SPECIAL REPORT OF RESEARCH

Conducted in

Department of Fuel Technology
College of Mineral Industries
The Pennsylvania State University

COAL CHARACTERISTICS
AND THEIR RELATIONSHIP TO
COMBUSTION TECHNIQUES

by

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STATEMENT OF TRANSMITTAL

The Special Report SR-7 transmitted herewith has been prepared by the Coal Research Section of the Mineral Industries Experiment Station. Each of the Special Reports presents the results of a phase of one of the research projects supported by the Pennsylvania Coal Research Board or a technical discussion of related research. It is intended to present all of the important results of the Coal Board research in Special Reports, although some of the results may already have been presented in progress reports. The following is a list of Special Research Reports issued previously.

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M. E. Bell, Director
M. I. Experiment Station
Preface

This report was recently presented at the 1959 annual AIME Convention at San Francisco, California, as a technical paper. As this comprehensive review of the relationship of coal characteristics to combustion techniques may be of interest to the Pennsylvania Coal Industry, it is being issued as a Special Report to the Coal Research Section. This paper should also serve as a good general background and introduction to the ignitibility project. For example, it is obvious that the significance of ignitibility will vary somewhat with the method of firing. Hence, in the past, methods of calibrating ignitibility in the laboratory have not been very successful in predicting across the board combustion performance. Perhaps it may be necessary to use one type of ignitibility test for fuel bed combustion and others for pulverized or cyclone firing.
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INTRODUCTION

Although the relationship of coal characteristics to the principal types of firing equipment is well known to the experienced coal combustion engineer, apparently there is need for a summary article on this subject. The author has received numerous requests for such a paper from purchasing agents, coal salesmen, coal customers and executives of coal producing and coal consuming companies. Consequently, the scope of this paper will be directed to this audience, with the hope that it may serve also as a review to others actively engaged in the combustion of coal.

The magnitude of this subject is so great that only a brief general treatise is possible. The author realizes that because there are so many special cases and exceptions to the generalities which follow, he is in jeopardy of contradicting himself. It is the hope, however, that the many references cited will prove valuable to those who wish to study the details excluded by necessity, due to space and time limitations. Hence, the characteristics of coals as determined by standard laboratory tests will be discussed; the major types of combustion techniques reviewed; and then the characteristics and firing will be related.

CHARACTERISTICS OF UNITED STATES COALS

The coals of the United States range from lignite to anthracite and each has its own general characteristics. The extensive coal fields of the United States are shown in Figure 1 and the estimated reserve according to rank for each state is illustrated in Figure 2.
<table>
<thead>
<tr>
<th>Billions of short tons</th>
<th>0</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quadrillions of Btu</td>
<td>0</td>
<td>2600</td>
<td>5200</td>
<td>7800</td>
<td>10400</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>North Dakota</th>
<th>Montana</th>
<th>Illinois</th>
<th>Wyoming</th>
<th>Kentucky</th>
<th>West Virginia</th>
<th>Colorado</th>
<th>Utah</th>
<th>Ohio</th>
<th>Missouri</th>
<th>Pennsylvania</th>
<th>Alabama</th>
<th>Washington</th>
<th>New Mexico</th>
<th>Oklahoma</th>
<th>Indiana</th>
<th>Texas</th>
<th>Iowa</th>
<th>Tennessee</th>
<th>Kansas</th>
<th>Virginia</th>
<th>Arkansas</th>
<th>South Dakota</th>
<th>Maryland</th>
<th>Other states</th>
</tr>
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<tr>
<td></td>
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</tr>
</tbody>
</table>

**EXPLANATION**

- **B** Bituminous coal
- **L** Subbituminous coal
- **A** Lignite

- **Anthracite and semianthracite**

Upper bar for each state shows coal reserves by tons; lower bar shows coal reserves by Btu

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1. Conversion factors: anthracite, 12,700 Btu per pound; bituminous coal, 13,000 Btu per pound; subbituminous coal, 9500 Btu per pound; and lignite, 6700 Btu per pound

2. Reserve estimate of States in capital letters supersede earlier estimates by M. R. Campbell

3. Reserve estimate of States in lower case letters were prepared by, or under the direction of M. R. Campbell prior to 1928

4. Includes Arizona, California, Georgia, Idaho, Louisiana, Michigan, North Carolina, and Oregon

**FIGURE 2**

Remaining Coal Reserves of the United States, January 1, 1953, by States, According to Tonnage and Heat Value.
Coals may be classified according to rank as shown by Table 1 from the ASTM Standards on Coal and Coke, D-388-38. (1) The basis of this classification is according to fixed carbon and heating value (Btu per pound) calculated to a mineral-matter-free basis. The high-rank coals are classified according to fixed carbon on the dry basis; and the low-rank coals according to Btu on the moist basis. Agglomerating and slacking (weathering) indices are used to differentiate between certain adjacent groups. While rank is not itself a characteristic it does signify certain characteristics that accompany a class of fuel. Anthracite, for example, immediately implies a hard, free-burning, smokeless coal of low volatile matter, usually having an ash of high fusibility.

Coals may also be classified according to grade as described by ASTM Designation D-398-37. (1) This quality classification is determined by size, calorific value, ash, ash-softening temperature and sulfur. This type of classification is not used as extensively by the industry as the rank classification. Figure 3 shows the heat value of different ranks compared to proximate analyses.

Coals may also be classified by sizes, as shown in Tables 2A and 2B, and sizes can be on both top and bottom limits. If this is done, then the coal is called "double screened"; otherwise, either top or bottom sizes can be specified as a limit. Bituminous coal sizing varies from field to field and depends upon the market demand. The

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1 Numbers in parentheses refer to the Bibliography at the end of the paper.
### TABLE 1

**Classification of Coals by Rank**

<table>
<thead>
<tr>
<th>Class</th>
<th>Group</th>
<th>Limits of Fixed Carbon or Btu Mineