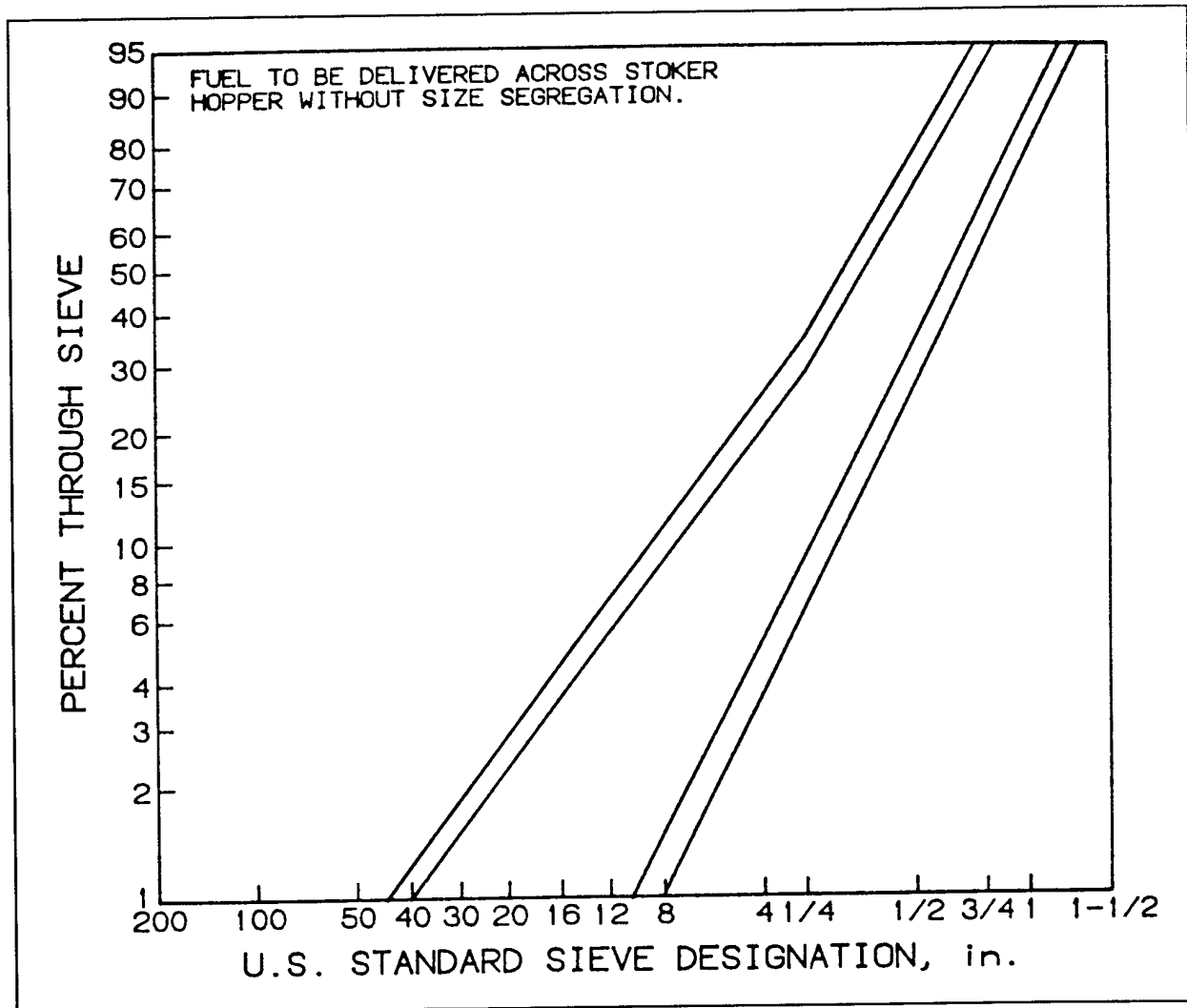


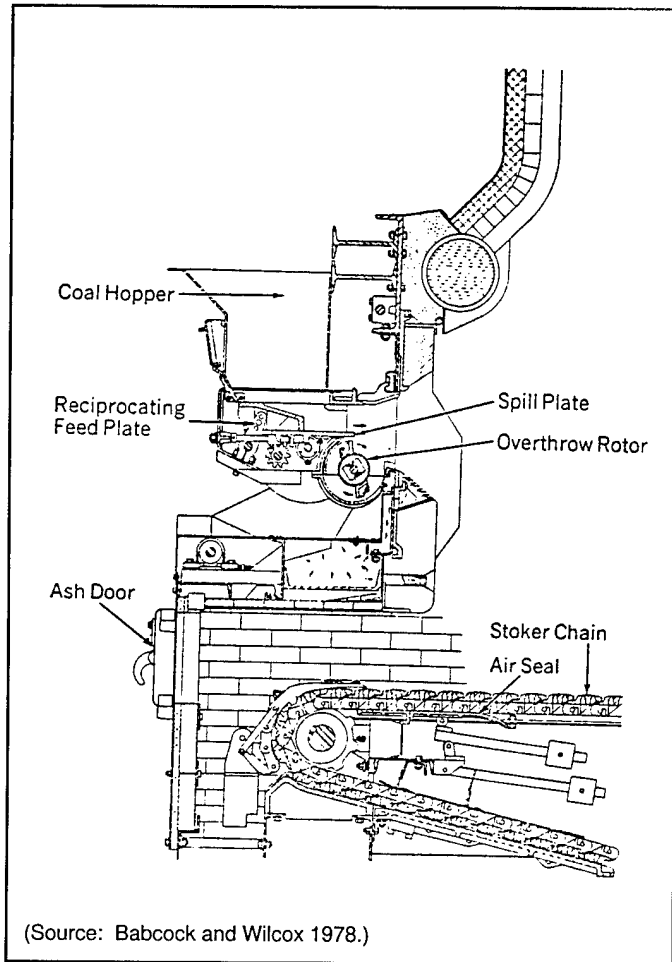
Figure 70. Recommended limits of coal sizes for overfeed stoker boilers.



While throwing coal may seem like a rather unsophisticated method for feeding coal, this technique offers substantial control over the combustion process. In fact, spreader stoker boilers are noted for their ability to change loads rapidly, due to the fact that 30 to 40 percent of the coal particles entering the furnace are small enough to burn in suspension before they reach the grate. Note that the coal should contain at least 20 percent volatile matter to ensure this level of suspension burning, a principal feature of spreader stokers.

Particles that do not completely combust in suspension fall to the grate, an advantage of throwing the coal. When the overthrow rotor slings the coal, heavier coal particles fly farther than lighter ones. This means that coal is distributed over the grate according to size. Because coal reaching the hoppers has a proper coal size distribution, it is distributed evenly throughout the grate. Since larger particles typically take longer to burn, it can be advantageous to have them together. For example, in a traveling grate stoker, the grate acts as a conveyor that moves the coal across the furnace. Coal that lands at the farthest end remains on the grate the longest before being discharged into the ash pit.

Generally speaking, spreader stokers maintain suspension burning and burning on the fuel bed. To facilitate suspension burning, air is injected directly into the furnace using overfire air jets, or secondary air. Not only do these jets provide air for combustion, but if positioned correctly, they create turbulence in the furnace, which forms a blanket over the fuel bed. This blanket holds down volatiles and particulates, improving combustion and reducing emissions. There are typically four sets of overfire air jets in a single furnace. The jets are aimed slightly downward towards the grate (Figure 72).



**Figure 71. Spreader stoker boiler showing overthrow rotor and reciprocating feed plate.**

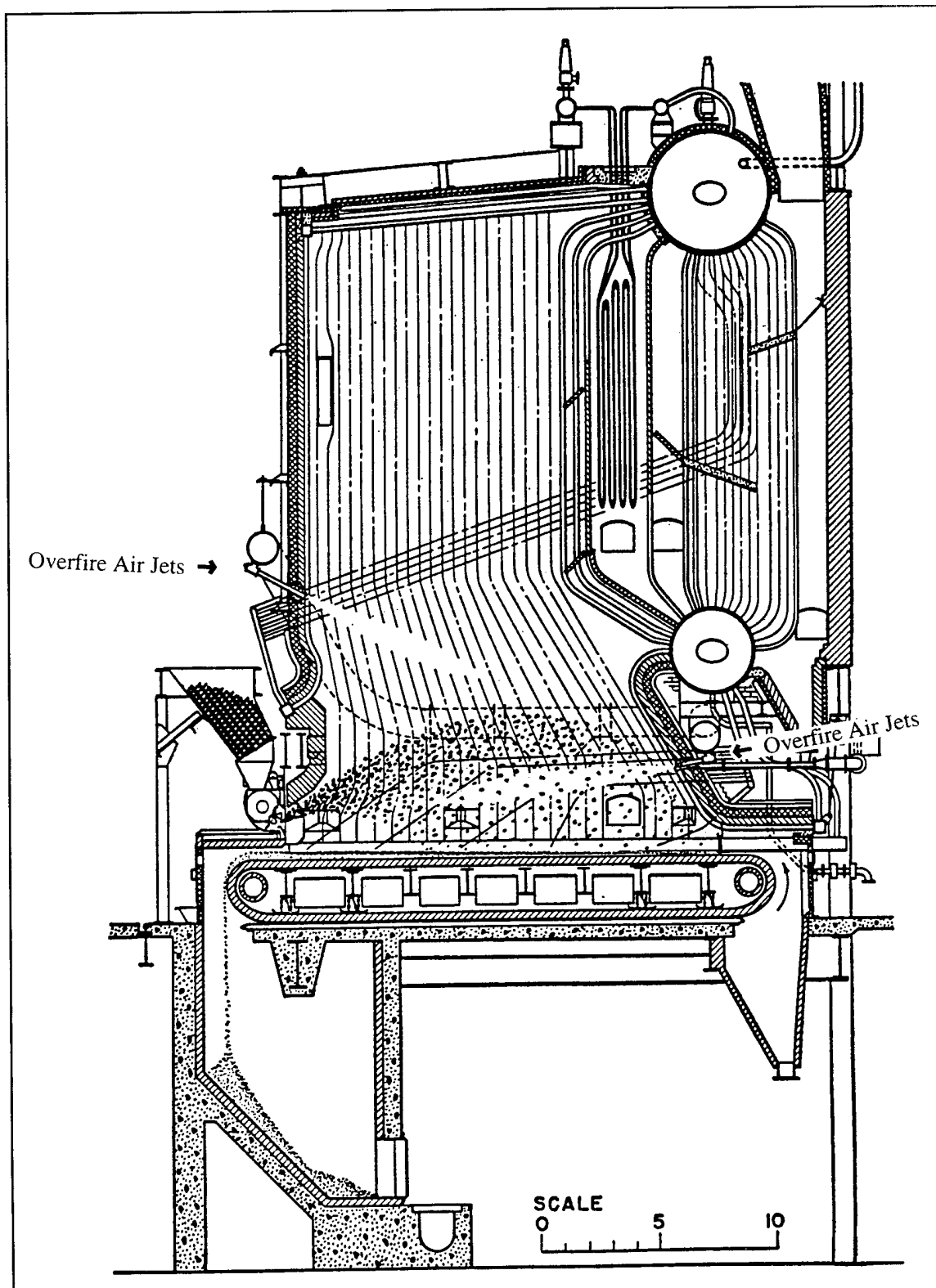


Figure 72. Overfire air jets.

Air for combustion on the fuel bed is supplied from beneath the grate by forced-draft fans. The air must pass through the ash accumulated on the grate. With certain coals, the ash bed can be 9 in. deep. Note, however, that thick ash beds add to the resistance of the air flow through the grate. On the other hand, a thick ash bed protects the grate from extreme temperatures.

An important parameter to consider is the “ash fusion” temperature of the coal. If this temperature is too low, ash will start to plug the grate holes and the underfire air will be reduced. Also, it is important that coal specifications, handling, and distribution into the furnace are conducted properly. Otherwise, coal segregation problems will occur in which thin and thick areas will develop on the grate, causing uneven air distribution. This will lead to clinkers in the thick areas and blowholes in the thin areas. Blowholes greatly increase particulate carryover.

The difference between spreader stokers lies in their grate types. The grate type determines how coal is moved through the furnace and how remaining ash is discarded. This section describes five spreader stoker types:

- traveling grate
- vibrating grate
- overlapping (reciprocating) grate
- dumping grate
- stationary grate.

The stationary grate spreader stoker, however, is omitted from the remainder of this handbook.

### **8.2.2    *Traveling Grate***

The traveling grate spreader stoker is available in capacities of up to 400,000 lb/hr steam. It can be designed to handle a wide variety of coals, ranging from lignite to bituminous. Traveling grates are composed of an endless grate that moves at speeds of 4 to 20 ft/hour (depending on the steam demand) toward the front of the boiler (Figure 73).

As with the other stoker types, proper coal sizing and size distribution is important. However, ash fusion temperature is not as critical with the traveling grate units because the traveling grates are constantly breaking the fuel and ash beds. As such, traveling grates do not form as many clinkers. Traveling grate stokers can tolerate ash fusion temperatures up to 150 °F lower than the other types of spreader stokers.

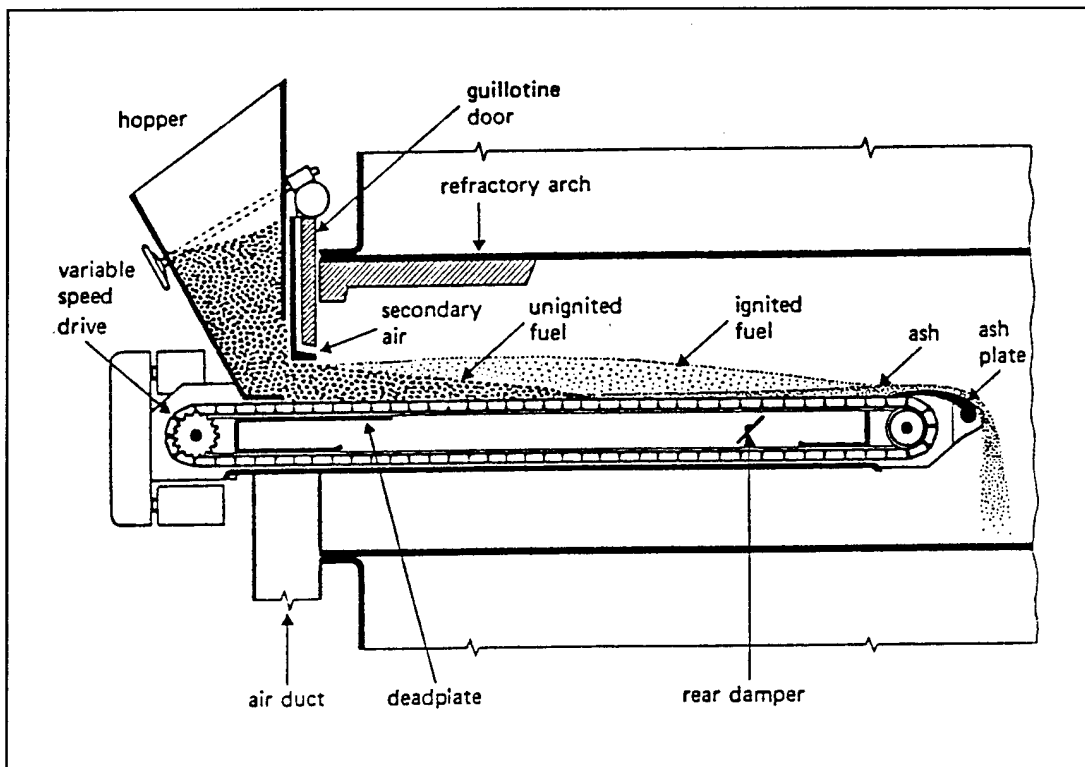


Figure 73. Traveling grate spreader stoker.

### 8.2.3 Vibrating Grate

The vibrating grate spreader stoker moves the fuel bed through the furnace by vibrating the grate. The motor that produces this agitation operates at intervals. The ash is discharged from the front of the furnace into the ash hopper below (Figure 74).

The agitating grate on the spreader stoker is more susceptible to low ash fusion temperature of the coal. This is because the bed is disturbed occasionally and the combustion zones are upset. Fresh coal is then exposed to different conditions on the grate, namely reducing and oxidizing conditions. This greatly effects the ash fusion temperatures and consequently the condition of the fuel and ash bed. The most important parameter for these units is proper size and distribution of coal to the stoker hoppers. Again, the ash fusion temperature is important for proper air distribution under the grate.

### 8.2.4 Overlapping (Reciprocating) Grate

Overlapping grates (or reciprocating grates) fit together like shingles on a roof. The grate bars overlap and are mechanically driven to move back and forth, alternately

increasing and decreasing the amount of overlap. This motion causes the ash to shift from one grate to another until it finally drops off into the ash pit. The rate of ash discharge is controlled by regulating the travel distance of the grate bars (Figure 75).

This form of agitating grate is susceptible to low ash fusion temperatures. This is because the bed is disturbed occasionally and the combustion zones are upset. This causes fresh coal to be exposed to different conditions on the grate, namely reduction and oxidizing conditions. This greatly affects the ash fusion temperatures and consequently the condition of the fuel and ash bed. The most important parameter for these units is proper size and distribution of the coal to the stoker hoppers. Again, the ash fusion temperature is important for proper air distribution under the grate.

### 8.2.5 Dumping Grate

Units with dump grates are designed to generate between 10,000 to 40,000 lbs/hr steam (Figure 76). Spreader stokers with a dump grate are cleaned manually. Dump grates operate by having several grate segments, with each section having its own spreader stoker and underfire air damper. When the ash builds up to about a 4-in. depth on a particular section of the grate, the fuel supply is discontinued temporarily to that section. As a result, underfire air is shut off and ash is dumped into the pit beneath the grate. Each grate bar is tipped or opened like a Venetian blind so ash will fall into an ash pit. The tipping of grate bars can be done manually or automatically.

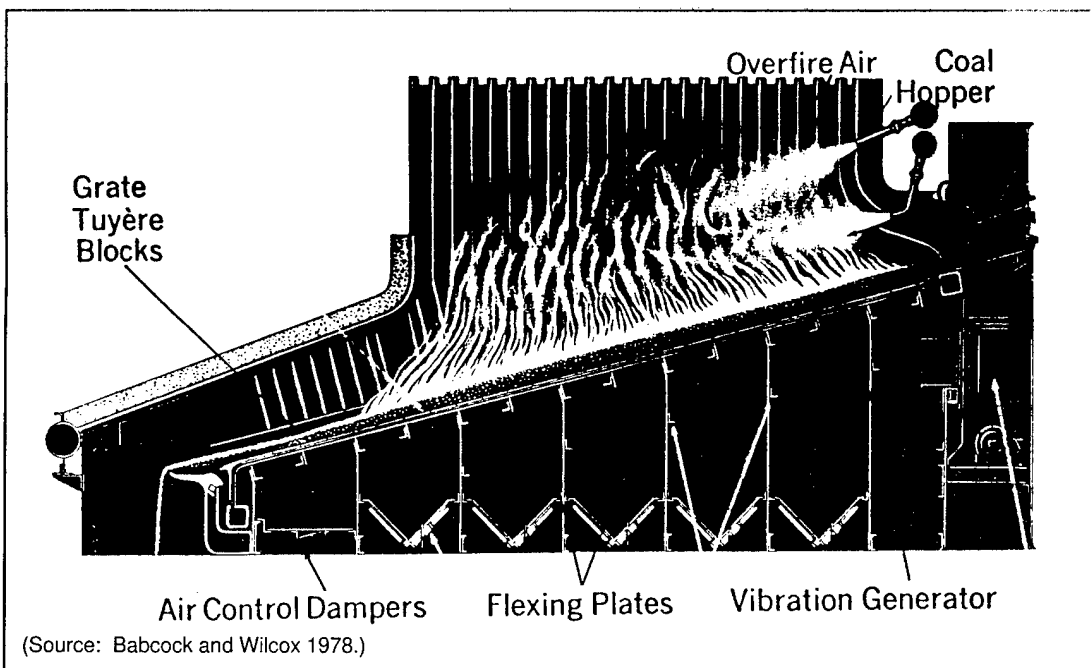
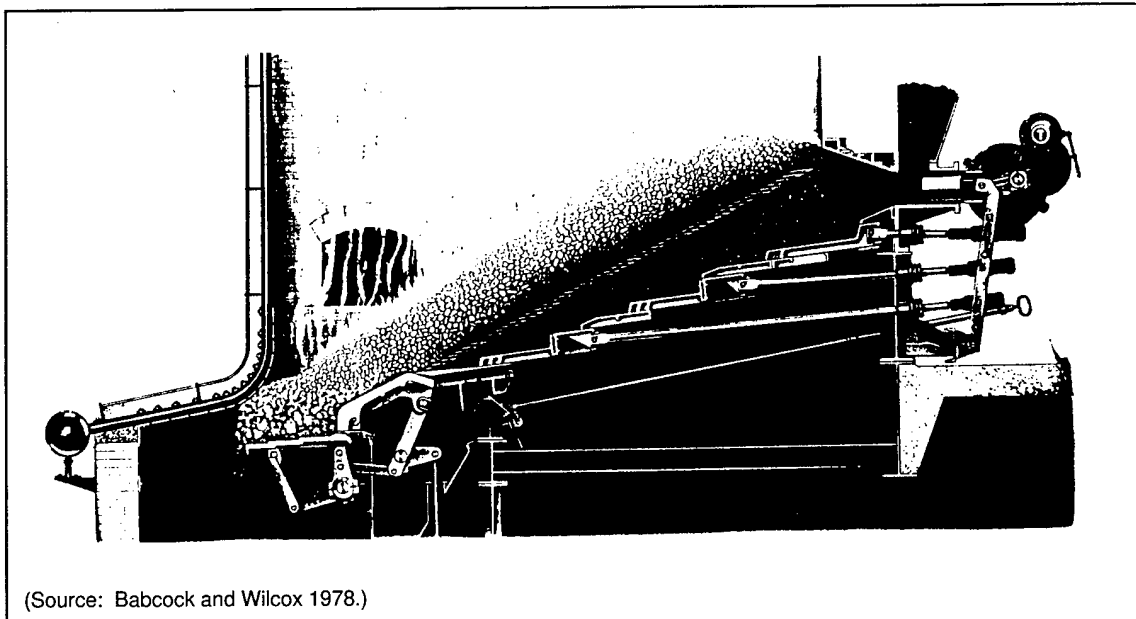


Figure 74. Vibrating grate spreader stoker.



(Source: Babcock and Wilcox 1978.)

Figure 75. Overlapping grate spreader stoker.

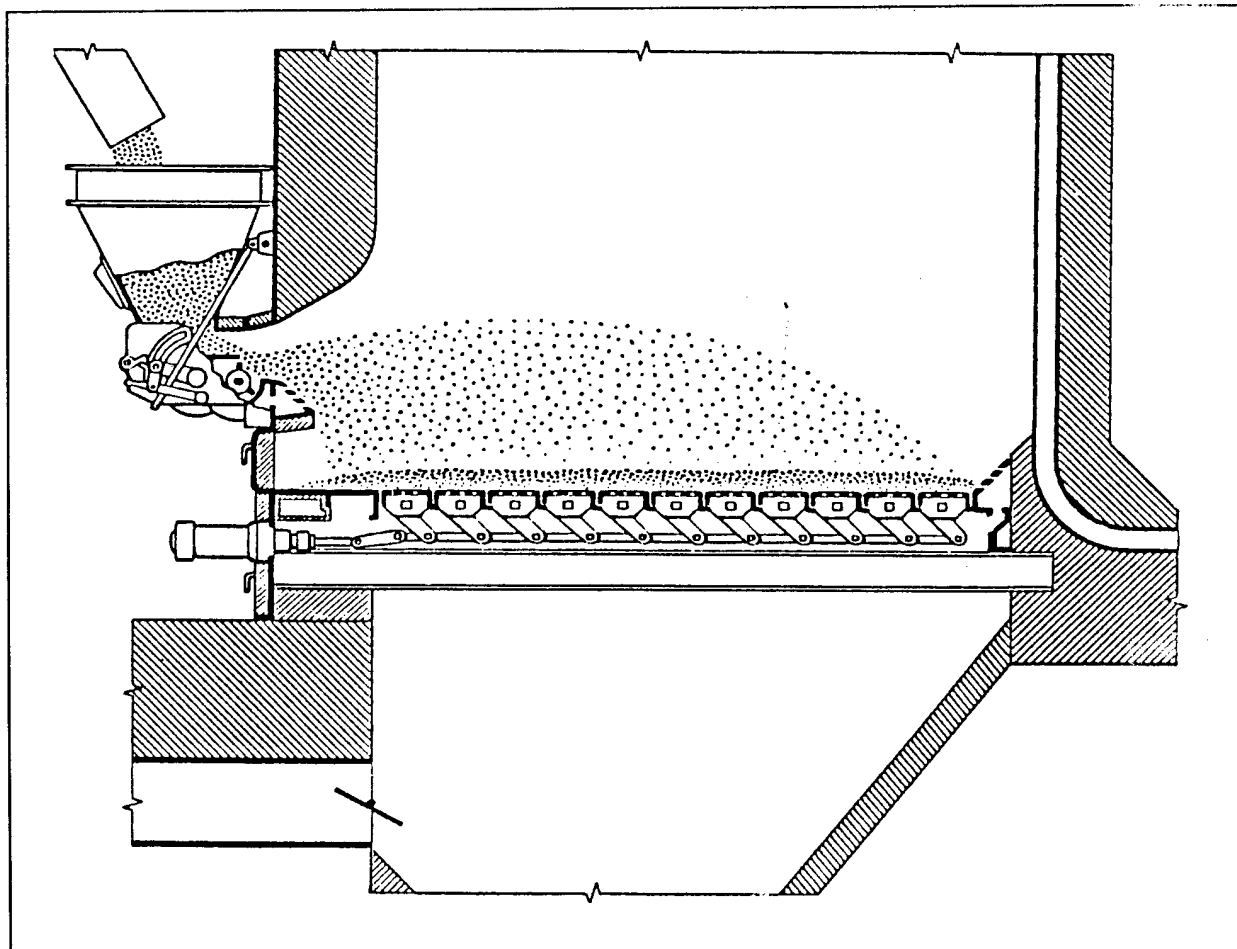


Figure 76. Dump grate spreader stoker.

The procedure of taking one feeder section out of service long enough to remove ash is the same as when stationary grates are used. After this, the grate is returned to its operating position, and the air and fuel are restored. Ignition is accomplished by heat from the other sections of the grate that still have coal and the reflective surfaces. This method of cleaning is very disruptive to the combustion process because the bed has to completely reform, causing large fluctuations in the required primary air.

### **8.2.6 Stationary Grate**

Stationary grate spreader stokers are no longer offered by manufacturers. The feeder automatically deposits coal on the grates and air for combustion enters the furnace through holes. At least two feeders are used, and one of the feeders is taken out of service before the ash deposits become deep enough to restrict airflow. The fuel on the grate is allowed to burn completely and the ash is raked through the furnace door.

The feeder is then started and after combustion has been reestablished, the remaining grate sections are cleaned in a similar manner. To be cleaned, the front access door must be opened and the ash pulled forward into the ash pit. This operation is very unsafe for the operator and is a tremendous liability for the owner of the system and the stoker manufacturer. During the cleaning process, a large dust cloud is created that causes opacity problems. Because of such problems, stationary grates are not recommended for continued service.

### **8.2.7 Coal Specifications**

**8.2.7.1 Baseline Specifications.** Poorly specified coal not only lowers boiler performance, but also makes the enforcement of contracts more difficult. Furthermore, newly generated contract bids are not likely to be responsive to the facility's needs. However, note that, even when coal has been properly specified, inadequate boiler performance can still occur. This can be caused by a number of operating, maintenance, and boiler design problems.

This section presents detailed coal specifications for spreader stoker boilers commonly used at DOD facilities. These should be used by central heating plant procurement and operating personnel as a guideline for establishing proper coal specifications. The following set of assumptions were made in establishing these coal specifications:

- Coal is delivered to the stoker without size segregation.
- The coal handling process from delivery to the boiler hopper does not generate more than 5 percent additional fines.
- The heat release rate of the stoker ( $\text{Btu/hr/ft}^2$ ) and of the furnace volume ( $\text{Btu/hr/ft}^3$ ) is within the recommended limits of the combustion technology and fuel type.
- Overfire air (if used) is within the recommended limits of the combustion technology.
- The combustion unit is in a good state of operation and in close compliance with design conditions.
- Particulate emission equipment is installed.
- There is a maximum of a 5 percent increase in excess air between the furnace exit and baghouse.
- The coal specifications are on an "as received" or "as fired" basis and not a "dry-basis."
- Lignite firing requires 450 °F preheated combustion air.

Tables 26 through 29 present coal specifications for traveling grate, vibrating grate, overlapping grate, and dumping grate spreader stokers.

Spreader stokers typically burn about 35 percent of the coal in suspension. This requires more volatiles than some of the mass burning stokers. Chain grate stokers also require more volatiles for ignition purposes. A low volatile coal might cause the fire to "walk" away from the ignition arch. Pulverized coal burns entirely in suspension and should therefore ignite easily. It is desirable to decrease the ash; the ash content can be decreased to a minimum of 5 percent for stoker boilers (the amount required to protect the grate).

**8.2.7.2 Heat Release Rates.** For stoker fired boilers, the allowable grate and furnace heat release rates reflect the ability of the grate and furnace to handle heat input. Clinker formation and the carry-over of carbon occur when the heat release rate exceeds the recommended limits. Clinker formation produces poor combustion by creating uneven underfire air distribution through the grate. It can also cause damage to the grate itself. Carry-over of unburned particles can cause slagging and fouling of downstream heat transfer surfaces.



Table 26. Recommended coal specifications for a traveling grate spreader stoker.

| Proximate Analysis                                      | Bituminous   | Subbituminous | Lignite |
|---|--|---------------|---------|
| Moisture (M)  | 0-20%  | 10-31%        | 25-45%  |
| Volatile Matter (VM)                                    | 30-40%   | 20-40%        | 22-32%  |
| Fixed Carbon (FC)                                       | 40-50%   | 30-50%        | 22-32%  |
| Ash   | 5-20%  | 5-15%         | 5-20%   |
| Hemispherical Temperature:                              | 2,300°F  |               |         |
| Heating Value, Btu/lb:                                  | 10,500 - 14,000 for Bituminous<br>8,300 - 11,500 for Subbituminous<br>5,800 - 7,500 for Lignite  |               |         |
| Size: 1¼ by ¼-in.                                       | Size Distribution:<br><br>plus 1¼-in. (31.5-mm) 5%<br>1¼ x ¾-in. (19.0-mm) 10%<br>¾ x ½-in. (12.5-mm) 35%<br>½ x ¼-in. (6.3-mm) 30%<br>¼ x No. 8 (2.38-mm) 15%<br>Less than No. 8 5%<br>100% |               |         |
| Free Swell Index:                                       | 7 maximum  |               |         |
| Lignite firing requires 450°F preheated combustion air. |  |               |         |

Table 27. Recommended coal specifications for a vibrating grate spreader stoker.

| Proximate Analysis                                      | Bituminous   | Subbituminous | Lignite |
|---|--|---------------|---------|
| Moisture (M)  | 0-15%  | 10-31%        | 25-45%  |
| Volatile Matter (VM)                                    | 30-40%   | 20-40%        | 22-32%  |
| Fixed Carbon (FC)                                       | 40-50%   | 30-50%        | 22-32%  |
| Ash   | 5-15%  | 5-15%         | 5-15%   |
| Hemispherical Temperature:                              | 2,300°F  |               |         |
| Heating Value, Btu/lb:                                  | 10,500 - 14,000 for Bituminous<br>8,300 - 11,500 for Subbituminous<br>5,800 - 7,500 for Lignite  |               |         |
| Size: 1¼ by ¼-in.                                       | <b>Size Distribution:</b><br><br>plus 1¼-in. (31.5-mm) 5%<br><br>1¼ x ¾-in. (19.0-mm) 10%<br><br>¾ x ½-in. (12.5-mm) 35%<br><br>½ x ¼-in. (6.3-mm) 30%<br><br>¼ x No. 8 (2.38-mm) 15%<br><br>Less than No. 8 <u>5%</u><br><br>100% |               |         |
| Free Swell Index:                                       | 7 maximum  |               |         |
| Lignite firing requires 450°F preheated combustion air. |  |               |         |

Table 28. Recommended coal specifications for a overlapping grate spreader stoker.

| Proximate Analysis                                      | Bituminous   | Subbituminous | Lignite |
|---|--|---------------|---------|
| Moisture (M)  | 0-15%  | 10-31%        | 25-45%  |
| Volatile Matter (VM)                                    | 30-40%   | 20-40%        | 22-32%  |
| Fixed Carbon (FC)                                       | 40-50%   | 30-50%        | 22-32%  |
| Ash   | 5-15%  | 5-15%         | 5-15%   |
| Hemispherical Temperature:                              | 2,300°F  |               |         |
| Heating Value, Btu/lb:                                  | 10,500 - 14,000 for Bituminous<br>8,300 - 11,500 for Subbituminous<br>5,800 - 7,500 for Lignite  |               |         |
| Size: 1 1/4 by 1/4-in.                                  | Size Distribution:<br><br>plus 1 1/4-in. (31.5-mm) 5%<br><br>1 1/4 x 3/4-in. (19.0-mm) 10%<br><br>3/4 x 1/2-in. (12.5-mm) 35%<br><br>1/2 x 1/4-in. (6.3-mm) 30%<br><br>1/4 x No. 8 (2.38-mm) 15%<br><br>Less than No. 8 5%<br><br>100% |               |         |
| Free Swell Index:                                       | 7 maximum  |               |         |
| Lignite firing requires 450°F preheated combustion air. |  |               |         |

Table 29. Recommended coal specifications for a dumping grate spreader stoker.

| Proximate Analysis  | Bituminous   | Subbituminous | Lignite |
|---|--|---------------|---------|
| Moisture (M)  | 0-15%  | 10-31%        | 25-45%  |
| Volatile Matter (VM)  | 30-40%   | 20-40%        | 22-32%  |
| Fixed Carbon (FC)   | 40-50%   | 30-50%        | 22-32%  |
| Ash   | 5-15%  | 5-15%         | 5-15%   |
| Hemispherical Temperature:  | 2,300°F  |               |         |
| Heating Value, Btu/lb:  | 10,500 - 14,000 for Bituminous<br>8,300 - 11,500 for Subbituminous<br>5,800 - 7,500 for Lignite  |               |         |
| Size: 1 <sup>1</sup> / <sub>4</sub> by 1 <sup>1</sup> / <sub>4</sub> -in. | <b>Size Distribution:</b><br><br>plus 1 <sup>1</sup> / <sub>4</sub> -in. (31.5-mm) 5%<br><br>1 <sup>1</sup> / <sub>4</sub> x 3 <sup>3</sup> / <sub>4</sub> -in. (19.0-mm) 10%<br><br>3 <sup>3</sup> / <sub>4</sub> x 1 <sup>1</sup> / <sub>2</sub> -in. (12.5-mm) 35%<br><br>1 <sup>1</sup> / <sub>2</sub> x 1 <sup>1</sup> / <sub>4</sub> -in. (6.3-mm) 30%<br><br>1 <sup>1</sup> / <sub>4</sub> x No. 8 (2.38-mm) 15%<br><br>Less than No. 8 <u>5%</u><br><br>100% |               |         |
| Free Swell Index:   | 7 maximum  |               |         |
| Lignite firing requires 450°F preheated combustion air.                   |  |               |         |

Table 30 presents the maximum allowable grate and furnace heat release rates based on sound design practices. The area of the grate is the total effective grate area where air passes through the grate. This area does not include the grate surface that has been sealed off below the grates. The furnace volume is the space from the grate to the first row of generating tubes from the steam drum. Understanding and identifying the grate and furnace heat release rate for each stoker in the boiler house is a critical aspect in the coal specification process.

The heat release rate is the rate at which heat is introduced into a furnace by its fuel. The heat release is indicated by the mean furnace exit temperature and maximum flame temperature. A change in the heat release rate will cause a change in temperature. In turn, the production of nitrogen oxide, capture of sulfur, and slagging and fouling in boilers will be affected. High heat release rates and high maximum temperatures will increase the potential for coals to slag the boilers. Also, high temperatures will increase the possibility of molten particles reaching the wall, sticking to the surface, and forming a molten deposit.

Previously, heat release rates of 45,000 to 80,000 Btu per cu ft of furnace were used. However, this presented some problems such as excessive flyash carryover and refractory failure. For this reason and for those above, heat release rates were gradually decreased to 20,000 to 30,000 Btu per cu ft of furnace per hour.

**8.2.7.3 Effects of Ash Softening Temperature.** It has been found that the allowable rating of a stoker decreases when the hemispherical ash softening temperature is lowered.

**Table 30. Recommended allowable grate and furnace heat release rates.**

| Type                   | Grate Heat Release Rate (Btu/hr-cu ft) |         | Furnace Heat Release Rate (Btu/hr-cu ft) |         |
|------------------------|--|---------|--|---------|
|                        | Conservative                           | Maximum | Conservative                             | Maximum |
| <b>Single Retort</b>   |  |         |  |         |
| Stationary Grate       | 250,000                                | 350,000 | 25,000                                   | 32,000  |
| Moving Grate           | 275,000                                | 400,000 | 25,000                                   | 32,000  |
| <b>Multiple Retort</b> | 350,000                                | 450,000 | 25,000                                   | 35,000  |
| <b>Chain Grate</b>     | 375,000                                | 475,000 | 25,000                                   | 32,000  |
| <b>Spreader Stoker</b> |  |         |  |         |
| Dump Grates            | 375,000                                | 450,000 | 25,000                                   | 32,000  |
| Traveling Grate        | 600,000                                | 650,000 | 25,000                                   | 32,000  |

#### **8.2.7.4 Recommended Derate for Stokers with Hemispherical Temperatures.**

Based on past experience with different stoker technologies, maximum allowable grate heat release rates have been established for decreasing hemispherical ash fusion temperatures. As the hemispherical reducing temperature decreases, the allowable grate heat release decreases also (Table 31).

### **8.2.8 Additional Specifications**

**8.2.8.1 Sulfur Content.** United States Environmental Protection Agency (USEPA) uses the following formula for determining sulfur in lb/MBtu.

$$\frac{\text{SO}_2}{\text{MBtu}} = \frac{(\% \text{ S in coal}) (38)}{(2000) (\text{HHV of coal})} \times 10^6 \text{ Btu/MBtu} \quad [\text{Eq 6}]$$

For example, suppose sulfur content = 2% and the high heat value (HHV)=13,000. Then, from the above formula:

$$\text{SO}_2(\text{lb/MBtu}) = [(2)(38)/(2000)(13,000)] \times 10^6 = 2.92 \text{ lb}$$

**8.2.8.2 Free Alkali.** Total alkalis present a distinct effect on the rate of buildup of deposits on screen tubes and on the ability to manage these deposits easily. The effect of the total alkalis is proportional to the quantity of alkali present in the coal. Coals containing high sodium content (greater than 4 percent) tend to produce fouling and slagging problems.

**Table 31. Recommended grate heat release rates in Btu/sq ft-hr versus hemispherical temperature for spreader stokers.**

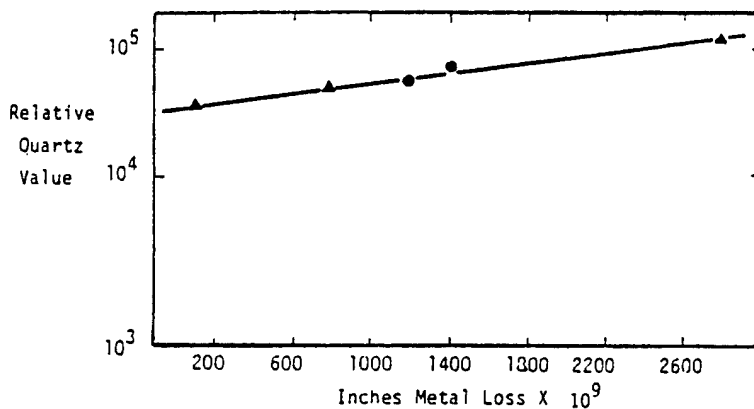
| H=1/2W<br>Red (°F) | Dump<br>Grate | % of<br>Rating | Chain<br>Grate | % of<br>Rating | Traveling<br>Grate | % of<br>Rating |
|--------------------|---------------|----------------|----------------|----------------|--------------------|----------------|
| 2700               | 450,000       | 100.0          | 650,000        | 100.0          | 700,000            | 100.0          |
| 2600               | 450,000       | 100.0          | 650,000        | 100.0          | 700,000            | 100.0          |
| 2500               | 425,000       | 94.4           | 615,000        | 94.6           | 665,000            | 95.0           |
| 2400               | 400,000       | 88.9           | 600,000        | 92.3           | 650,000            | 92.9           |
| 2300               | 375,000       | 83.3           | 575,000        | 88.5           | 625,000            | 89.3           |
| 2200               | NA            | NA             | 565,000        | 86.9           | 615,000            | 87.9           |
| 2150               | NA            | NA             | 550,000        | 84.6           | 600,000            | 85.7           |
| 2100               | NA            | NA             | NA             | NA             | NA                 | NA             |
| 2000               | NA            | NA             | NA             | NA             | NA                 | NA             |

**8.2.8.3 Flyash Erosion.** This is a property of ash to erode parts of the combustion system. It is largely related to the free minerals that are present in the ash, such as quartz. To minimize this effect, one should keep the free mineral content to a minimum.

**8.2.8.4 Relative Free Quartz.** Mineral matter that penetrates its way into the combustion system can abrade and erode preparation, transportation, and combustion equipment. High concentrations of materials that are harder than the equipment can cause serious erosion to occur. Quartz is one such mineral. The relative quartz index is the number of quartz particles greater than 44 microns that are freed from the mineral matter. Figure 77 shows the relation between relative quartz value and loss of metal in a laboratory ball mill. It is important to keep the relative quartz value at a minimum.

**8.2.8.5 Abrasion Index.** Figure 78 shows the correlation between laboratory results and abrasion in field tests. The lab results in all cases but one present higher abrasion than actually observed in the field. However, the correlation is relatively consistent.

**8.2.8.6 Chlorine Content.** Methods for determining the chlorine concentration in coal have been established as ASTM D2361. In this method, a sample is oxidized either by combustion with oxygen in a high-pressure bomb or by heating it with Eschka mixture (magnesium oxide and sodium carbonate) under specified conditions. Chlorine from the bomb washing or residue from the Eschka is titrated with silver nitrate solution potentiometrically or by the Volhard procedure. The values from the chlorine test can be used in the correlation of corrosion and fouling and slagging.



(Source: EPRI, February 1986.)

**Figure 77. Correlation between relative quartz value with metal loss in a laboratory ball mill.**

**8.2.8.7 Flyash Resistivity.** Coal resistivity is less than that of ash. The resistivity of combustibles in the flyash depends on the nature of the coal and the combustion process. Therefore, unburned coal in the flyash can lower the resistivity of the flyash, but only for flyash that is greater than 12 percent combustibles. However, the amount of carbon in the ash, which is dictated by the rate of coal combustion, also influences the ash's potential to sell. For example, some ash is sold as an aggregate for cement in the United States or for roads in Europe. The combustible content must be kept (less than 5 percent in most cases) low if the ash is to be sold for these uses.

### 8.2.9 Design Considerations

**8.2.9.1 Ash Softening Temperature.** This parameter is important for all spreader stoker boilers. If this temperature is allowed to fall below the minimum set value, ash will start to plug the grate holes and restrict the flow of underfire air, possibly decreasing efficiency. Therefore, it is critical that the temperature does not fall below this minimum set value.

**8.2.9.2 Volatile Matter.** This is another very important parameter for spreader stoker boilers. The volatile matter content must be at a minimum of 20 percent to allow for 35 percent suspension combustion.

**8.2.9.3 Free Swell Index.** This factor must be watched for some of the same reasons as above. When exposed to heat, coal swells volumetrically. This swelling of the coal can plug the grate holes and cut off some of the underfire air.

**8.2.9.4 Size.** Coal size is the most important factor for any spreader stoker boiler. It is critical that proper size distribution to the stoker hopper is maintained. If these specifications are not met, segregation problems will occur, developing thin and thick areas on the grate. This can lead to greater particulate carryover and lower efficiencies. Figure 79 shows the recommended limits of coal sizes for spreader stokers.

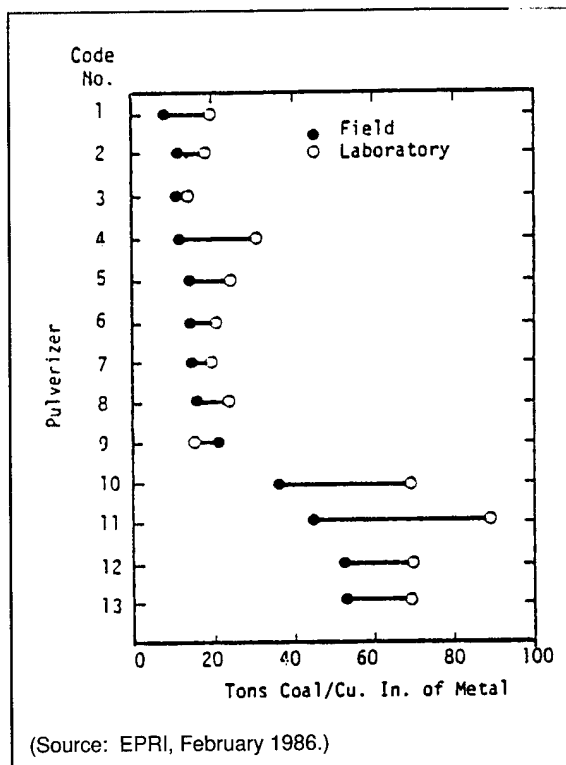


Figure 78. Relationship between abrasion as determined in the laboratory and field.



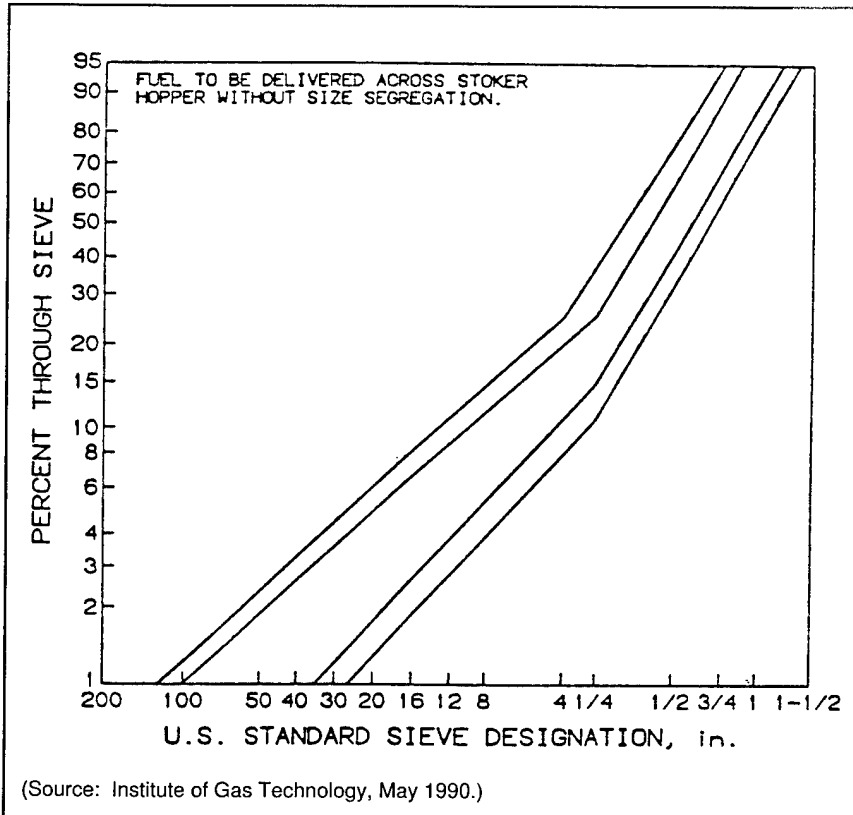


Figure 79. Recommended limits of coal sizes for spreader stoker boilers.

### 8.2.10 Fine Tuning of Specifications

Any combustion system must be envisioned as a system of interrelated components. Listed below are key coal parameters and operational practices that can affect combustion performance and compliance.

**8.2.10.1 Increasing Ash Softening Temperature.** Increasing the ash softening temperature has a pronounced effect on underfeed, chain grate, traveling grate, and spreader stoker boilers. If the ash softening temperature is too low for the type of combustion process, clinkers will form, which will cut off the supply of underfire air to that area of the bed. This condition will increase grate temperatures and particulate emissions by generating high carbon content (greater than 70 percent) flyash particles in the 1-micron size range. These small particles will pass through a mechanical collector and blind the bags of a fabric filter, decreasing the bag life and increasing maintenance costs. An electrostatic precipitator cannot collect these particles because of the high carbon content. The particle will accept a charge, but then will quickly release it to the collection plate and become re-entrained. In wet scrubbers, the flyash particles will pass through the scrubber chamber even at very high pressure drops (up to 90-in. water gauge).

**8.2.10.2 Decreasing Fines.** Excessive fines will magnify the problems caused by coal segregation. If there are too many fines, every time the coal is handled or stored, segregation will be increased. Coal segregation in the stoker feeding system leads to problems with incomplete combustion on the grate. Fine coal piles do not allow the underfire air to penetrate the bed and can lead to clinker formation and high grate temperatures. High grate temperatures will damage the grate and increase maintenance costs. The formation of clinkers will also create the 1-micron flyash particles with the same inherent problems mentioned above.

**8.2.10.3 Decreasing Allowable Top Size.** Decreasing the allowable top size will provide for faster ignition. The smaller coal particle has more surface area for interaction with heat and air. This solution has to be used carefully. If the top size is decreased too far from the recommended values, there can be problems with obtaining proper fuel distribution on the grate. Poor fuel distribution causes hot spots on the grate, that increase grate temperature. These hot spots occur at thick ash areas on the grate, decreasing air flow, causing clinkers, and forming submicron particles as discussed above.

**8.2.10.4 Decreasing Free Swell Index.** Specifying a lower free swell index will result in a more porous fuel and ash bed. This condition will enhance air distribution and the mixing of fuel and air.

**8.2.10.5 Increasing Volatile Matter Content.** Another way to improve combustion is to allow a higher volatile matter content in the coal. The hydrogen content will increase, enhancing ignition and combustion in the lower furnace zone. This measure will increase the lower furnace zone temperature, reduce carbon loss, and increase combustion efficiency.

**8.2.10.6 Decrease the Fixed Carbon Content.** Specifying a lower fixed carbon content translates to increasing the volatile matter. Lower furnace temperature is increased and combustion is more efficient.

**8.2.10.7 Decrease the Ash.** The ash content requirement can be decreased to a minimum of 5 percent for stoker boilers. (Five percent is required to protect the grate.) With a lower ash content, the fuel will burn more efficiently because less inert material is being heated. Decreased ash corresponds to increased volatile matter and fixed carbon content, which facilitates combustion. Less ash in the fuel also will produce less flyash and create thinner ash beds on the grate. A thinner ash bed allows better air and fuel mixing, which improve combustion efficiency.

**8.2.10.8 Decreasing the Water Content.** Decreasing the allowable water content of the coal will raise the Btu/lb of fuel. This means less fuel is required to produce the same amount of energy. Less fuel input will also produce a thinner ash bed, which will improve air/fuel mixing. Decreasing the water content of the fuel means that less water will leave the stack. The inherent moisture of the coal should not, however, be dropped below 3 percent; that amount of moisture is required to physically hold the fuel together.

**8.2.10.9 Increase the Heating Value of the Fuel.** The higher the heating value of the fuel, the fewer pounds of coal are required to produce the same amount of heat input; the relationship can be described in a direct proportion. Also, as described above, the less fuel required, the less fuel and ash is on the grate, which enhances air/fuel mixing and increases combustion efficiency. As the heating value of the fuel increases, moisture content decreases. Higher heating value also means less ash in the fuel. The main disadvantage of purchasing coal with a higher heating value is its higher cost.

**8.2.10.10 Tempering the Coal.** Tempering the coal that is on chain and traveling grate stokers by adding surface moisture will create air holes in the fuel and ash bed. The extra surface moisture on the coal forms steam upon heating and blow holes in the fuel bed through which underfire air can be admitted.

**8.2.10.11 Derate the Boiler.** Derating the boiler will decrease the lower furnace and grate temperatures, making the entire system more tolerant of "off-spec" coal. By lowering the furnace temperature, the ash softening temperature becomes less critical as does the amount of fines. While this is not the most desirable solution for producing steam, it does enhance the combustion of below-grade coal and the operation of poorly-designed or maintained equipment.

### **8.3 Underfeed Stoker Boilers**

#### **8.3.1 System Descriptions**

The different types of underfeed stokers used today use the same principle of operation. Coal, fed into a hopper, free flows down to a screw (Figure 80) or a mechanical ram (Figure 81), which forces the coal into a retort chamber. Small- and medium-sized boilers are equipped with single or double retort stokers.

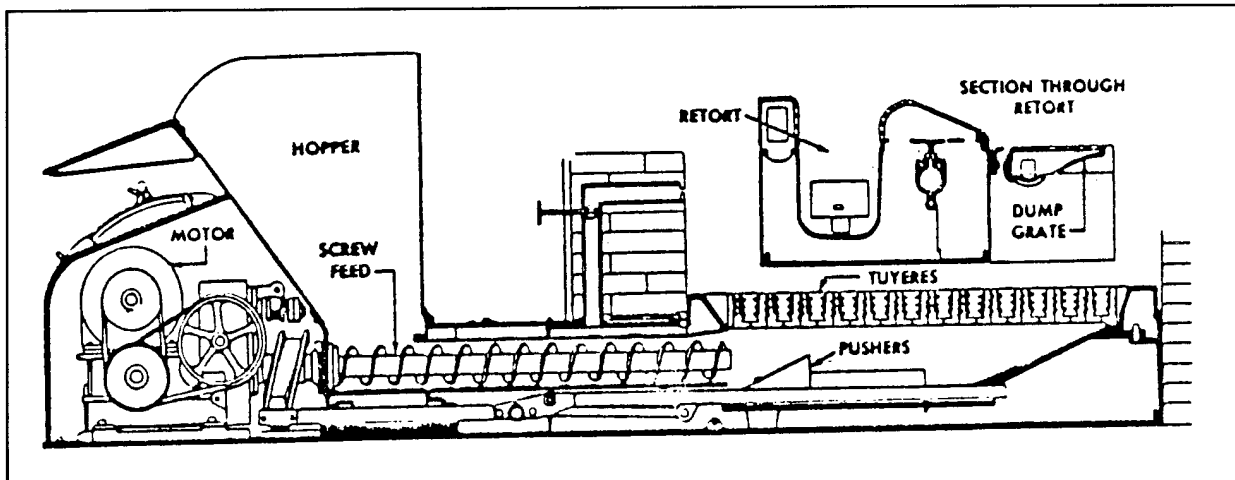


Figure 80. Screw-fed single retort underfeed stoker.

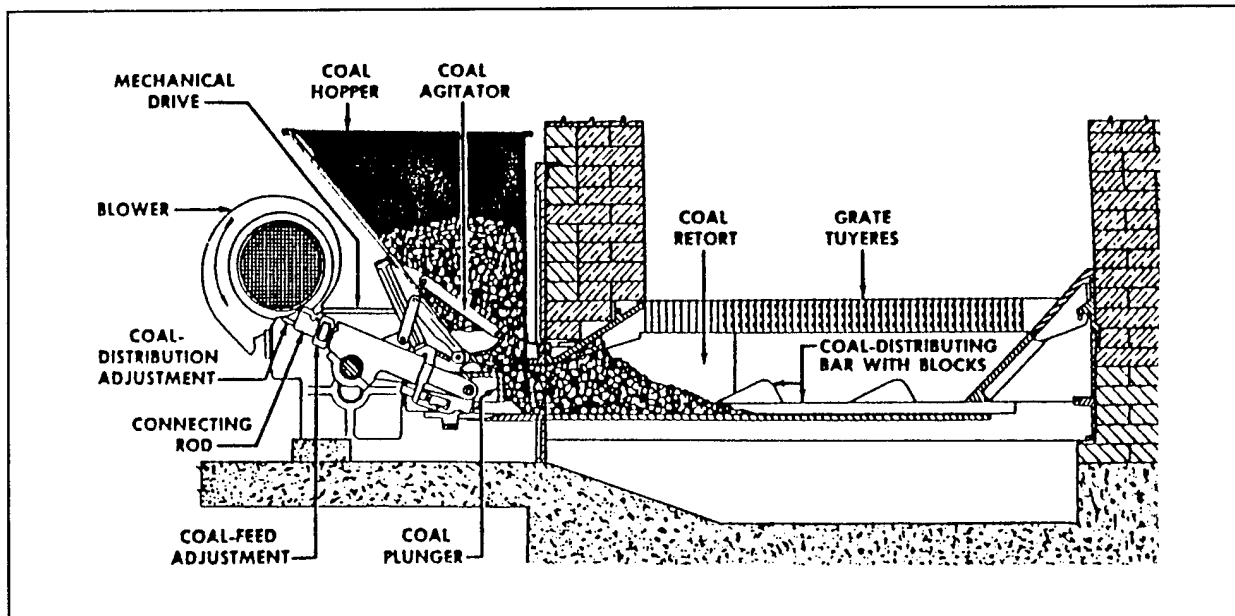


Figure 81. Mechanical ram-fed single retort underfeed stoker.

The feed ram or screw forces the coal from the hopper into the retort. During normal operation the retort contains fresh coal, which is continuously pushed out over the air-admitting grates by the secondary ram or pusher plates (blocks). The heat absorbed from the coal bed above and the action of the air being admitted through the grates cause the volatile gases to be distilled off and burn as the volatiles pass through the coal bed. The burning coal slowly moves over the grates from the retort toward the sides of the stoker. As the coal moves down the grates, the flame becomes short since the volatile gases have been consumed, and only coke remains. Some coke travels to the dump grates and a damper admits air under the grates to complete combustion before the ashes are dumped. The secondary ram or

pusher plates (blocks) are adjustable so coal flow from the retort onto the grates can be varied to obtain optimum fuel-bed conditions.

Underfeed stokers are equipped with forced draft fans for maintaining sufficient air flow through the bed. The air pressure in the windbox under the stoker can be varied to meet load and coal-bed conditions. Air pressure can also be varied under different sections of the stoker to correct for irregular coal-bed conditions.

Multiple-retort ("multi-retort") stokers operate similar to single- or double-retort stokers, and are used under large boilers to obtain high combustion rates. Multiple-retort stokers can have up to 12 retorts and grate sections arranged side-by-side to make required stoker width. A ram feeder supplies each retort with coal. These stokers are inclined at 25 to 30 degrees from the rams toward the ash-discharge end. They are also equipped with secondary rams or pusher plates (blocks) that, together with the effects of gravity produced by the inclined stoker, move the coal toward the refuse discharge in the rear.

Large multiple-retort stokers have mechanical devices for discharging refuse from the furnace. Dumping grates receive refuse as it comes from extension grates. When a sufficient amount has been collected, the grates are lowered and the refuse is dumped into the ashpit.

Rotary ash discharge may also be used to regulate the rate of refuse discharged from multiple-retort underfeed stokers. Stokers using this type of ash discharge are referred to as "clinker grinders." They consist of two rollers with protruding lugs installed in place of dumping grates. These rollers operated at variable speeds to discharge refuse continuously.

**8.3.1.1 Single-Retort.** Fresh coal is introduced into the underfeed single-retort stoker through a feed trough or "retort" and then to the furnace beneath the burning fuel bed. The fresh coal spills onto the grate at either side of the retort. Air comes from openings called tuyeres on both sides of the trough. There are two types of underfeed single-retort stokers: the stationary grate and the undulating grate. The stationary grate underfeed single-retort stoker moves the coal by the force of the incoming fuel from the retort. Air is introduced under the grate through the main air chamber. The undulating grate stoker moves the coal by force of the incoming fuel and by movement of the grate.

The moisture is driven off by the air coming in through the tuyeres and by exposure to the furnace heat. Ignition then occurs by distillation of the volatile constituents of the coal while it is below the active fuel bed. The gases then filter up through the

bed and mix with air coming through the grates from the forced draft fan and overfire air coming from ports located at the front of the stoker. As the coal is pushed out of the retort by the incoming fuel, the fixed carbon in the coal is burned over the grates on the sides of the retort. This burning fuel continues to move towards the sides of the furnace through the combined forces of the incoming fuel and undulating grate movement until only ash is left at the sides of the furnace. This ash is discharged to the ashpit by releasing a latch on the dumping mechanism. Normal operation is resumed by means of a hand lever located at the stoker front.

Underfeed single-retort stokers have a maximum capacity of 25,000 pounds per hour steam (pph steam) and are designed to burn mildly caking bituminous coals and certain free-burning bituminous coals. Underfeed stokers are not too adaptable to non-agglomerating coals such as lignite. Due to the thick fuel bed of underfeed stokers, high pressure is needed to move air through the system. This type of agitation will cause nonagglomerating coal such as lignite to break into very small pieces and fall through the grates unburned, thus decreasing the efficiency of the unit.

Undulating underfeed single-retort stokers (Figure 82) are usually used for burning eastern caking and mildly caking bituminous coals, as well as those Midwestern free-burning bituminous coals that have an ash fusion temperature sufficiently high for successful use in the relatively thick beds that characterize underfeed firing. Stationary grate single-retort stokers are more suited for the mildly caking bituminous coals because of the lack of grate agitation necessary to break up the caking coals.

Appropriate coal size is a primary consideration for proper combustion of coal on single-retort stokers. Appropriate coal size is critical for even fuel distribution across the length of the retort. Fine coal tends to rise at the front end of the retort while the more coarse coal moves further down the retort. This causes coal segregation problems, which correlate to very poor combustion. Single-retorts with undulating grates are capable of firing caking coals, meaning they can fire coals that pass through a plastic state in which individual pieces fuse together into large masses that are impervious to the flow of air. Thus, in the specification of coal for single-retorts, the Free Swell Index is an indication of the caking tendency of the coal.

Free-burning coal, such as subbituminous and lignite coals, do not fire as well as the mildly caking coals in single-retort stokers. Free-burning coals do not fuse together, or if they do, they quickly break apart into fragments.

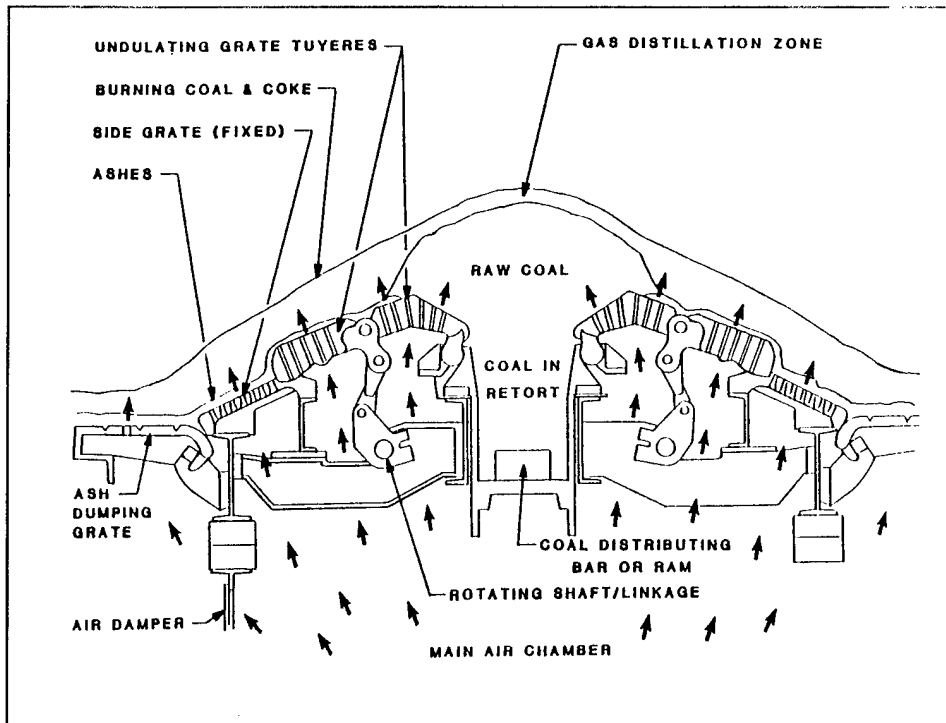


Figure 82. Undulating underfeed single retort stoker.

The ash fusion temperature is also important because of the thick ash beds that are typical for this type of unit. If the ash fusion temperature is dropped too far, the fuel bed will form clinkers and greatly reduce combustion efficiency.

**8.3.1.2 Multiple-Retort.** Multi-retort stokers consist of a series of inclined feeding retorts extending from the front to the rear of the boiler. The coal burns in the same manner as in the single-retort except that air is introduced through tuyere sections between the individual retorts. The coal is introduced onto the front of the retorts and it gradually forces its way up under the fire as described for single-retort stokers. Multi-retort stokers have secondary pushers that move the coal mass towards the rear of the boiler. The ash is deposited on a dump grate section, where it usually is manually dumped to a rear ash pit. The multi-retort type of stoker can be designed for steam capacity of up to 60,000 pph steam. Units have been designed up to 450,000 pph, but because of the introduction of the popular spreader stoker, these large multi-retort stokers are no longer commercially available.

Coals that have a tendency to cake, but break into a porous fuel bed when agitated, are suitable for multi-retort stokers. Like the single-retort stoker, free burning bituminous coals are most suitable; however, other ranks can be considered but are not necessarily recommended. Multi-retort stokers, like single-retorts, process mildly caking coals more effectively than free-burning coals.

### **8.3.2 Design Considerations**

**8.3.2.1 Ash Softening Temperature.** The ash temperature is very important for single and multi-retort stokers because these units usually have thick ash beds. If the proper temperature is not maintained, clinkers will form on the fuel bed and reduce the efficiency of the system.

**8.3.2.2 Size.** Proper coal sizing is the most important factor for single and multi-retort stoker boilers. Improper sizing will cause an uneven fuel distribution across the length of the retort. This will lead to coal segregation problems and poor coal combustion.

**8.3.2.3 Underfeed Single-Retort Stokers.** In underfeed single-retort stokers, fresh coal is introduced into the furnace beneath the burning fuel bed through a feed trough or retort. The fresh coal spills onto the grate at either side of the retort. Air is introduced on both sides of the trough through tuyeres. There are two types of underfeed single-retort stokers: the stationary grate and the undulating grate. The stationary grate underfeed single-retort stoker moves the coal by the force of the incoming fuel from the retort. Air is introduced under the grate through the main air chamber. The undulating grate stoker moves the coal by the force of the incoming fuel and the movement of the grate.

Underfeed single-retort stokers have a maximum capacity of approximately 25,000 lb/hr of steam and are designed to burn mildly caking bituminous coals and certain free-burning bituminous coals. As such, underfeed stokers are not very adaptable to nonagglomerating coals such as lignite. The maximum free swell index for the stationary grate single-retort stoker is 4, whereas the undulating grate single-retort stoker can accommodate a free swell index of up to 6. Due to the thick fuel bed typical of underfeed stokers, a high air pressure is needed to move the air through the system. Agitation caused by the high pressure combustion air will cause nonagglomerating coals such as lignite to break into small pieces and fall through the grates unburned, thereby decreasing the efficiency of the unit. Therefore, firing lignite in underfeed stokers is not recommended.

Undulating underfeed single-retort stokers are usually used for burning eastern caking and mildly caking bituminous coals, and Midwestern free-burning bituminous coals, which have an ash fusion temperature high enough for successful use in the relatively thick beds that characterize underfeed firing. Stationary grate single-retort stokers are more suitable for mildly caking bituminous coals due to the lack of grate agitation necessary to break up caking coals. If the ash fusion temperature



is dropped too much, the fuel bed will form clinkers and greatly reduce combustion efficiency.

The primary consideration for proper combustion of coal on single-retort stokers is proper coal sizing, which is critical for achieving an even fuel distribution across the length of the retort. Fine coal tends to rise at the front end of the retort while coarse coal moves further down the retort. This causes coal segregation problems, which correlate to very poor combustion. Single-retorts with undulating grates are capable of firing caking coals. Free-burning coal, such as subbituminous and lignite coals, do not fire as well as the mildly caking coals in single-retort stokers.

Table 32 lists the coal specification recommendations for single-retort stokers burning subbituminous, bituminous, and anthracite. Recommendations are presented for the proximate analysis value ranges as well as ranges for heating value, free swell index, hemispherical ash softening temperature ( $H=1/2$  W Reducing), and coal sizing.

**8.3.2.4 Underfeed Multi-Retort Stokers.** The multi-retort type of stoker can be designed for steam capacities of up to 60,000 lb/hr steam. Although units of up to 450,000 lb/hr have been built, spreader stokers have replaced this technology in today's commercially available units. Multi-retort stokers consist of a series of inclined feeding retorts extending from the front to the rear of the boiler. The coal burns in the same manner as the single-retort except that air is introduced through tuyere sections between the individual retorts. Coal is introduced at the front of the retorts where it gradually forces its way up under the fire. Secondary pushers are used to move the whole mass of coal toward the back of the boiler. The ash is deposited on a dump grate section where it is usually manually dumped into a rear ash pit.

Coals that have a tendency to cake, but break into a porous fuel bed when agitated are suitable for multi-retort stokers. Like the single-retort stoker, free burning bituminous coals are most suitable, but other ranks can also be considered. However, lignites and anthracites are not recommended.

Table 33 lists the coal specification recommendations for multi-retort stokers burning subbituminous, and bituminous coals. Recommendations are presented for the proximate analysis value ranges as well as ranges for heating value, free swell index, hemispherical ash softening temperature ( $H=1/2$  W Reducing), and coal sizing.

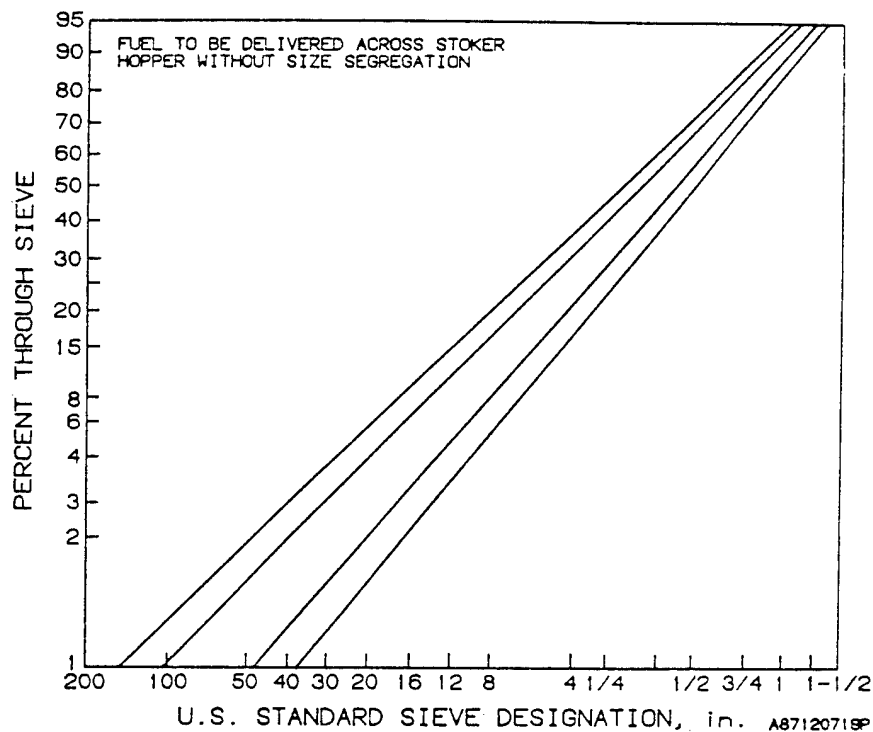
Figure 83 shows recommended limits of coal sizes for underfeed stokers.

Table 32. Recommended coal specifications for a single retort stokers.

| Proximate Analysis   | Bituminous  | Subbituminous                 | Lignite |
|--|---|-------------------------------|---------|
| Moisture (M)   | 5-12%   | 0-25%                         | 10-30%  |
| Volatile Matter (VM)   | 1-12%   | 30-45%                        | 20-40%  |
| Fixed Carbon (FC)  | 79-90%  | 40-55%                        | 30-50%  |
| Ash  | 8-20%   | 6-20%                         | 5-10%   |
| Heating Value, Btu/lb:   | 11,500 - 13,500 for Bituminous<br>10,500 - 14,000 for Subbituminous<br>8,300 - 11,500 for Lignite |                               |         |
| Hemispherical Ash Softening Temperature<br>(H = ½ W Reducing): | Anthracite<br>Bituminous/Subbituminous  | 2,400 °F Min.<br>2,250 °F Min |         |
| Free Swelling Index:   | Stationary Grate<br>Undulating Grate  | 4 Maximum<br>6 Maximum        |         |
| Size: Top size = 1 in.   |   |                               |         |
| Size Distribution:   | <u>Bituminous and Subbituminous</u>   |                               |         |
|  | Top Size (TS) 1 in.   | 5%                            |         |
|  | TS × ¾ in.  | 10%                           |         |
|  | ¾ × ½ in.   | 25%                           |         |
|  | ½ × ¼ in.   | 25%                           |         |
|  | ¼ in. × No. 8   | 25%                           |         |
|  | Less than No. 8   | 10%                           |         |
|  |   | 100%                          |         |
|  | <u>Anthracite</u>   |                               |         |
|  | Buckwheat #2<br>(5/16 × 3/16 in.)   | Rice                          |         |
|  | Allowable oversize  | 10% Max                       |         |
|  | Allowable undersize   | 15% Max with<br>7.5% Min      |         |

**Table 33. Recommended coal specifications for a multi-retort stokers.**

| Proximate Analysis   | Bituminous   | Subbituminous |
|--|--|---------------|
| Moisture (M)   | 0-15%  | 10-30%        |
| Volatile Matter (VM)   | 30-40%   | 20-40%        |
| Fixed Carbon (FC)  | 40-50%   | 30-55%        |
| Ash  | 5-10%  | 5-10%         |
| Heating Value, Btu/lb:   | 10,500 - 14,000 for Bituminous<br>8,300 - 11,500 for Subbituminous |               |
| Hemispherical Ash Softening Temperature<br>(H = ½ W Reducing): | 2,300 °F Min   |               |
| Free Swelling Index:   | 5 Maximum  |               |
| Size: Top size = 1-1/4 in.                                     |  |               |
| Size Distribution:   | Top Size (TS) 1-1/4 in.  | 5%            |
|  | TS × 3/4 in.   | 10%           |
|  | 3/4 × ½ in.  | 25%           |
|  | ½ × 1/4 in.  | 25%           |
|  | 1/4 in. × No. 8  | 25%           |
|  | Less than No. 8  | 10%           |
|  |  | 100%          |



(Source: Institute of Gas Technology, May 1990.)

**Figure 83. Recommended limits of coal sizes for underfeed stokers.**

## 8.4 Topfeed Static Grate Boilers

Top feed stokers (Figure 84) are usually smaller than the other available units. For these stokers, coal is deposited at the top of the unit and dropped down a conical shoot onto a stationary grate. Ash is removed manually for top feed boilers, usually with a raking procedure.

### 8.4.1 System Descriptions

**8.4.1.1 The Fliegerhorst Heating Plant.** The Fliegerhorst Heating Plant consists of four identical units manufactured by Kewanee Boilers in the United States. The recorded thermal design of each boiler is approximately 5.86 MW, with a total plant capacity of 23.45 MW. The units are three-pass, fire-tube, wet back boilers with an allowable working pressure of 10 bars (145 psig).

Delivered coal is normally unloaded directly into a hydraulically activated, tilting Kipp bunker for direct feed to the boiler day bunkers or, alternately, to adjacent garage-type coal storage enclosures. The coal storage facilities consist of six enclosed but open-front, sectionalized garage bins, with an aggregate capacity of approximately 800 metric tons. The tilting Kipp bunker can be bypassed, and coal pneumatically conveyed from the garage bins to the boiler day bunkers. Coal is unloaded with moveable, inclined vibratory conveyors and flexible hose connections to the pneumatic conveying system.

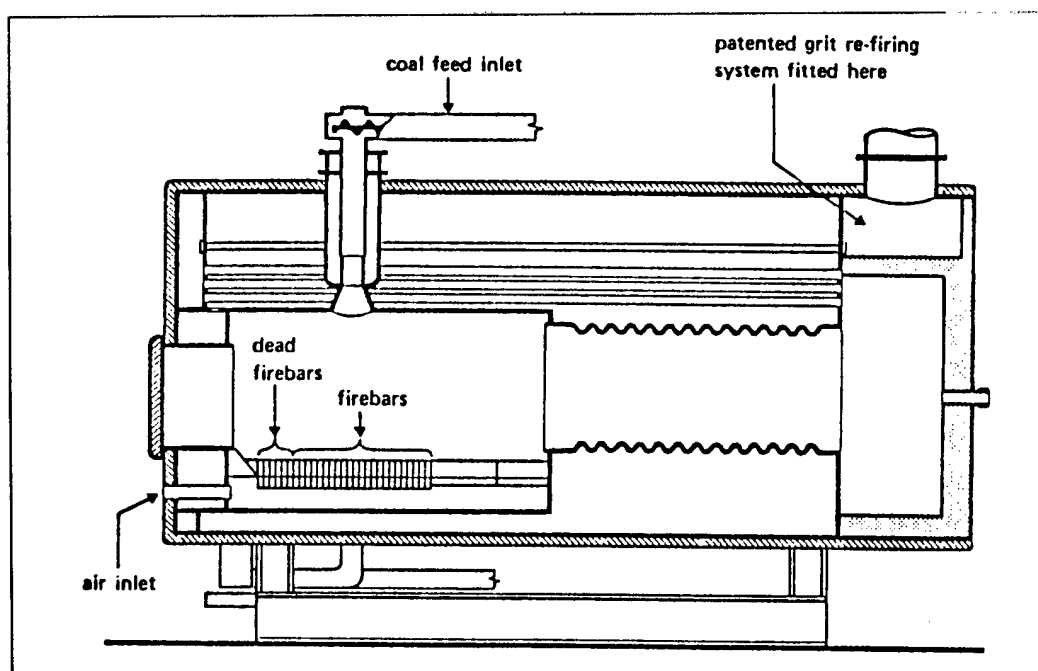


Figure 84. Top feed boiler.

Coal stored in the Kipp bunker is pneumatically conveyed to two 6-ton/day bunkers located above each boiler. Coal is withdrawn from the bottom of a day bunker with a speed-controlled auger, conveyed to a cyclone separator on top of the boiler, and then fed to a fixed grate via an integral drop tube and a cast iron cone, which distributes the coal onto a stationary grate. As the coal level in one day bunker drops, a level probe is activated to switch to the reserve bunker and refill the now-empty bunker. Alternate filling and emptying of the bunkers is carried out under automatic control. The coal feed rate is controlled automatically to respond to firing-rate changes by:

- preadjustment of the variable-speed feed augers from the day bunkers
- automatic activation of the pneumatic conveying system supplying coal to the cyclone separator.

The control variable is boiler steam operating pressure.

Ash is hand-raked from the boiler hearth into standard ash dollies at the front of each boiler, and is manually wheeled outside the building where it is dumped onto the ground for truck disposal. Ash-removal procedures involve a systematic shut-down of the forced-air and coal-feed systems before opening the hearth door.

A forced-draft fan mounted on the front and top of each boiler supplies both primary and secondary combustion air. Control dampers regulate the split, with secondary air passing down the outside of the coal feed drop tube and primary air moving through a wind box and the underside of the hearth grates. The boilers operate under positive pressure (about 0.25 to 0.30 psig). The boilers presently installed do not have any means of adjusting the amount of excess air provided to the boilers for combustion. The amount of excess air is pre-set by the size of the orifice plate through which the air is supplied.

Flue gas is withdrawn from the combustion chambers and passes through a multi-cyclone dust collector (one for each boiler). Flyash and grit collected in the multi-cyclone units are screw conveyed into dedicated pneumatic conveyors for reinjection into the combustion chambers of individual boilers. Flue gas is withdrawn from the multi-cyclone dust collectors by induced draft fans and discharged to the atmosphere through boiler chimney stacks. The induced-draft fans supply energy for operating the multi-cyclone dust collectors.

**8.4.1.2 The Baumholder Heating Plant.** The Baumholder Heating Plant consists of four identical 5.814 MW units manufactured by Robey of Lincoln Ltd. The total

plant capacity is 23.256 MW. The units are three-pass, combined flame/smoke-tube wet-back boilers with an allowable working pressure of 10 bars (145 psig).

Coal is delivered into the coal yard by train and is tipped from a coal hopper in the yard, conveyed to the roof of the heating plant by a vertical chain-conveyor system, and dropped into a horizontal chain-conveyor system that moves the coal into day bunkers. The capacity of each day bunker is 325 metric tons, sufficient for 7 operating days at full load. There is a coal-weighing system at the intersection of the vertical and horizontal conveyors.

Coal is moved from each day bunker by a screw conveyor and pneumatic conveyor system (controlled in accordance with the desired boiler load) through the steam and water area of the system to the center of the fixed grate of each boiler, where the distributor mechanism feeds coal evenly throughout the grate.

Ash is removed from the boiler hearths manually into a filling bin, from which it is passed through a slag breaker for size reduction. The ash is then moved via a bucket wheel sluice into an ash bunker.

Primary air is directed to the underside of the grate by a blower located on one side of the boiler. Secondary air is introduced into the coal-feed conveyor and directed downward onto the grate, thus developing a slight overpressure within the furnace. Regulation of primary and secondary air is accomplished through an automatic control system on the blowers.

Flue gases pass through a cyclone dust collector and into the stack via an induced-draft fan and breeching system. The fine particulates separated in the dust collector are returned to the furnace by a pneumatic conveying system.

#### **8.4.2 Coal Baseline Specifications**

Table 34 lists recommended coal specifications for topfeed static grate coal boilers.

**Table 34. Recommended coal specifications for a topfeed static grate coal boilers.**

| <b>Proximate Analysis</b>       |                      |
|---------------------------------|----------------------|
| Moisture (M)                    | 0-12%                |
| Volatile Matter (VM)            | 30-40%               |
| Fixed Carbon (FC)               | 40-50%               |
| Ash                             | 4-8%                 |
| <b>Heating Value, Btu/lb:</b>   | 10,500 - 14,000      |
| <b>Free Swelling Index:</b>     | 3 Maximum            |
| <b>Size:</b>                    | Top size = 1-1/4 in. |
| <b>Ash Hemispherical Temp.:</b> | 2700 °F Min.         |

### **8.5 Pulverized Coal Boilers**

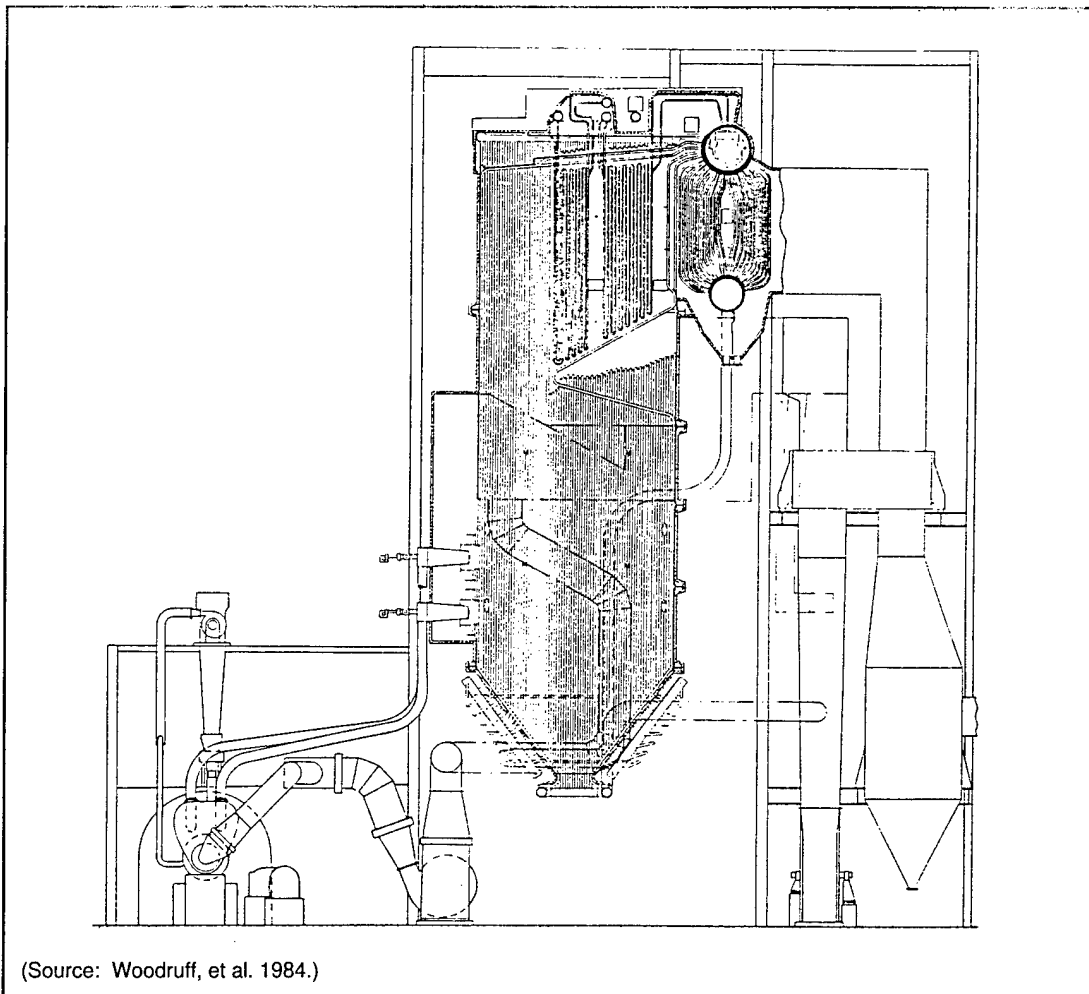
#### **8.5.1 System Descriptions**

Pulverized coal (PC) fired boilers are commonly used in larger industrial facilities and

utility power generation units. Figure 85 shows a typical pulverized coal boiler with one pulverizer. PC boilers have an extensive and successful history in the power industry. Pulverized coal units have many advantages when large boiler capacity is required. One advantage is the ability to change loads rapidly. Because of the suspension type combustion, these units are extremely responsive to changing loads.

The turndown rate of PC units is a function of the number of pulverizers. Pulverizers can be turned down to about 60 percent capacity. PC boilers that have multiple pulverizers can turn down each of the pulverizers 60 percent, allowing for more flexibility in meeting the load.

In PC firing, coal is ground to a very fine powder, then sent to the burners. On mixing with air, the fuel is ignited and burned in the furnace. To ensure proper combustion, the type and size of the equipment must be matched to the available coals. Crushers may be required if the coal is purchased as run-of-mine, that is with little or no sizing done at the mine. With the exception of waste coal, run-of-mine



**Figure 85. Pulverized coal boiler.**

coal is the most cost effective product that can be purchased from a mine. For this reason, it is commonly used with PC units. Crushers equipped with magnetic separators prepare the coal by crushing it to at least 1-1/2 x 0 in. The prepared coal is then sent to the pulverizers for final fuel preparation. The various types of pulverizers grind coal to at least 70 percent through 200 mesh and typically 98 percent through 50 mesh.

**8.5.1.1 Rotation Speed.** Pulverizers are classified by the speed of rotation, either low-, medium-, or high-speed.

**8.5.1.1.1 Low Speed Pulverizers.** Low speed pulverizers are of the Ball-Tube Mill configuration. This mill is basically a hollow horizontal cylinder that rotates on its axis and is filled with steel balls. The steel balls rotate at about 18 to 35 revolutions per minute (rpm). Ball-Tube Mills have a relatively large quantity of pulverized coal in the grinding zone, which acts as a reservoir of fuel. This provides some time for continued operation in the event of an emergency. A major disadvantage of the Ball-Tube Mill is that it is a high power consumer and has a high initial capital cost.

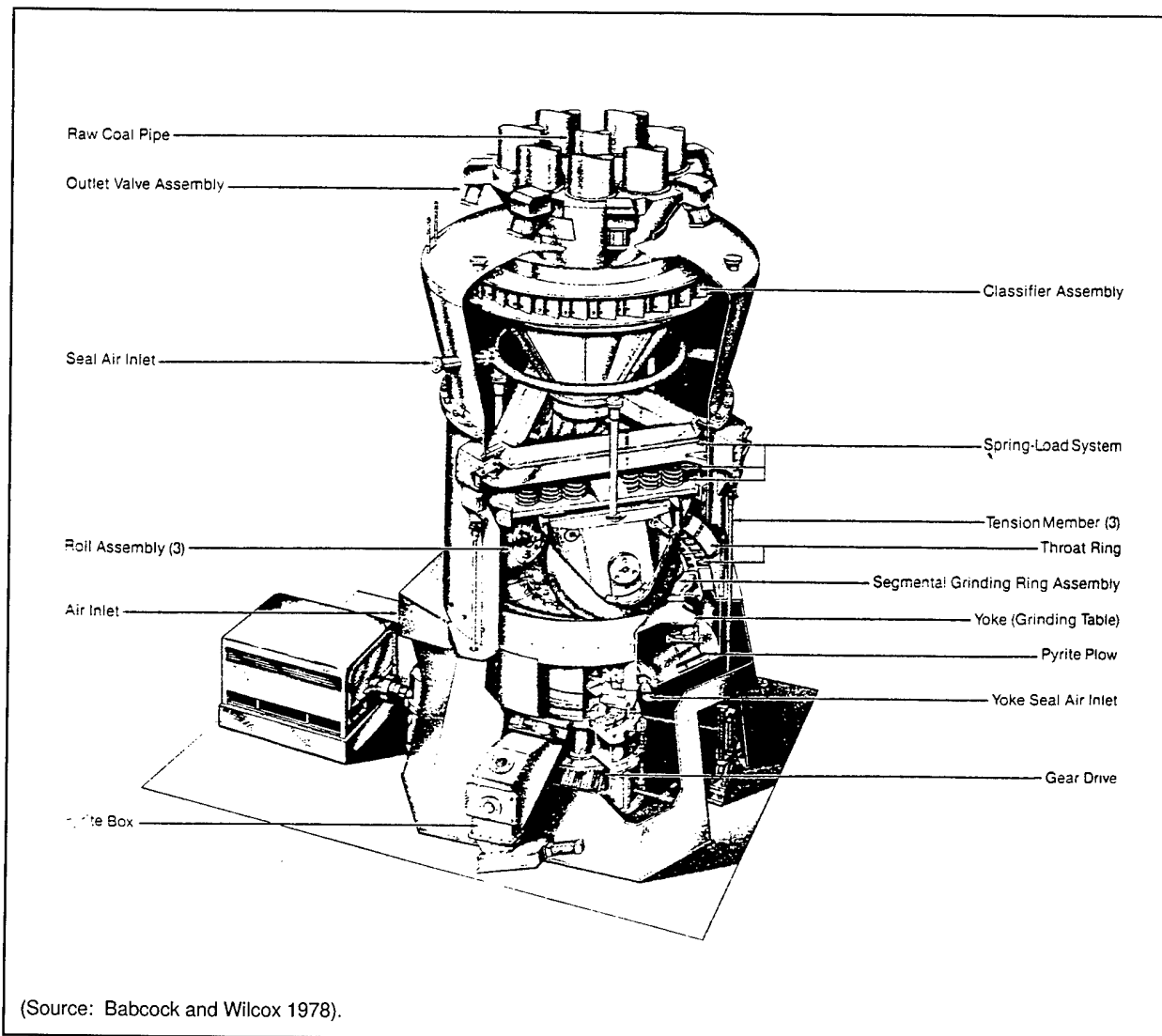
**8.5.1.1.2 Medium Speed Pulverizers.** Medium speed pulverizers include Ring-Roll or Ball-Ace Mills, and Bowl Mills (Figure 86). These pulverizers are the most common types used in the industry. They operate between 70 and 300 rpm, with the larger size mills running at the slower speeds. They require a small amount of floor space and are relatively quiet. They provide a good fuel size consistency, and as long as the mill is equipped with sufficient heated air to produce a satisfactory mill outlet temperature, they can handle wet coals with only a slight reduction in capacity.

**8.5.1.1.3 High Speed Pulverizers.** High speed mills are of the Impact, Hammer, or Attrition-Mill type (Figure 87). These mills have a simple design philosophy and low capital costs. However, they require large amounts of power and are high-maintenance items. Finally, the maximum capacity of these mills is lower than the medium speed pulverizers.

## **8.5.2 Burner Configurations**

**8.5.2.1 Horizontal-Burner Configuration.** PC units have a number of available burner configurations. The most common, particularly in smaller PC units, is the horizontal-burner arrangement. Burners are located either on the front or back wall of the furnace, and the fuel is introduced horizontally into the furnace. One modification of this type of burner configuration is to have horizontal burners on both the front and back walls aimed at each other to facilitate turbulent mixing in the furnace.





**Figure 86. Medium-speed pulverizer mill.**

**8.5.2.2 Tangential Firing.** Another burner configuration is called “tangential firing.” With this method, one or more burners are placed in each corner of the furnace and aimed in such a manner as to impart a swirling effect inside the furnace section. This promotes a more complete mixing of the fuel and air, thus improving combustion. A modification of either of these burner arrangements is to have adjustable or tilting burners. This type of burner arrangement allows a greater range of fuels to be fired because the residence time in the furnace can be changed. Thus, for coals with lower volatile matter contents requiring more time for complete combustion, the burners can be pointed downward to force the fuel and gases to remain in the combustion zone longer.

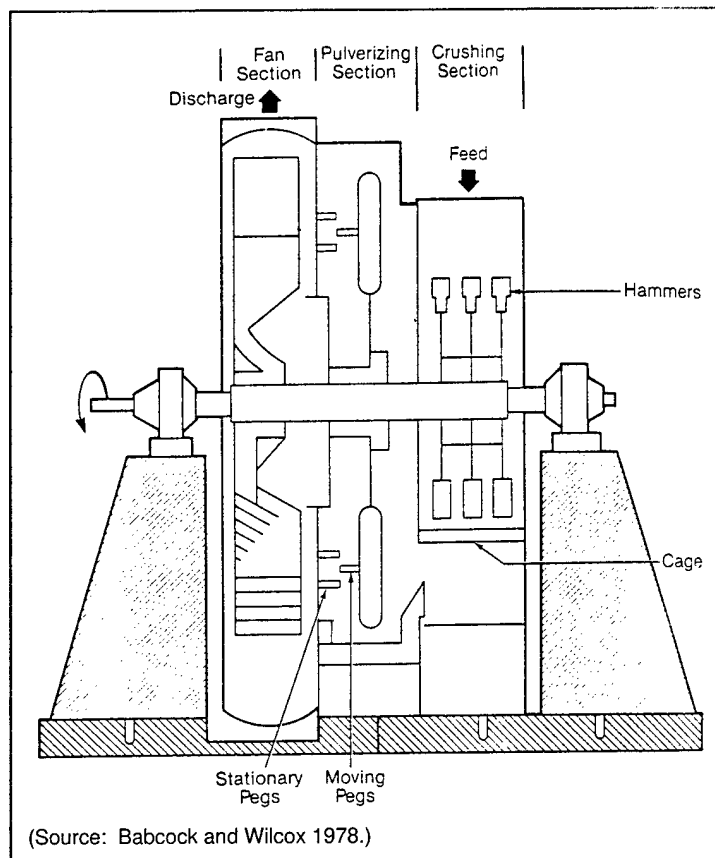


Figure 87. High-speed pulverizer mill.

### 8.5.3 Coal Quality Specifications

**8.5.3.1 Grindability.** When pulverizers are selected for a boiler house, they should be chosen with enough flexibility to account for small changes in the grindability of the coal. Figure 88 illustrates the relationship between Hardgrove Grindability and the relative pulverizer capacity. For a coal with a Hardgrove Index of 50, the pulverizer would be rated for 100 percent. If the Hardgrove Index were to increase to 60, then the relative capacity of the pulverizer would increase by 20 percent. If the Hardgrove Index were decreased to 40, the relative capacity of the pulverizer would be decreased by 20 percent. Figure 89 presents the range of grindability for various types of coal. The general trend is that as the rank of the coal increases, so does the grindability index. Figure 89 also illustrates how bituminous and anthracite coals have a variety of Hardgrove grindabilities.

Three parameters are of special importance to proper pulverized coal combustion, grindability, moisture content, and volatile matter content.

**8.5.3.2 Grindability.** The first parameter, the grindability of the coal, is measured on the Hardgrove Index; if the Hardgrove index of the coal is too low, then the cost

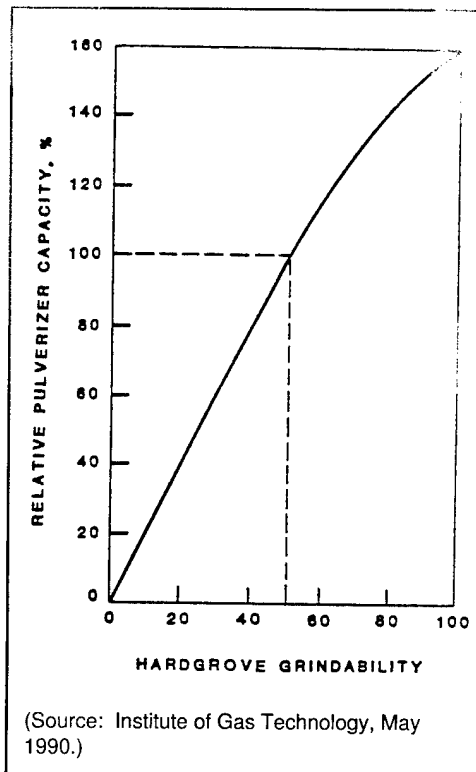


Figure 88. Relative pulverizer capacity as a function of hardgrove grindability.

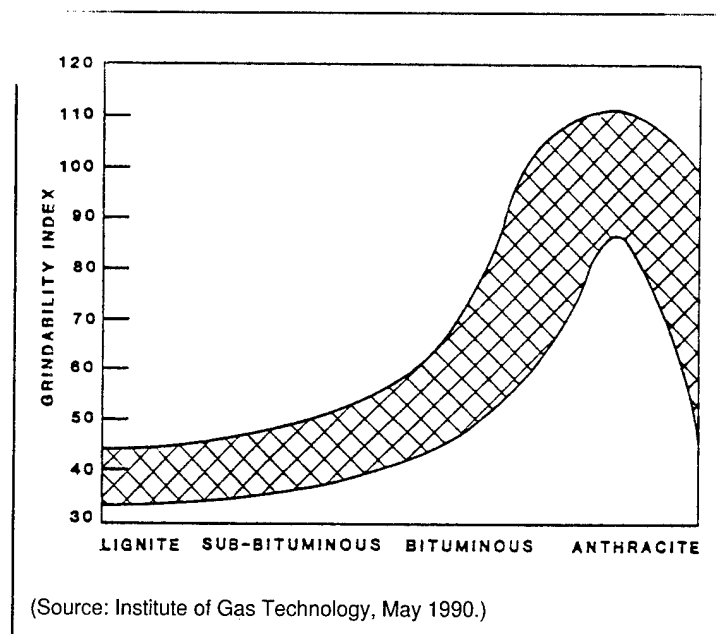


Figure 89. Grindability vs coal rank.

of grinding the coal to the proper size will be excessive. When pulverizers are selected for a boiler house, they should be chosen with enough flexibility to account for small changes in the grindability of the coal. If the coal is hard to grind, then the cost of grinding the coal to the proper size will be excessive.

**8.5.3.3 Moisture Content.** Another parameter related to the grindability of the coal is moisture content. If the moisture content is allowed to stray too far from the design, the quantity of coal to be fired must be increased to handle the same Btu output. In addition to increased coal thru-put, the pulverizer may not have the capacity to remove this excess moisture without a derate in capacity. Thus, moisture content of the coal should be kept within the design limitations, or the unit will have to be derated.

**8.5.3.4 Volatile Matter Content.** A final and very important parameter to be considered is the volatile matter content. Coals with low volatile content (such as anthracite) can be fired in PC units, but have to be designed specifically for this coal. As the volatile matter content decreases, the required furnace volume increases. Volatile matter content is a design parameter for PC boilers; thus, changing this specification without modifying the boiler is not recommended.

Figure 90 illustrates how the degree of coal fineness required affects the capacity of the pulverizer. If 70 percent of the coal is to pass through 200 mesh, the pulverizer capacity factor is 1. If 80 percent of the coal is required to pass through 200 mesh, the pulverizer capacity factor drops by 20 percent to 0.80. It should be noted that pulverizer capacity is linearly related to the coal's heating value. As the Btu/lb value of coal decreases, the required output of the pulverizers increases. For example, for 70 percent boiler load, the required pulverizer output for 12,000 Btu/lb coal is 58 percent; for 11,000 Btu/lb coal, it is 65 percent; and for 10,000 Btu/lb coal, it is 70 percent.

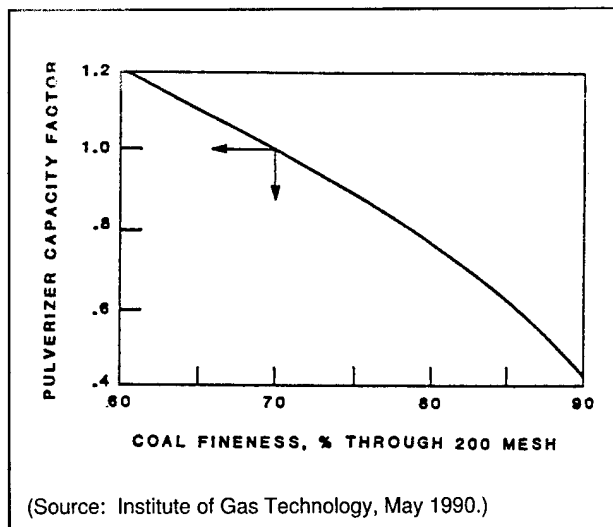


Figure 90. Pulverizer capacity as a function of fineness.

Table 35 presents the coal specification recommendations for pulverized coal fired boilers burning bituminous, subbituminous, and lignite coals. Recommendations are presented for the proximate analysis value ranges as well as ranges for heating value, free swell index, hemispherical ash softening temperature ( $H=1/2$  W reducing), and coal sizing.

Table 35. Recommended coal specifications for pulverized coal boilers.

| Proximate Analysis   | Bituminous  | Subbituminous | Lignite |
|--|---|---------------|---------|
| Moisture (M)   | 0-22%   | 10-30%        | 25-45%  |
| Volatile Matter (VM)   | 30-40%  | 30-40%        | 30-45%  |
| Fixed Carbon (FC)  | 40-50%  | 40-50%        | 30-50%  |
| Ash  | 0-20%   | 0-20%         | 0-20%   |
| Heating Value, Btu/lb:                                       | 10,500 - 14,000 for Bituminous<br>8,300 - 11,500 for Subbituminous<br>5,800 - 7,500 for Lignite |               |         |
| Size Distribution:   | 70% through 200 mesh<br><br>98% through 50 mesh   |               |         |
| Hardgrove Grindability Index:                                | Bituminous  | 50-100        |         |
|  | Subbituminous   | 35-50         |         |
|  | Lignite   | 35-45         |         |
| Sodium and Potassium must be less than 3.5% in ash analysis. |   |               |         |
| Lignite firing requires 450 °F preheated combustion air.     |   |               |         |

### 8.5.4 Additional Considerations

**8.5.4.1 Sulfur Content.** United States Environmental Protection Act (USEPA) uses the following formula for determining sulfur in lb/MBtu:

$$\frac{\text{SO (lb)}}{\text{MBtu}} = \frac{(\% \text{S in coal}) (38)}{(2000) (\text{HHV of coal})} \times 10^6 \text{ Btu/MBtu} \quad [\text{Eq 7}]$$

For example, suppose sulfur content = 2% and the high heat value (HHV) = 13,000. Then, from the above formula:

$$\text{SO}_2 (\text{lb/MBtu}) = [(2) (38) (2000) (13,000)] \times 10^6 = 2.92 \text{ lb}$$

**8.5.4.2 Free Alkali.** Total Alkalies have a distinct affect on the rate of buildup of deposits on screen tubes. The effect of the total alkalies is proportional to the quantity of alkali present in the coal. Coals containing high sodium content (greater than 4 percent) tend to produce fouling and slagging problems.

**8.5.4.3 Flyash Erosivity.** Flyash erosivity is the ability of ash to erode parts of the combustion. It is largely related to the free minerals present in the ash, such as quartz. To minimize this effect, the free mineral content should be kept to a minimum.

**8.5.4.4 Relative Free Quartz.** Mineral matter that penetrates into the combustion system can abrade and erode preparation, transportation, and combustion equipment. High concentration of freed materials that are harder than the equipment can cause serious erosion to occur. Quartz is one such mineral. The relative quartz index is the number of quartz particles freed from the mineral matter that are greater than 44 microns. Figure 77 shows the relationship between relative quartz value and loss of metal in a laboratory ball mill. It is important to keep the relative quartz value at a minimum.

**8.5.4.5 Abrasion Index.** Figure 78 shows the correlation between laboratory results and abrasion in field tests. The lab results in all cases but one present higher abrasion than actually observed in the field. However, the correlation is relatively consistent.

**8.5.4.6 Chlorine Content.** Methods for determining the chlorine concentration in coal have been established as ASTM D2361. In this method, a sample is oxidized either by combustion with oxygen in a high-pressure bomb or by heating it with

Eschka mixture (magnesium oxide and sodium carbonate) under specified conditions. Chlorine from the bomb washing or residue from the Eschka is titrated with silver nitrate solution potentiometrically or by the Volhard procedure. The values from the chlorine test can be used in the correlation of corrosion, fouling, and slagging.

**8.5.4.7 Flyash Resistivity.** The resistivity of combustibles in the flyash depends on the nature of the coal and the combustion process, but will be lower than the resistivity of the ash. Therefore, unburned coal in the flyash can lower the resistivity of the flyash, but only for ash that has greater than 12 percent combustibles. However, the amount of carbon in the ash, which is dictated by the rate of coal combustion, also influences the potential to sell the ash. For example, some ash is sold as an aggregate for cement in the United States or for roads in Europe. The combustible content must be kept low (less than 5 percent in most cases) if the ash is to be sold for these uses.

**8.5.4.8 Hardgrove Grindability.** The Hardgrove Grindability index is used to correlate the performance of bowl mill and roller/race mills to predict their capacity and power consumption when pulverizing coal. If the grindability is high, then the capacity of the pulverizer is greater. It is important to make sure that the grindability of the coal meets the specifications required for the pulverizer being used.

**8.5.4.9 Moisture.** Moisture is a very important parameter for PC boilers. The moisture content of the coal should be kept between the prescribed limits. If it is allowed to deviate too much, then more coal must be fired to maintain the same Btu output. In addition, the pulverizer may not have the capacity to remove excess moisture without derating capacity. Therefore, the moisture limitations should be followed or the unit will have to be derated.

**8.5.4.10 Volatile Matter.** Volatile matter is also a very important parameter to the operation of PC boilers. Low volatile content coals can be fired in PC units as long as these units are designed specifically for this type of coal. A decrease in volatile matter content must be accompanied by an increase in furnace volume. For these reasons, the volatile matter specifications for each particular boiler must be followed.

Any combustion system must be envisioned as a system of interrelated components. Listed below are key coal parameters and operational practices that can affect combustion performance and compliance.

### **8.5.5 Coal Parameters**

Increasing the ash softening temperature has a pronounced affect on underfeed, chain grate, traveling grate, and spreader stoker performance. If the ash softening temperature is too low for the type of combustion process, clinkers will form, which will cut off the supply of underfire air to that area of the bed. This condition will increase grate temperatures and particulate emissions by generating high carbon content (greater than 70 percent) flyash particles in the 1-micron size range.

These small particles will pass through a mechanical collector and blind the bags of a fabric filter, decreasing the bag life and increasing maintenance costs. An electrostatic precipitator cannot collect these particles because of their high carbon content. The particle will accept a charge, but will quickly release it to the collection plate and become re-entrained. In wet scrubbers, the flyash particles will pass through the scrubber chamber even at very high pressure drops (up to 90-in. water gauge).

**8.5.5.1 Decreasing Fines.** Excessive fines will magnify the problems caused by coal segregation. If there are too many fines, segregation will increase every time the coal is handled or stored. Coal segregation in the stoker feeding system leads to problems with incomplete combustion on the grate. Fine coal piles do not allow the underfire air to penetrate the bed and can lead to clinker formation and high grate temperatures. High grate temperatures will damage the grate and increase maintenance costs. The formation of clinkers will also create the 1-micron flyash particles with the same inherent problems mentioned above.

**8.5.5.2 Decreasing Allowable Top Size.** Decreasing the allowable top size will provide for faster ignition. The smaller coal particle has more surface area for interaction with heat and air. This solution has to be used carefully. If the top size is decreased too far from recommended values, there can be problems with obtaining proper fuel distribution on the grate. Poor fuel distribution causes hot spots on the grate, increasing the grate temperature. These hot spots occur at thick ash areas on the grate, decreasing air flow, causing clinkers, and forming submicron particles as discussed above.

**8.5.5.3 Decreasing Free Swell Index.** Specifying a lower free swell index will result in a more porous fuel and ash bed. This condition will enhance air distribution and fuel/air mixing.

**8.5.5.4 Increasing Volatile Matter Content.** Another way to improve combustion is to allow higher volatile matter content in the coal. The hydrogen content will increase, enhancing ignition and combustion in the lower furnace zone. This

measure will increase the lower furnace zone temperature, reduce carbon loss, and increase combustion efficiency.

**8.5.5.5 Decrease the Fixed Carbon Content.** Specifying a lower fixed carbon content increases the volatile matter, lowers furnace temperature, and combustion efficiency.

**8.5.5.6 Decrease the Ash.** The ash content requirement can be decreased to a minimum of 5 percent for stoker boilers (the ash content required to protect the grate). With a lower ash content, the fuel will burn more efficiently because less inert material is heated. Decreased ash corresponds to increased volatile matter and fixed carbon content, which also facilitate combustion. Less ash in the fuel also produces less flyash and creates thinner ash beds on the grate. A thinner ash bed allows for better air and fuel mixing, improving combustion efficiency.

**8.5.5.7 Decrease the Water Content.** Decreasing the allowable water content of the coal will raise the Btu/lb of fuel. This means less fuel is required to produce the same amount of energy. Less fuel input will also produce a thinner ash bed, improving air/fuel mixing. Decreasing the water content of the fuel means less water will leave the stack, thus increasing efficiency. The inherent moisture of the coal should not, however, be dropped below 3 percent, which is the amount of moisture required to physically hold the fuel together.

**8.5.5.8 Increase the Heating Value of the Fuel.** The higher the heating value of the fuel, the fewer pounds of coal required to produce the a given amount of heat input. This can be expressed in a direct proportion. As described above, a lesser fuel requirement leads to less fuel and ash on the grate and greater air/fuel mixing and combustion efficiency. As the heating value of the fuel increases, there is a corresponding decrease in the moisture content, which has the same benefits described above. Higher heating value also means less ash in the fuel. The main disadvantage of purchasing coal with a higher heating value is its higher cost.

**8.5.5.9 Tempering the Coal.** Tempering the coal on chain and traveling grate stokers, that is, adding surface moisture, will create air holes in the fuel and ash bed. The extra surface moisture on the coal, upon heating, will form steam and blow holes in the fuel bed, through which underfire air can be admitted.

**8.5.5.10 Derate the Boiler.** Derating the boiler will decrease the lower furnace and grate temperatures, making the entire system more tolerant of "off-spec" coal. By lowering the furnace temperature, the ash softening temperature becomes less critical as does the amount of fines. While this is not the most desirable solution for



producing steam, it does enhance the combustion of below-grade coal and the operation of poorly-designed or maintained equipment.

## 8.6 Fluidized-Bed Combustors

### 8.6.1 System Descriptions

Fluidized bed combustors (FBCs) are considered to represent the future norm for coal combustion in the United States. FBCs respond to the need for using the most cost-effective fuel in the most environmentally acceptable manner. FBCs can successfully fire a wide range of fuels including low cost, high sulfur coals.

FBCs agitate the bed of fuel, limestone, and ash to the point at which solids act as a fluid. The degree of fluidization defines the FBC as either bubbling bed or recirculating bed. Bubbling bed boilers have a defined height for the fuel, limestone, and ash bed (Figure 91). The circulating bed has no defined height because fluidization is distributed evenly throughout the furnace (Figure 92).

The recent trend in FBC technology has been to concentrate on recirculating fluidized bed boilers because of the degree of control available over the fuel bed. With a bubbling bed, the solid materials can fall back on the combustion air inlet nozzles and plug the air holes. This condition causes a problem with control over the bed as it tends to form areas of low fluidization. The recirculating bed avoids this problem because the fuel bed is fluidized to such a degree that the solids cannot fall back. Particles carried through the convective section are collected in a hot cyclone and reinjected into the furnace combustion zone.

Consideration should be given to the degree of erosion in the furnace section of the FBC. The recirculating fluid bed boilers may cause a

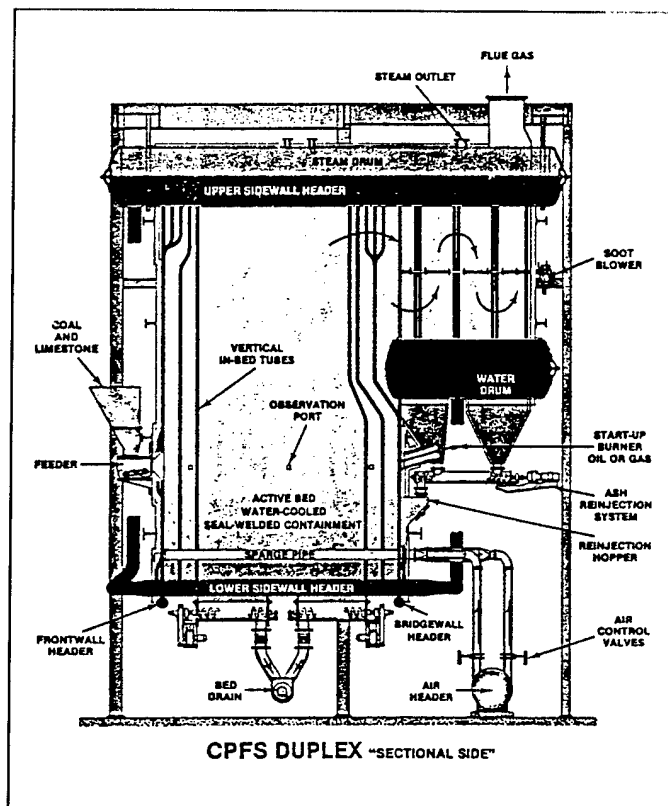


Figure 91. Bubbling bed boiler.

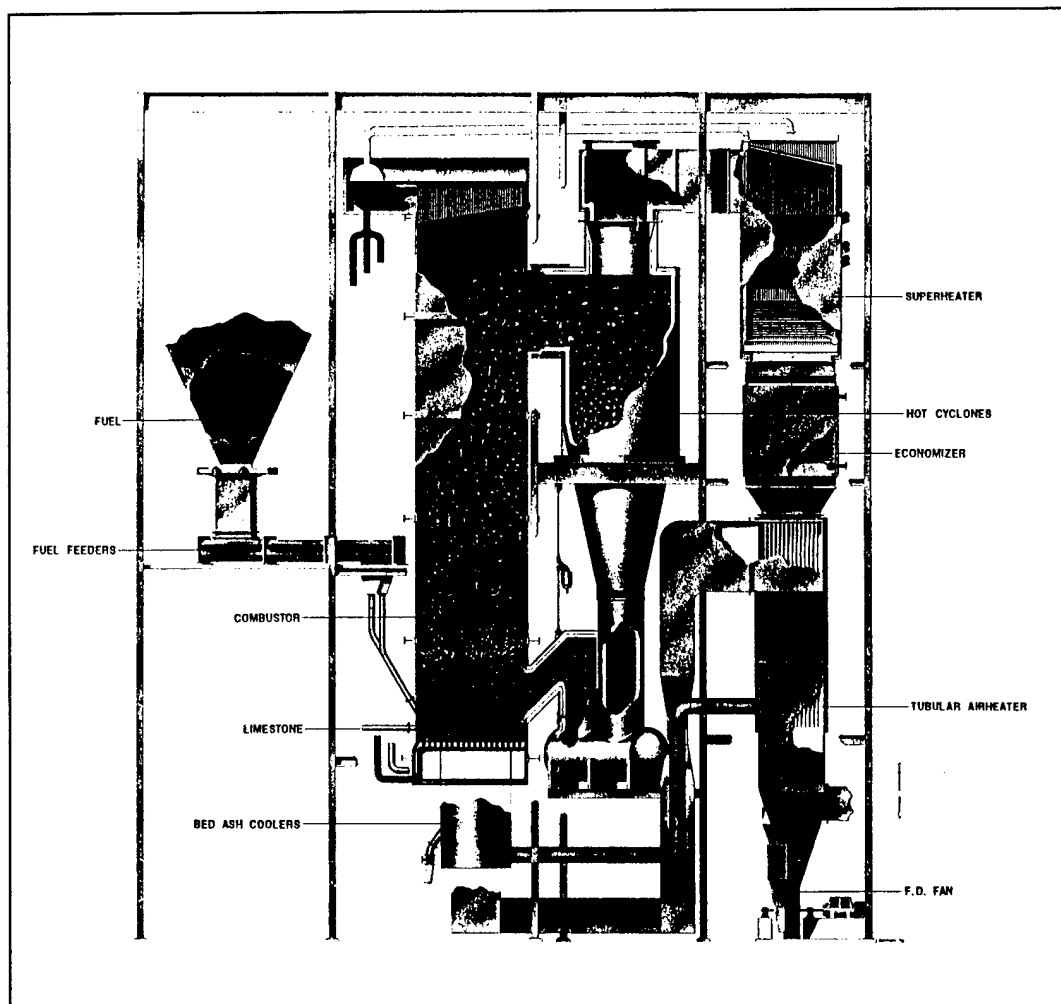


Figure 92. Circulating bed boiler.

higher degree of erosion in the upper convective areas of the boiler because of the large amount of particle carryover. An additional consideration is the degree of erosion to the hot cyclone, which is used to control recirculation of limestone and fuel. The tops of the cyclones are subjected to high temperatures, pressures, and velocities and as such, are susceptible to erosion. This problem has not been addressed adequately because of lack of operating time for these units. It may be that, with proper materials such as ceramics, this erosion problem could be solved.

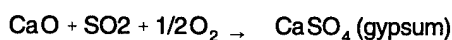
FBC units are currently in operation at several industrial sites. The long-term performance of these units has yet to be determined, but FBCs are believed to be the wave of the future. This optimism is due to the high degree of pollution control, ease of operation, and ability to burn a broad range of fuels.

Fluidized bed boilers control both nitric oxide (NO<sub>x</sub>) and sulfur oxide (SO<sub>x</sub>) emissions. NO<sub>x</sub> emissions are formed through two release mechanisms. The first is inherent in the nitrogen content of the fuel, called "fuel bound nitrogen," for which

there is no environmental control other than specification of lower nitrogen content fuel. The other release mechanism for nitric oxide emissions is through formation of thermal NOx at elevated furnace temperatures. Thermal NOx is formed when the nitrogen in the combustion air complexes with oxygen at elevated temperatures. Therefore, thermal NOx can be controlled through staged combustion in which the air is introduced farther downstream of the flame to promote secondary combustion.

Another control method is to keep the temperature of the flame low. The FBC controls thermal NOx formation by a combination of both mechanisms. FBC lends itself conveniently to staged combustion, which limits the formation of thermal NOx. In addition, FBCs operate between 1550 and 1750 °F, which is an optimal balance for combustion and thermal NOx control.

The strongest incentive for the development of FBC technology was the need to reduce sulfur oxide (SOx) emissions. FBCs control SOx emissions through the introduction of limestone (CaCO<sub>3</sub>) at elevated temperatures into the fuel bed. The basic chemical reaction is as follows:



The rate and extent of absorption of SO<sub>2</sub> on CaO depends on many variables, including fluid bed density, pressure and temperature, residence time, excess air, moisture in the air, limestone quality, limestone particle size, and sulfur content of the coal. The stoichiometric ratio of calcium to sulfur varies with the percentage of sulfur removal required, the temperature, and the residence time. In general, the higher the temperature and the lower the residence time, the higher the Ca:S molar ratio required for sulfur removal. Conversely, the lower the operating temperature and the longer the residence time, the lower the Ca:S molar ratio. The operating temperature range in which sulfur capture is optimized is 1550 to 1750 °F. The driving force behind manipulation of these variables is the degree of sulfur capture required by environmental regulations. The amount and quality of limestone versus the amount of sulfur in the coal is dictated by these regulations.

FBC has many advertised advantages over traditional forms of combustion with sulfur removal equipment. These include:

- use of lowest cost fuels available
- broad fuel flexibility
- excellent SOx removal

- competitive capital and operating costs compared with conventional technology using flue gas desulfurization
- reduced NO<sub>x</sub> emissions
- reduced slagging and fouling
- ash ruled nonhazardous by the U.S. Environmental Protection Agency (USEPA).

### 8.6.2 Coal Specifications

**8.6.2.1 Baseline Specifications.** Table 36 lists recommended coal specifications for fluidized bed combustion boilers.

**8.6.2.2 Design Considerations.** The only restriction on the coal quality being fired in an FBC unit is the effect changes in coal quality will have on the ancillary equipment and chemical feeds. As an example, if the coal's sulfur content increases greatly, the moles of CaO also will have to increase. Therefore, the equipment that handles the limestone will have to be flexible enough to handle this increased material. The ash-handling system must be large enough to accommodate the extra spent time, lime, and ash.

Table 36. Recommended coal specifications for a fluidized bed combustion boilers.

| Proximate Analysis               | Bituminous   | Subbituminous | Lignite |
|----------------------------------|--|---------------|---------|
| Moisture (M)                     | 0-30%  | 0-30%         | 25-45%  |
| Volatile Matter (VM)             | 30-45%   | 20-40%        | 22-32%  |
| Fixed Carbon (FC)                | 40-55%   | 30-50%        | 22-32%  |
| Ash                              | 5-20%  | 5-20%         | 5-20%   |
| <b>Heating Value, Btu/lb:</b>    | 4,500 - 15,000 for Bituminous<br>4,500 - 15,000 for Subbituminous<br>4,500 - 15,000 for Anthracite |               |         |
| <b>Hemispherical Temperature</b> | 1950 °F Min  |               |         |
| <b>Free Swell Index:</b>         | 7 Maximum  |               |         |

## References

- Berkowitz, N., *An Introduction to Coal Technology* (Academic Press 1979).
- Blazek, Christopher F., and Richard Biederman, "Coal Specifications and Contracting Handbook," *Final Report* (Institute of Gas Technology, May 1990).
- Coal Handling and Sampling* (March 1989).
- Conveyor Components Company, Bulletin No. C-228, corporate merchandising literature.
- Department of the Army, *Ground Storage of Coal* (March 1984).
- EPRI CS-4283, Project 2256-1, Vol 4: *Review of Coal Science Fundamentals of Effects of Coal Quality on Power Plant Performance and Costs* (Electric Power Research Institute, February 1986).
- Gorzelnik, Eugene F., ed., "Managing the Coal Pile: Brute Force and Finesse," *Electrical World* (December 1985).
- Johnson, A.J., and G.H. Auth, eds., *Fuels and Combustion Handbook*, 1st ed. (McGraw-Hill, 1951), vol VI, p 42.
- Kong, Pedro, M. Lee, and S. Hathaway, *Fuels: State of the Art in Industrial Utilization*, Technical Report E-135/ADA063239 (USACERL, November 1978).
- Maples, Glennon, David F. Dyer, and Martin J. Savoie, *U.S. Air Force Central Heating Plant Tuneup Workshop, Volume IX: Combustion Control—Coal*, SR E-90/03/ADB143011 (January 1990).
- Perry, R.H., and C.H. Chilton, eds., *Chemical Engineers Handbook* (McGraw-Hill, 1973).
- Perry, R.H., and C.H. Chilton, eds., *Chemical Engineers Handbook* (McGraw-Hill, 1984).
- "Power from Coal—Part I," *Power*, vol 118, No. 2 (February 1974).
- Richards, John, and Martin J. Savoie, *U.S. Air Force Central Heating Plant Tuneup Workshop, Volume XVI: Air Pollution Control Systems*, SR E-90/03/ADB142292 (USACERL, January 1990).
- Schmidt Associates, Inc., *Coal-Fired Boiler Presentation Design—Operating* (July 1986).

Schmidt, Charles M., Jill E. Davidson, Sam McCammon, Ralph Moshage, and Martin Savoie, "U.S. Air Force Central Heating Plant Tuneup Workshop, Volume V: Coal Quality," SR E-90/03/ADB142914 (USACERL, January 1990).

Schmidt, Charles M., Jill E. Davison, Sam McCammon, Ralph Moshage, and Martin J. Savoie, *U.S. Air Force Central Heating Plant Tuneup Workshop, Volume VII: Coal Combustion Equipment*, SR E-90/03/ADB141114 (USACERL, January 1990).

Standerfer, James F., and Martin J. Savoie, "U.S. Air Force Central Heating Plant Tuneup Workshop, Volume VI: Coal Handling and Storage," SR E-90/03/ADB143136 (USACERL, January 1990).

*Steam: Its Generation and Use* (Babcock & Wilcox 1978).

*Steam: Its Generation and Use, 40th ed.* (Babcock & Wilcox 1992).

Woodruff, Everett B., and Herbert B. Lammers, *Steam-Plant Operations*, 5th ed. (McGraw-Hill 1984).

## Glossary

**ABMA:** American Boiler Manufacturers Association

**absolute pressure:** Pressure measured with respect to a vacuum (zero pressure); the sum of the gauge and atmospheric pressures

**ACF:** Actual cubic feet

**ACFM:** Actual cubic feet per minute

**acid dew point:** The temperature at which acid in a vapor state condenses into liquid

**actual cubic feet:** The volume of a gas in cubic feet at the actual temperature and pressure of the gas

**AFBC:** Atmospheric fluidized bed combustion

**agglomeration:** The bringing together of small particles to form clumps; when coal is heated, a sticky tar-like material may form, which encourages small coal particles to gather into large clumps

**air classification:** The separation of light materials from heavier materials by means of forcing air up a cylindrical container at a controlled velocity

**air-to-cloth ratio:** The volume of flue gas that passes through a given filter area in 1 minute

**air distributor:** A plate, grid, or pipe containing either perforations, nozzles, or bubble caps, serving as a means for evenly distributing combustion/fluidizing air in a fluidized bed

**air dried:** A sample of coal that has been exposed to 85 to 95 °F air until its weight remains constant

**air, dry:** Air containing no water vapor

**air-fuel ratio:** The ratio of the weight (or volume) of air to that of the fuel

**air heater or air preheater:** A heat exchanger that transfers heat from a high temperature medium such as hot gas, or steam, to an incoming air stream

**regenerative air preheater:** A heat exchanger having heat transfer surfaces that are alternatively exposed to hot exhaust gases and cooler incoming ambient air

**recuperative air heater:** A heat exchanger that uses the heat transfer medium to separate the two gas streams

**tubular air heater:** A continuous heat exchanger in which one fluid travels through a bundle of tubes while the other flows around and between the tubes

**plate air heater:** A continuous heat exchanger in which one fluid travels across another separated by conductive plates

**air infiltration:** The leakage of air into a setting, furnace, boiler or duct

**air, saturated:** Air that cannot hold any more water vapor at a given temperature and pressure

**air seal:** Using air pressure to prevent pulverized material from gathering between the shaft and yoke of a pulverizer

**air transport system:** A fuel transport system utilizing air as the conveying medium

**ambient air:** The air surrounding the equipment; The American Boiler Manufacturer's Association standard for performance calculations is air at 80 °F (26.7 °C), 60 percent relative humidity, and a barometric pressure of 29.92 in. Hg (101,325 Pa); these conditions yield a specific humidity of 0.013 lb. (kg) of water vapor per lb. (kg) of air

**analysis, proximate:** Analysis of a solid fuel determining moisture, volatile matter, fixed carbon, and ash expressed as percentages of the total weight of the sample



**analysis, ultimate:** Chemical analysis of a solid, liquid, or gaseous fuel; in the case of coal, it is the determination of carbon, hydrogen, sulfur, nitrogen, oxygen and ash content

**anthracite coal:** An ASTM coal classification by rank; anthracite is a hard, black lustrous coal containing a high percentage (between 92 and 98 percent) of fixed carbon and a low percentage (between 2 and 8 percent) of dry volatile matter on a mineral-matter-free basis; typically it has a heating value of 12,000 to 15,000 Btu/lb. The following names identify certain anthracite coal sizes:

*broken* - passes through 4-3/8-in. round mesh screen, retained on 3 to 3-1/4-in. round mesh screen

*egg* - passes through 3 to 3-1/4-in. round mesh screen, retained on 2-7/16-in. round mesh screen

*stove* - passes through 2-7/16-in. round mesh screen, retained on 1-5/8-in. round mesh screen

*chestnut* - passes through 1-5/8-in. round mesh screen, retained on 1-3/16-in. round mesh screen

*pea* - passes through 1-3/16-in. round mesh screen, retained on 9/16-in. round mesh screen

*No. 1 (buckwheat)* - passes through 9/16-in. round mesh screen, retained on 5/16-in. round mesh screen

*No. 2 (rice)* - passes through 5/16-in. round mesh screen, retained on 3/16-in. round mesh screen

*No. 3 (barley)* - passes through 3/16-in. round mesh screen, retained on 3/32-in. round mesh screen

*No. 4* - passes through 3/32-in. round mesh screen, retained on 3/64-in. round mesh screen

*No. 5* - passes through 3/64-in. round mesh screen

**arch firing:** Method of firing in which burners are placed in a furnace arch and directed downward

**arch-furnace:** A horizontal structure extending into the furnace to serve as a deflector of the gases and to act as a radiant reflector

**arch-roof:** A structure composed of refractories (or a combination of refractories and water tubes) that encloses the top of the furnace's combustion chamber

**as-fired fuel:** The condition of a fuel when it is fed to the fuel burning equipment.

**ash:** The incombustible solid matter in a fuel; the mass remaining after all combustible materials have been consumed

**ash bed:** The layer of ash left on grates or deposited on a furnace floor after the fuel is burned

**ash-free basis (af):** The method for describing a fuel's constituents whereby ash is deducted and the remaining constituents are recalculated to total of 100 percent

**ash fusion (temperatures):** The temperatures at which a cone of coal, or coke ash, exhibits certain melting characteristics; See ASTM-D 1857.

**ash gate:** A gate or valve through which refuse is removed from an ash pit or soot hopper

**ash pit:** A pit or hopper, located below a furnace, where refuse is accumulated and periodically removed

**ASHRAE:** American Society of Heating, Refrigerating, and Air-Conditioning Engineers

**ASME Boiler and Pressure Vessel Code:** The boiler and pressure vessel code of the American Society of Mechanical Engineers including amendments and interpretations made and approved by the council of the Society

**aspect ratio:** The ratio of width to depth in a rectangular duct or elbow used to calculate flow resistance

**ASTM:** American Society for Testing and Materials

**atmospheric pressure:** The pressure of the air at sea level: 14.7 psi, 29.92 in. Hg, or 101,325 Pa

**attenuator:** See desuperheater

**availability factor:** The fraction of the time during which the unit is in operable condition

**axial fan:** A disc wheel or propeller contained within a cylinder that draws air parallel to its axis of rotation

**B&W:** Babcock and Wilcox

**baffle:** A device such as a steel plate, louver, or screen used to retard the flow of materials

**bag:** The customary form of filter element, also known as a tube, stocking, etc.; a bag can be unsupported (dust collected on the inside) or used on the outside of a grid support (dust collected on the outside)

**bag filter:** A device containing one or more cloth bags used for recovering particles from the dust-laden gas or air that is blown through

**baghouse:** An air pollution abatement device used to trap particulates by filtering gas streams through large fabric bags usually made of glass fibers

**balanced draft:** Maintaining a fixed value of draft in a furnace at all combustion rates by controlling the incoming air and the outgoing products of combustion

**banking:** Burning a solid fuel on a grate in a boiler at a combustion rate sufficient to maintain ignition only

**barley:** See anthracite coal

**banking (live):** Burning a solid fuel on a grate in a boiler at a combustion rate just sufficient to maintain normal operating pressure under conditions of no steam/water load demand

**base/acid ratio:** The total weight of basic constituents divided by the total weight of acid constituents in coal ash; the bases normally considered are the oxides of iron, sodium, calcium, magnesium and potassium; acids are silicon, aluminum and titanium.

**base load:** Base load is the term applied to that portion of a station or boiler load that is practically constant for long periods

**bed material:** Granular particles that compose the fluidized bed in fluidized bed boilers

**bed moisture:** The amount of water that a coal will hold when fully saturated at 100 percent humidity (as in an undisturbed coal seam), bed moisture reflects the total pore volume of the coal to which the moisture has access

**benefication:** Coal cleaning

**bin system:** A system in which fuel is pulverized, stored in bins, and subsequently transported via feeders to the burners in amounts sufficient to satisfy load demands

**bituminous coal:** ASTM coal classification by rank on a mineral-matter-free basis and with bed moisture only

*low volatile:* Dry fixed carbon between 78 and 86 percent; dry volatile matter between 14 and 22 percent

*medium volatile:* Dry fixed carbon between 69 and 78 percent; dry volatile matter between 22 and 31 percent

*high volatile (A):* Nonagglomerating bituminous coal having dry fixed carbon less than 69 percent, dry volatile matter greater than 31 percent, and a heating value greater than or equal to 14,000 Btu on a moist, mineral-matter-free basis

*high volatile (B):* Nonagglomerating bituminous coal having a heating value between 13,000 and 14,000 Btu on a moist, mineral-matter-free basis *high volatile (C):* Either agglomerating or nonweathering bituminous coal and having a heating value between 11,000 and 13,000 Btu

**blinding (blinded):** The loading, or accumulation, of fly ash on dust collector bags to the point where capacity is diminished; also termed "pluggage"

**blowdown:** Removal of a portion of boiler water for the purpose of reducing solids concentration, or to discharge sludge from the mud drum

**blower:** The fan used to force air through a pulverizer, or to force primary air through an oil or gas burner register

**blowhole:** A local area in a burning fuel bed through which a disproportionately large quantity of air passes

**boiler:** A closed pressure vessel in which a liquid, usually water, is vaporized by the application of heat

*watertube:* A boiler in which tubes carry water through the products of combustion

*bent tube:* A watertube boiler consisting of two or more drums connected by tubes; practically all of these tubes are bent near the ends to permit attachment to the drum shell along radial lines

*horizontal:* A watertube boiler in which the main bank of tubes lies on a slope of 5 to 15 degrees from the horizontal; these tubes are straight

*sectional header:* A horizontal boiler of the longitudinal or cross drum type, with the tube bank composed of multiple parallel sections—each section made up of a front and rear header connected by one or more vertical rows of generating tubes, and with the sections or groups of sections having a common steam drum

*box header:* A horizontal boiler of the longitudinal or cross drum type consisting of a front and rear inclined rectangular header connected by tubes

*cross drum:* A sectional header or box header boiler in which the axis of the horizontal drum is at right angles to the center lines of the tubes in the main bank longitudinal drum; a sectional header or box header boiler in which the axis on the horizontal drum, or drums, is vertical and parallel to the tubes

*low head:* A bent tube boiler having three drums with relatively short tubes in a vertical plane

*firetube:* A boiler with straight tubes; the tubes carry the products of combustion through water

*horizontal return tubular:* A firetube boiler in which the products of combustion pass under the bottom half of a shell and then return through tubes that run through the shell

*locomotive:* A horizontal firetube boiler with an internal furnace, at the rear of which is a tube sheet directly attached to a shell; the shell

contains tubes through which the products of combustion leave the furnace

*horizontal firebox:* A firetube boiler with an internal furnace, at the rear of which is a tube sheet directly attached to a shell containing tubes; the first-pass bank of tubes is connected between the furnace tube sheet and the rear head; the second-pass bank of tubes (passing over the crown sheet) is connected between the front and rear end closures

*refractory lined firebox:* A horizontal firetube boiler in which the front portion sits over a refractory or water cooled refractory furnace, and the rear portion either contains or is connected to the first- and second-pass tubes

*vertical:* A firetube boiler consisting of a cylindrical shell where the tube sheet that forms the top of the internal furnace connects to the top head; the products of combustion pass from the furnace directly through the vertical tubes

*submerged vertical:* Same as vertical above, except that use of a water leg construction as part of the upper tube sheet makes it possible to carry the water-line above the top ends of the tubes

*scotch boiler:* A cylindrical steel shell containing one or more cylindrical steel furnaces. These furnaces are typically positioned in the lower portion of the shell, with banks of tubes attached to both end closures; in stationary service, the boilers are either of the Dry-Back or Wet-Back type

**boiler convection bank:** A group of two or more rows of tubes that form part of a water boiler circulatory system and to which heat is transferred from the products of combustion through convection

**boiler efficiency:** The ratio of usable boiler output to input as defined by the ASME Power Test Code

**boiler, high-pressure steam:** A boiler that produces steam at pressures in excess of 15 psi (103,422 Pa)

**boiler, high-temperature hot water:** A water heating boiler operating at a pressure exceeding 160 psi (1,103,168 Pa) or temperatures exceeding 250 °F (121 °C)

**boiler horsepower:** The evaporation of 34.5 lbs/hr (15.648 kg/hr) of water at 212 °F (100 °C) into dry saturated steam at the same temperature—equivalent to 33,472 Btu/hr (35,291,203 joule)

**boiler, low-pressure hot-water and low-pressure steam:** A boiler furnishing hot water at pressures not exceeding 160 psi (1,103,168 Pa) and temperatures not exceeding 250 °F (121 °C); steam is at pressures no greater than 15 psi (103,422 Pa)

**boiler layup:** Preparation and storage of an out-of-service boiler

**boiler slag screen:** A screen formed by one or more rows of widely spaced tubes that constitute part of (or are positioned in front of) a watertube boiler convection bank; this screen lowers the temperature of the products of combustion and serves as an ash cooling zone

**boiler water:** A term used to define a representative sample of the circulating boiler water; the sample is obtained after the generated steam has been separated and before feedwater or chemicals have been added

**boiler wet-back:** A baffle provided in a firetube boiler or water leg construction that covers the rear end of the furnace and tubes and that is completely water cooled; combustion products leaving the furnace are turned in this area and enter the tube bank

**boiling out:** The removal of oils, greases, etc. prior to normal operation or after major repairs by heating a highly alkaline solution of water in the boiler pressure parts

**bone coal:** Coal from that part of a seam that has a very high ash content

**breeching:** A duct, usually constructed of sheet metal, that transports flue gases to the stack

**bridgewall:** A wall in a furnace over which the products of combustion must pass

**bridging:** The accumulation of ash and slag between heat absorbing tubes that causes complete or partial blockage

**British thermal unit (Btu):** One Btu is the quantity of energy required to raise the temperature of 1 pound of water by 1 °F; 1 Btu is approximately 252 calories

**broken:** See anthracite coal

**brown coal:** A lignite coal lowest in classification according to rank; it is brown or brownish-black and commonly retains the structures of the original wood; it is high in moisture, has a heating value less than 8,300 Btu, and crumbles easily on drying

**Btu:** British thermal unit

**bubbling bed:** A fluidized bed in which the fluidizing velocity is less than the terminal velocity of individual bed particles; this causes the fluidizing gases to pass through the bed as bubbles

**buckwheat:** See anthracite coal

**burner:** A device that controls the velocity, turbulence, and concentration of fuel and air entering the furnace to maintain proper ignition and combustion of the fuel:

*burner, automatically ignited:* A burner that has its main fuel turned on and ignited automatically

*manually ignited:* A burner that has its main fuel turned on and ignited manually

*forced draft:* A burner where air for combustion is supplied above atmospheric pressure

*natural draft type:* A burner that depends on the natural draft of the furnace to draw air for combustion

**burner windbox:** A plenum chamber around a burner that insures the proper distribution and discharge of secondary air



**burner windbox pressure:** The air pressure maintained in the windbox, or plenum chamber

**bus section:** The smallest portion of an electrostatic precipitator that can be independently de-energized (by subdivision of the high voltage system and arrangement of support insulators)

**bypass temperature control:** Control of vapor or air temperature by diverting part or all of the heating medium from passing over the heat absorbing surfaces, usually by means of a bypass damper

**caking:** Property of certain coals to become plastic and form large masses of coke when heated

**calcium sulfate:** A solid, relatively insoluble material, with a chemical formula of  $\text{CaSO}_4$  ; it is normally formed by the oxidation of Calcium Sulfite, a by-product of FGD systems; Calcium Sulfate is commonly produced as Calcium Sulfate Dihydrate,  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ , also known as gypsum

**calorie:** One calorie is the quantity of energy required to raise the temperature of 1 gram of water by 1 degree Centigrade; 1 calorie is approximately 4.184 joules

**calorific value:** The quantity of heat liberated when a unit weight, or unit volume, of a fuel is completely burned

**calorimeter:** An apparatus for determining the calorific value of a fuel

**capacity:** The maximum power output, or load, for which a machine is rated by the manufacturer

**capacity factor:** The ratio of a boiler's actual output to its maximum theoretical output (capacity)

**carbon:** A nonmetallic element existing in all organic compounds; carbon is the principal combustible constituent of most fuels

**carbon conversion efficiency:** The degree to which carbon compounds are oxidized to form  $\text{CO}_2$ —the volume of  $\text{CO}_2$  actually produced by combustion divided by the theoretically expected volume

**carbonization:** The destructive distillation of coal accompanied by the formation of char (coke), liquid (tar), and gaseous products

**carbon loss:** The incomplete oxidation (or combustion) of the carbon within a fuel

**carbon residue:** The quantity of carbonaceous material remaining after volatile compounds are vaporized

**carryover:** The passing of water and impurities to the steam outlet of the boiler

**CE:** Combustion Engineering

**chain grate stoker:** A stoker that uses chains to form the grate surface

**chemical feed pipe:** The pipe inside a boiler drum that delivers chemicals for treating the boiler water

**cinder:** Partially burned fuel (free of volatile gases) that is carried from the furnace by the products of combustion

**cinder catcher:** An apparatus that separates and collects cinders from the products of combustion (See also fly ash collector, dust collector, or precipitator)

**cinder return:** An apparatus that returns collected cinders to the furnace, either directly or with the fuel

**circulating bed:** A fluidized bed in which the fluidizing velocity exceeds the terminal velocity of individual bed particles

**circulation:** The movement of water and steam within a steam generating unit

**class:** Rank of a coal

**classification:** Method for separating coals in terms of their properties; see also rank

**classifier:** The part of a coal pulverizer system that removes coarse particles from the air that carries the pulverized fuel

**clinker:** Fuel and ash that has fused into a hard, compact, congealed mass

**clinkering:** The formation of clinkers

**clinker grinder stoker:** A stoker system that discharges clinkers into a pit containing one or more grinding roll; these grinding rolls crush the clinkers and then discharge them into the ash pit

**coal:** Solid hydrocarbon fuel formed by ancient decomposition of woody substances under conditions of heat and pressure

**coal-oil mixtures (com):** A mixture of coal and oil typically containing at least 50 percent (by weight) ground or finely powdered coal (Stabilizing agents are also added); the heat content and viscosity of the mixture depends on the concentration of coal

**coal reclaim:** Moving coal from plant storage (e.g., coal pile) to the system that delivers coal to the boiler

**coal tar:** A black viscous liquid formed by the distillation of coal

**cogeneration:** When a facility uses its own waste energy to generate electricity or to perform some other useful work

**coke:** The solid carbonaceous residue that remains after destructive distillation removes the volatile materials from bituminous coal

**coking:** The conversion of a carbonaceous fuel (particularly certain bituminous coals) into a coherent, firm, cellular carbon product known as coke by heating it in the absence (or near absence) of air

**combustible:** The heat producing constituents of a fuel

**combustible in refuse:** The heat producing matter left in the solid refuse as a result of incomplete fuel combustion

**combustible loss:** The unreleased chemical energy due to incomplete oxidation of the combustible matter in the fuel

**combustion:** Combustion is a rapid chemical reaction that generates heat; heat energy is liberated when oxygen combines with the combustible elements of a fuel

**combustion chamber:** See furnace

**combustion efficiency:** A measure of the completeness of a fuel's oxidation; it is typically quantified as the ratio of actual heat released by combustion to the maximum heat available through combustion

**combustion rate:** The quantity of fuel fired per unit time

**compartment:** One or more air chambers located beneath a stoker

**complete combustion:** The complete oxidation of all combustible constituents in a fuel

**condensate:** Liquid water resulting from the removal of latent heat from steam

**conduction:** The transmission of heat through matter by the transfer of kinetic energy from molecule to molecule rather than by a flow of heated material

**conductivity:** The ease with which heat will flow through a material as determined by the material's physical characteristics

**continuous blowdown:** The continuous removal of boiler water to reduce the concentration of solids

**convection:** The transmission of heat by the circulation of a liquid or gas; convection may be natural or forced

**convection heating surface:** A surface that is heated primarily by convection; for example, a surface exposed to the flow of hot combustion gases

**conveyor:** A coal delivery system that transports coal to the furnace; conveyors typically move coal only a short distance

**corner firing:** A method for firing a liquid, gaseous or pulverized fuel in which the burners are located at the corners of the furnace (See tangential firing)

**corrosion:** The gradual destruction of a material by a chemical process such as oxidation or solution; boiler corrosion is usually due to the presence of acids or strong alkalies

**culm:** The fine refuse from anthracite production

**cyclone:** A device that uses centrifugal action to separate materials of varying densities

**cyclone collector:** A device that uses centrifugal action to remove fine particles suspended in air or ga.

**cyclone furnace:** A furnace that uses swirling gas and fuel flows to induce rapid combustion

**degree of superheat:** For steam, it is the difference between the actual steam temperature and the theoretical saturation temperature for the given pressure

**design load:** The load for which a steam generating unit is designed; design load is typically the maximum load to be carried

**design pressure:** The maximum allowable working pressure permitted under the rules of the ASME Construction Code; design pressure is used to determine minimum thicknesses and other physical characteristics of boilers and related components

**desuperheater:** An apparatus that reduces and controls the temperature of a superheated vapor

*shell and tube type:* A pressure vessel that reduces heat by circulating a cooling medium through the walls

*spray type:* An atomized fluid is injected into the superheated vapor reducing the temperature

*submerged type:* Tubular elements are positioned in the boiler circulation system below the water line

**dew point:** The temperature, at constant pressure and water vapor content, to which air must be cooled for saturation or condensation to occur

**distillation zone:** The region in a solid fuel bed where the volatile constituents of the fuel are vaporized

**DOD:** Department of Defense

**downcomer:** A pipe in a boiler (or waterwall circulating system) through which fluid flows downward

**draft:** The difference between atmospheric pressure and the pressure existing in the gas passages of a boiler

**draft loss:** The pressure drop due to friction of a gas flowing between two points in a system

**drum:** A cylindrical shell closed at both ends that is designed to withstand internal pressure

**drum internals:** All equipment contained within a drum

**dry air:** Air containing no water vapor

**dry ash:** Non-combustible matter in a solid state, usually in granular dust form

**dry, ash-free basis (daf):** The method for describing a fuel's constituents whereby ash and moisture are deducted and the remaining constituents are recalculated to total 100 percent

**dry basis (d):** The method for describing a fuel's constituents whereby moisture is deducted and the remaining constituents are recalculated to total 100 percent

**dry bottom furnace:** A pulverized-fuel furnace in which ash particles are deposited on the furnace bottom in a dry, nonadherent condition

**dry, mineral-matter-free basis (dmmf):** Same as dry, ash-free basis, but substitute "mineral matter" for "ash"

**dry pipe:** A perforated or slotted pipe or box located inside the drum and connected to the steam outlet used to eliminate moisture from the steam

**dry scrubber:** A FGD system in which sulfur dioxide is collected by a solid medium; the final product is totally dry, typically a fine powder

**dry steam:** Steam containing no moisture; commercially dry steam contains no more than 0.5 percent moisture

**Dulong's formula:** A formula for calculating the approximate heating value of a solid fuel from its ultimate analysis

**dump grate stoker:** A stoker system equipped with movable ash trays, or grates, that can discharge ash at a desired time interval.

**dust:** Fine-grain particulate matter, typically suspended in a gas

**dust collector:** A device designed to remove fly ash in dry form from flue gas (See also cinder catcher, fly ash collector, or precipitator)

**dust loading:** The weight of solid particulates suspended in a gas stream; this loading is usually expressed in terms of grains per cubic foot, grams per cubic meter, or pounds per thousand pounds of gas

**economizer:** A heat exchanger that recovers heat from flue gases and uses it to heat feedwater

**eductor:** A device that uses water, steam, or air to induce the flow of ash from an ash pit

**efficiency:** The ratio of output to input; the efficiency of a steam generating unit is the ratio of the heat absorbed by the water and/or steam to the heat released from the firing of the fuel

**egg:** See anthracite coal

**ejector:** A device that uses a jet of water (or other fluid) to remove a fluid or fluent material from a tank or hopper

**electrostatic precipitator (ESP):** A device for collecting particulate matter from a gas stream using an electrostatic charge

**endothermic reaction:** A chemical reaction in which heat must be supplied for the reaction to continue

**enthalpy:** A thermal property of a fluid, equivalent to the internal energy plus the product of the pressure and the volume

**entrained bed:** A coal combustion or gasification process in which pulverized coal is carried along in a gas stream

**EPRI:** Electric Power Research Institute

**erosion:** The wearing away of refractory or of metal parts by the action of slag, fly ash, or soot blower jet streams

**excess air:** Air supplied for combustion in excess of that theoretically required for complete combustion

**excluded mineral matter:** Minerals surrounding the coal field that are mined with the coal

**exhauster:** A fan used to withdraw air or gases under suction

**exothermic reaction:** A chemical reaction that results in the liberation of heat

**expansion joint:** A joint that permits movement due to expansion without undue stress

**fabric filter:** A cloth device that removes dust and particles from industrial or utility emissions

**feeder:** Coal conveying system used to transport coal over a larger distance—usually from the plant's coal storage (e.g., coal pile) to the plant's conveyor system

**feedwater:** Water introduced into a boiler including make-up water and returned condensate

**ferric percentage:** Actual ferric iron in slag, expressed as a percentage of the total iron calculated as ferric iron

**FGD:** Flue gas desulfurization

**filter:** A device for separating solids or suspended particles from liquids or gases

**fin:** Usually a strip of steel welded longitudinally or circumferentially to a tube

**fin tube:** A tube with one or more fins

**fin tube wall:** Spaced waterwall tubes on which flat metal extensions are welded in a plane parallel to the wall



**fineness:** The percentage by weight of a pulverized material able to pass through a specified mesh size when subjected to a prescribed sampling and screening procedure (ASTM D 197)

**finer:** Very small material produced in breaking up larger lumps

**fire box:** The equivalent of a furnace

**firetube:** A tube that carries the products of combustion through water

**fixed ash:** The portion of the ash derived from inherent mineral matter

**fixed carbon:** The solid residue other than ash obtained by the destructive distillation of coal

**flashing:** Flashing is the immediate conversion of a liquid into a gas; for steam, flashing occurs when steam at a given temperature experiences a sudden drop in pressure

**flue dust:** Solid particles carried in flue gas

**flue gas:** The gaseous products of combustion in the flue to the stack

**flue gas desulfurization (FGD):** A method for controlling sulfur dioxide emissions by removing sulfur compounds from flue gases

**flue gas recirculation:** The reintroduction of flue gases into the furnace (upstream from the point of removal) for the purpose of controlling steam temperature or NO<sub>x</sub> emissions

**fluidized bed:** A fluidized bed results when finely divided solid materials are kept in suspension by a rising current of air or other gas, this condition is ideal for gas/solid reactions because each solid particle is in constant motion and surrounded by the moving gas stream

**fluid temperature:** The temperature at which a standard ash cone fuses down into a flat layer when heated in accordance with a prescribed ASTM D 1857 procedure

**fly ash:** The fine particles of ash that are carried by the products of combustion

**fly ash collector:** A device designed to remove fly ash in dry form from flue gas; (see also cinder catcher, dust collector, or precipitator)

**foaming:** The development of foam on the surface of water in the boiler drum caused by impurities in the water and can lead to carryover

**forced circulation:** The pumped circulation of water in a boiler as contrasted to natural circulation

**forced draft fan:** A fan supplying air under pressure to the fuel burning equipment

**fouling:** The formation of solid deposits in gas passages or on heat transfer surfaces

**free ash:** The portion of the ash derived from included and excluded mineral matter

**freeboard:** The space in a fluidized bed reaction between the top of the bed and the top of the reactor

**free moisture:** Same as surface moisture; the moisture in coal that can be removed by ordinary air drying; it is that portion of the moisture in the coal that comes from external sources such as water seepage, rain, snow, condensation, etc.

**friability:** The tendency of coal to crumble or break into small pieces

**front discharge stoker:** A stoker arranged such that the ash is discharged from the grate surface at the same end of the furnace as the solid fuel is fed

**FSI:** Free-swelling index

**fuel-air ratio:** The ratio of the weight (or volume) of fuel to that of the air

**fuel bed:** The layer of burning fuel on a furnace grate

**fuel bed resistance:** The static pressure differential across a fuel bed

**furnace:** An enclosed space that facilitates the combustion of fuel

**furnace draft:** The draft in a furnace measured at a point immediately in front of the furnace outlet

**furnace release rate:** The heat available per square foot of heat absorbing surface in the furnace; heat absorbing surfaces include tubes and extended metallic surfaces on the furnace's sides (such as the walls, floor, roof, partition walls and platens), and the area of the furnace exit that is defined as the entrance to the convection tube bank

**furnace slag screen:** A screen formed at the furnace outlet by one or more rows of tubes; these tubes serve to create a cooling zone for the particles suspended in the products of combustion

**furnace volume:** The cubic size of the furnace or combustion chamber

**fusibility:** The property of slag to fuse and coalesce into a homogeneous mass

**fusible plug:** A plug located in the wall between the fire box and water of a firetube boiler; when the water level in the boiler drops below the plug, the plug blows, warning the operator of the low water level

**fusion:** The melting of ash

**gag, safety valve:** A clamp designed to prevent a safety valve from lifting while applying a hydrostatic test at higher pressure than the safety valve setting

**grate:** The surface on which fuel is supported and burned, and through which air is passed for combustion

**grate bars:** Part of the fuel supporting surface arranged to admit air for combustion

**grindability:** Grindability describes the ease by which coal can be pulverized; it is one of the factors used in determining the capacity of a pulverizer; the index is relative—a value of 100 represents a coal that is easy to pulverize, while smaller values represent coals that are more difficult to pulverize

**hand fired grate:** A grate on which fuel is placed manually, usually by means of a shovel

**hardness:** A measure of the amount of calcium or magnesium salts in boiler water, usually expressed as grains per gallon or parts per million (ppm)

**header:** Headers are branch pipes with many outlets; usually these branch pipes are parallel to each other

**heat available:** Available heat is the quantity of thermal energy capable of being absorbed for useful work; in boiler practice, the heat available in the furnace is usually taken to be the higher heating value of the fuel, less radiation losses, unburned combustibles, vaporization of fuel moisture and vaporization of water formed by the combustion of hydrogen in the fuel, plus the heat in the air (and recirculated gases) used for combustion, all above ambient temperatures

**heat balance:** The energy output must equal the energy input

**heat exchanger:** A device that transfers heat from one medium to another

**heat release rate:** The total quantity of thermal energy above a fixed datum introduced into a furnace by a fuel; it is considered to be the product of the hourly fuel rate and the fuel's higher heating value, and is expressed in Btu per hour per cubic foot of furnace

**heating surface:** A surface that is exposed to a heating medium for the purpose of absorption and transfer of that heat to a second medium

*boiler and waterwall heating surfaces:* These surfaces include all component parts in contact with the water (or wet steam) on one side and with the hot gases (or refractory) on the other; these surfaces should be measured on the side receiving the heat; waterwall heating surfaces should be measured as the sum of the projected areas of the tubes and the extended metallic surfaces on the furnace's sides; these surfaces include the walls, floor, roof, partition walls, and platens, consisting of bare or covered tubes

Continuation of furnace tubes beyond the furnace's gas outlet should be included as boiler heating surface; these surfaces should be measured along those portions of the circumferential and extended metallic surfaces receiving heat

All other boiler surfaces, including furnace screen tubes, should be measured along those portions of the circumferential and extended metallic surfaces receiving heat; surfaces should not be included in more than one category

*Superheater and Reheater Surface:* These surfaces include all component parts in contact with the water (or wet steam) on one side and with the hot gases (or refractory) on the other, these surfaces should be measured on the side receiving the heat

Radiant superheating or radiant reheating surfaces should be measured as the sum of the projected areas of the tubes and the extended metallic surfaces on the furnace's sides; these surfaces include the walls, floor, roof, partition walls, and platens

Continuation of superheater tubes beyond the furnace's gas outlet should be included as convection superheater surface; these surfaces should be measured along those portions of the circumferential and extended metallic surfaces receiving heat

All other superheater and reheater surfaces, including screen tubes, should be measured along those portions of the circumferential and extended metallic surfaces receiving heat; surfaces should not be included in more than one category

**hemispherical temperature:** A fusion temperature at which a standard ash cone, when heated in accordance with a prescribed procedure (ASTM D-1857), is fused down to a hemispherical lump with a height equal to one-half the width of the base

**HGI:** Hardgrove grindability index

**HHV:** Higher heating value

**higher heating value:** See calorific value

**high pressure boiler:** See boiler, high pressure

**high-temperature hot water boiler:** See boiler, high-temperature hot water

**hopper:** A vessel used for holding and easily discharging coal or refuse

**hopper bottom furnace:** A furnace bottom with one or more inclined sides forming a hopper for the collection and easy removal of ash

**horizontal firing:** A furnace in which the burners discharge the fuel and air for combustion horizontally

**hydrocarbon:** A chemical compound of hydrogen and carbon

**ignition arch:** A refractory arch, or surface, located over the fuel bed that radiates heat back onto the fuel to sustain combustion

**ignition temperature:** The minimum temperature needed to sustain combustion of a fuel

**inches water gage ("w.g.):** A term expressing the measurement of relatively low pressures or pressure differentials by means of a U-tube; 1 inch w.g. equals 5.2 lbs/sq ft or 0.036 lbs/sq in

**included mineral matter:** Minerals that settled in among the coal during its formation

**incomplete combustion:** The partial oxidation of the combustible constituents of a fuel

**induced draft fan:** A fan located in the flue ducts between the boiler and chimney; this fan pulls combustion gases through the fuel burning equipment

**inherent mineral matter:** Minerals that existed as part of the original plant material that formed the coal

**inherent moisture:** Moisture held so closely by the coal that it does not produce wetness. Sometimes called bed moisture

**initial deformation:** The temperature at which the apex of a standard ash cone begins to round or bend when heated in accordance with a prescribed procedure

**LHV:** Lower heating value

**lignite A:** A coal of low ASTM ranking with a calorific value of between 6,300 and 8,300 Btu/lb on a moist, mineral-matter-free basis

**lignite B:** A coal of lowest ASTM ranking with a calorific value of less than 6,300 Btu/lb on a moist, mineral-matter-free basis

**lime:** Lime (calcium oxide,  $\text{CaO}$ ) is a chemical used in some FGD systems, It is mixed with water to form calcium hydroxide,  $\text{Ca(OH)}_2$

**limestone:** Limestone (calcium carbonate,  $\text{CaCO}_3$ ) is a chemical used in some FGD systems

**lining:** A high grade tile, brick, or plastic refractory layer used on the walls of a furnace to protect it from high temperatures, abrasive fuels, and combustion gas constituents

**live steam:** Steam direct from the boiler and under full pressure, as distinguished from exhaust steam, which is at low pressure

**load:** The rate of boiler output

**load factor:** The ratio of the average load carried by a boiler system during a specific period to its peak load during that period (See also capacity factor.)

**lower heating value:** The higher heating value of a fuel minus the heat required to vaporize the water in the fuel, and minus the heat required to vaporize the water formed from the combustion of hydrogen in the fuel

**make-up:** Water added to the boiler to compensate for water lost through exhaust, blowdown, leakage, etc.

**maximum allowable working pressure:** The maximum pressure for which a boiler is designed and constructed to withstand; this pressure is used for setting the pressure-relieving devices that protect the boiler

**maximum continuous load:** See capacity

**maximum continuous rating:** See capacity

**mechanical stoker:** A device that mechanically feeds fuel onto a furnace grate, that acts as a fuel bed, admitting air for combustion and providing a means for removing refuse

*overfeed stoker*: A stoker in which fuel is fed onto the grates above the point of air admission to the fuel bed

*spreader stoker*: A stoker in which fuel is distributed over the fuel bed; a portion of the fuel is burned in suspension, while the rest is burned on the grates

*underfeed stoker*: A stoker in which fuel is introduced through retorts at a level below the point of air admission to the fuel bed

**meta-anthracite**: The highest ASTM coal classification according to rank; it has a dry fixed carbon content greater than 98 percent, and dry volatile matter content less than 2 percent on a mineral-matter-free basis

**micron**: One millionth of a meter; the diameter of fly ash particles is usually expressed in microns

**mineral-matter-free basis (mmf)**: Same as ash-free basis, but substitute "mineral matter" for "ash"

**moisture**: Water in the liquid or vapor phase

**moisture and ash-free basis**: See dry, ash-free basis

**moisture in steam**: Particles of liquid water carried in steam, usually expressed as a percentage by weight

**mud or lower drum**: A pressure chamber located at the lower extremity of a watertube boiler convection bank; the drum normally contains a valve to blow off collected sediment

**multiple retort stoker**: An underfeed stoker consisting of two or more retorts (parallel and adjacent to each other, but separated by a line of tuyeres) and arranged such that refuse is discharged at the ends of the retorts

**multistage furnace**: A combination of two or more furnaces connected in series

**natural circulation**: The circulation of water through a boiler due to variations in water temperature (density)—sometimes referred to as thermal, thermally induced, or thermal-siphon circulation

**NO<sub>x</sub>**: A general notation of nitrogen oxides



**NOx emissions:** NO and NO<sub>2</sub> contained in the flue gas

**NPDES:** National Pollution Discharge Elimination System

**nut:** See anthracite coal

**nut and slack:** A mixture of commercially available coal sizes containing a percentage of each of these two grades

**opacity:** The ability to reflect light, For example, a window has zero opacity, while a wall is 100 percent opaque; opacity numbers relating to boiler emissions are not intended to include the effect of condensing water vapor

**orsat:** A gas analysis apparatus in which concentrations of certain gaseous constituents (CO<sub>2</sub>, O<sub>2</sub> and CO) are measured by absorption in separate chemical solutions

**overfire air:** Combustion air admitted into the furnace at a point above the fuel bed; overfire air encourages complete combustion; in addition, overfire air reduces the release of particulates by forming an air curtain over the fuel bed and also reduces NOx formation by promoting staged combustion firing

**overfire air fan:** A fan used to deliver air to the overfire air components

**oxidation:** A chemical reaction in which oxygen combines with other elements

**oxidizing atmosphere:** An atmosphere that tends to promote the oxidation of immersed materials

**packaged boiler:** See packaged steam generator

**packaged steam generator:** A boiler equipped and shipped complete with fuel burning equipment, mechanical draft equipment, automatic controls, and accessories usually shipped in one or more major sections

**particulate loading:** See dust loading

**particulates:** Fine liquid or solid particles such as dust, smoke, mist, or fumes found in input air or boiler emissions

**PC:** Pulverized coal

**pea:** See anthracite coal

**peak load:** The maximum load carried for a stated short period of time

**peat:** Partially decomposed organic material formed in marshes and swamps; this is an early stage of coal formation

**pH:** Denotes the degree of acidity or alkalinity of a solution; at 25 °C, a pH above 7 indicates alkalinity, and a pH below 7 indicates acidity; the pH number is the negative exponent of 10 representing a solution's hydrogen ion concentration in grams per liter; for instance, a pH of 7 represents 10 to 7 grams per liter

**pitting:** The formation of small depressions in a surface due to corrosive chemicals or particle bombardment

**plenum:** An enclosure in which air or other gas is at a pressure greater than that outside the enclosure

**plunger:** An element of a stoker that propels solid fuel into a fuel distributor; fuel rate can be controlled by varying the frequency or amplitude of the plunger's reciprocating motion

**pneumatic conveying:** The use of forced air to transport fuel through a conduit

**ppm:** Parts per million

**precipitator:** An air pollution control device that collects particles from an emissions source by mechanical or electrical means

**preheated air:** Air at a temperature exceeding that of ambient air

**pressure drop:** The difference in pressure between two points in a system

**primary air:** Air introduced with the fuel at the burners

**primary air fan:** A fan that delivers primary air to the furnace

**priming:** A condition in which excess quantities of fine water particles are carried along with the steam

**process steam:** Steam used for industrial purposes other than for producing power or for space heating

**products of combustion:** The gases, vapors, and solids resulting from the combustion of a fuel

**proximate analysis:** See analysis, proximate

**pulsation:** Rapid fluctuations in furnace pressure

**pulverized coal:** Coal that has been reduced in size; for example, bituminous coal is considered pulverized when 65 percent will pass through a 200-mesh sieve and 99 percent will pass through a 40-mesh sieve

**pulverizer:** A machine that reduces a solid fuel to a fineness suitable for burning in suspension.

*high speed:* Over 800 rpm, including impact and attrition pulverizers

*medium speed:* Between 70 and 300 rpm, including roller and ball pulverizers

*low speed:* Under 70 rpm, including ball or tube pulverizers

**pusher:** An element of a stoker that propels solid fuel into a fuel distributor; fuel rate can be controlled by varying the frequency or amplitude of the pusher's reciprocating motion

**pyrites:** A compound of iron and sulfur naturally occurring in coal

**radiation loss:** A comprehensive term used to account for conduction, radiation, and convection heat losses from the boiler system to the surrounding ambient air

**rank:** Method of classifying coal based on the degree of progressive alteration in the natural series from brown coal to meta-anthracite; the limits under classification according to rank are on a mineral-matter-free basis

**rated capacity:** See capacity

**rate of blowdown:** A rate normally expressed as a percentage of the incoming water

**rear discharge stoker:** A stoker that discharges ash from the grate at the end of the furnace opposite the solid fuel feed

**reciprocating grate:** A grate element that moves back and forth quickly, usually for the purpose of fuel agitation

**reducing atmosphere:** See oxidizing atmosphere

**refractory:** A concrete like material capable of withstanding extremely high temperatures and having a relatively low thermal conductivity

**reinjection:** Returning collected fly ash to the furnace to burn out its carbon content

**retort:** A trough or channel in an underfeed stoker through that fuel is forced upward into the fuel bed

**rice:** See anthracite coal

**rifle or rifle distributor:** A device that divides a flow into equal parts; it is typically used to reduce the size of coal samples and also to divide a stream of pulverized coal when a pulverizer feeds multiple burners

**Ringelmann chart:** A series of illustrations ranging from light grey to black used to measure the opacity of smoke emitted from stacks and other sources, The shades of grey simulate various smoke densities and are assigned numbers ranging from zero to five, Ringelmann No. 1 is equivalent to 20 percent density; No. 5 is 100 percent density, Ringelmann charts are used in the setting and enforcement of emission standards

**run of mine:** Unscreened coal direct from the mine

**riser tube:** A nonheat absorbing tube through which the steam-water mixture generated by a furnace is passed upward to a waterwall header or a drum

**safety relief valve:** Similar to a safety valve

**safety valve:** A spring loaded valve that prevents excessive pressure from building up in a boiler by automatically opening when pressure reaches a set value

**saturated air:** See air, saturated

**saturated steam:** Water vapor at a temperature and pressure such that any reduction in temperature or increase in pressure will cause condensation

**saturated water:** Water at its boiling point

**saturation pressure:** The pressure at which vaporization takes place for a given temperature

**saturation temperature:** The temperature at which vaporization takes place for a given pressure

**scale:** A hard coating that forms on boiler surfaces

**SCF:** Standard cubic feet

**SCFM:** Standard cubic feet per minute

**screen:** A perforated plate, cylinder, or mesh fabric used for separating coarser materials from finer ones

**screening:** The separation of solid materials of different sizes by use of screen

**scrubber:** An apparatus that cleans waste gases by means of a liquid sorbent

**seam:** A continuous deposit of coal bedded between parallel strata of sandstone, shale, or clay

**segregation:** The tendency for solid materials of varying sizes to deposit selectively on different parts of a pile

**semi-anthracite:** An ASTM coal classification according to rank on a mineral-matter-free basis; it has a dry fixed carbon content between 86 and 92 percent, and a dry volatile matter content between 8 and 14 percent

**semi-bituminous:** A former coal classification according to rank that included low volatile bituminous,

**shaking grate:** A grate that shakes periodically forcing ash to sift through it

**sieve:** A laboratory apparatus comprised of various sized screens that allows the finer particles of a substance to be separated from the coarser ones

**siftings:** The fine particles of solid fuel that sift through a grate

**silt:** Fine particles obtained as a residue from a coal cleaning process

**single-retort stoker:** An underfeed stoker consisting of only one retort in the assembly of the complete stoker; a single furnace may contain one or more single-retort stokers

**slack:** A rock formation sometimes overlaying or mixed with a coal seam; when connected with anthracite coal, any material that has less than 40 percent fixed carbon

**slacking:** The breaking down of friable coals due to changes in moisture content

**slag:** Molten or fused refuse

**slag blower:** See soot blower

**slag screen:** See furnace slag screen

**slag tap furnace:** A pulverized-fuel fired furnace in which the ash particles are deposited and retained on the furnace floor, while molten ash is removed by tapping (either continuously or intermittently)

**slag viscosity:** The flow characteristics of coal slags

**slate:** A rock formation sometimes overlaying or mixed with a coal seam; when connected with anthracite coal, any material that has less than 40 percent fixed carbon

**slip velocity:** For a fluidized bed, slip velocity is the difference between the gas and solid velocities

**smoke:** Small gas borne particles of carbon or soot, less than 1 micron (0.001 mm) in size, resulting from incomplete combustion of carbonaceous materials and sufficient in number to be observable

**smoke number, Ringelmann:** An integer between zero to 5 that is used to describe the degree of blackness of a visible stack plume; see also Ringelmann chart

**smoke spot number (Bacharach):** An integer between zero and 9 used to indicate the relative smoke density of stack emissions; the technique involves drawing stack gases through a filter and then comparing the appearance of this filter to the Bacharach scale

**softening:** A process that reduces the quantity of calcium and magnesium salts dissolved in water; these salts cause scaling

**softening temperature:** A fusion temperature at which a standard ash cone, when heated in accordance with a prescribed procedure (ASTM D 1857), is fused down to a spherical mass with a height equal to the width of the base

**solvent refined coal (SRC):** Coal that has been cleaned using a solvent to remove a substantial portion of its impurities, particularly ash and sulfur compounds

**soot:** Fine black particles, mainly carbon, derived from incomplete combustion

**soot blower:** A mechanical device that discharges steam, air, or water for the purpose of cleaning heat absorbing surfaces

**sorbent:** A constituent in a fluidized bed that captures a pollutant by chemically reacting with it

**SOx:** A general notation of sulfur oxides

**spalling:** The breaking of surface refractory materials due to internal stresses caused by an excessive temperature gradient

**spontaneous combustion:** The ignition of a combustible material without the application of a high temperature from an external source; this occurs following slow oxidation of a material in conditions where the heat generated is unable to escape

**stack:** A vertical conduit used for discharging combustion products to the atmosphere; also known as a chimney or smokestack

**stack effect:** Hot gas moves upward because it is less dense than the surrounding atmosphere

**standard temperature and pressure (STP):** Conditions used to define a standard volume for gases

*Boilers (U.S.)* - Standard temperature is 60 °F; standard pressure is 14.7 psia

*Air Pollution Control (U.S.)* - Standard temperature is 70 °F; standard pressure is 14.7 psia

*Other* - Standard temperature is zero°C (32 °F); standard pressure is 760 mm Hg (14.7 psia)

**standard volume:** The volume of a gas at standard temperature and pressure; in the United States, this volume is normally expressed in standard cubic feet (SCF)

**stationary grate:** A grate having no moving parts

**steam and water drum:** A pressure chamber located at the upper extremity of a boiler's circulation system in which generated steam is separated from liquid water; this steam is discharged above the water level maintained in the drum

**steaming economizer:** An economizer designed to vaporize some of the fluid passing through it

**steam quality:** The percentage (by weight) of vaporized water contained in a steam and water mixture

**steam scrubber:** A series of screens, wires, or plates through which steam is passed to remove entrained moisture

**steam separator:** A device for removing the entrained water from steam

**steam washer:** A device in a steam drum that exposes steam to water having a lower concentration than the boiler water; this process reduces the concentration of solids entrained in the steam

**stoker:** See mechanical stoker

**stoker grate:** See grate

**stove:** See anthracite coal



**subbituminous A:** An ASTM coal classification according to rank; it has a calorific value of between 10,500 and 11,500 Btu/lb on a moist, mineral-matter-free basis

**subbituminous B:** An ASTM coal classification according to rank, It has a calorific value of between 9,500 and 10,500 Btu/lb on a moist, mineral-matter-free basis

**subbituminous C:** An ASTM coal classification according to rank, It has a calorific value of between 8,300 and 9,500 Btu/lb on a moist, mineral-matter-free basis

**superheated steam:** Steam at a higher temperature than its saturation temperature

**superheater:** A mechanism for raising the temperature of a fluid above its saturation temperature using heat from the products of combustion

*convection superheater:* A superheater that draws heat mainly by convection

*radiant superheater:* A superheater that absorbs heat in the form of radiation

*baretube superheater:* A superheater in which the only heat transfer surfaces are the tubes themselves

*fin superheater:* A superheater made up of elements with extended heat transfer surfaces

*girth superheater:* A superheater for a horizontal return tubular boiler in which the superheater elements are wrapped partially around the shell

*interbank superheater:* A superheater located in a space between the tube banks of a bent tube boiler

*interdeck superheater:* A superheater located in a space between the tube banks of a straight tube boiler

*intertube superheater:* A superheater located in a space between the tubes of a boiler convection bank

*overdeck superheater:* A superheater located above the tube bank of a straight tube boiler

*pendant tube superheater:* A superheater arranged such that the heat absorbing elements are suspended vertically

*platten superheater:* A superheater made up of closely spaced tubes forming a plane and arranged so heat is absorbed primarily by radiation

**superheating:** To raise the temperature of a substance above its saturation temperature (boiling point)

**supply tube:** A tube that carries water to the inlet water header

**surface moisture:** Same as free moisture, surface moisture is the moisture found in coal that comes from external sources, such as water seepage, rain, snow, condensation, etc.; this moisture can be removed by ordinary air drying

**suspended arch:** An arch in which refractory blocks are suspended by metal hangers

**swinging load:** A load that changes frequently

**tangential firing:** A firing method in which several burners are located such that their center lines are tangential to an imaginary circle

**tempering air:** Cool air added to a stream of hot air or gas

**tempering moisture:** Water added to coals that have an insufficient moisture content for proper combustion

**theoretical air:** The exact quantity of air required for complete combustion

**total carbon:** Represents the sum of the fixed carbon and the carbon contained in the volatile matter.

**total moisture:** The sum of inherent moisture and surface moisture in coal

**TSG:** Troubleshooting guide

**tuyeres:** Openings through which air is forced into a furnace

**ultimate analysis:** See analysis, ultimate

**underfire air:** Combustion air delivered to the furnace below the primary air openings. Underfire air reduces NO<sub>x</sub> development

**USACERL:** U.S. Army Construction Engineering Research Laboratories

**vapor plumes:** Flue gases that are visible because they contain water droplets

**vertical firing:** An arrangement of a burner such that air and fuel are discharged vertically, either up or down

**volatile matter:** Those products, excluding moisture, that are liberated by a material as gas or vapor, determined by definite prescribed methods that may vary according to the nature of the material; in the case of coal and coke, the methods employed are those prescribed in ASTM Designation D 271

**water screen:** A screen formed by one or more rows of watertubes spaced above the bottom of a pulverized fuel furnace

**water tube:** A boiler tube that carries the water through the combustion chamber

**weathering:** See slacking

**wet scrubber:** An apparatus that uses a liquid to separate particulate matter or contaminants from a gas stream by one or more mechanisms such as absorption, condensation, diffusion, inertial impaction, interception, etc.

**windbox:** A chamber below the grate or surrounding a burner, through which pressurized air is supplied for combustion

**windbox pressure:** The static pressure in the windbox of a burner, firing system, or stoker

**zone:** Divisions of the stoker windbox in which air can be maintained at different and controllable pressures

**zone control:** The control of air flow into individual zones of a stoker

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ATTN: Energy Coordinator  
Tooele Army Depot 84074  
Tobyhanna Army Depot 18466  
Radford Army Ammunition Plant 24141  
Rock Island Arsenal 61299  
Red River Army Depot 75507

FORSCOM 30330  
ATTN: Energy Coordinator  
Installations:  
Fort McCoy 54656  
Fort Drum 13602  
Fort Meade 20755

TRADOC 23651  
ATTN: Energy Coordinator  
Installations:  
Fort Dix 08640

Naval Facilities Engr Command  
ATTN: Facilities Engr Command  
Code1652B

Holston Army Ammunition Plant 37660-9982  
ATTN: Energy Coordinator

Lima Army Tank Plant 45804-1898  
ATTN: Energy Coordinator

Fort Wainwright 99703-5000  
ATTN: Energy Coordinator

Kings Bay Naval Submarine Base 31547-2606  
ATTN: Energy Coordinator

Camp LeJeune USMC 28542-0004  
ATTN: Energy Coordinator

Cherry Point USMC Air Station 28533  
ATTN: Energy Coordinator

Little Creek Naval Base 23521-2438  
ATTN: Energy Coordinator

Norfolk PWC 23511-6098  
ATTN: Energy Coordinator

Puget Sound Naval Shipyard 98314-5000  
ATTN: Energy Coordinator

Tyndall AFB 32403  
ATTN: HQAFCEA/CES

Eielson AFB 99702-1830  
ATTN: Energy Coordinator

Wright Patterson AFB 45433  
ATTN: Energy Coordinitor

Selfridge ANG 48045-5029  
ATTN: Energy Coordinator

Warren AFB 82005-2271  
ATTN: Energy Coordinator

Griffiss AFB 13441  
ATTN: Energy Coordinator

Malmstrom AFB 59402-5000  
ATTN: Energy Coordinator

Defense Construction Supply Center 43216-5000  
ATTN: Energy Coordinator

Defense Electronics Supply Center 45444-5020  
ATTN: Energy Coordiniator

Defense Fuel Supply Center 22060-6222  
ATTN: DFSC-PR

Defense Tech Info Center 22060-6218  
ATTN: DTIC-O (2)

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10/96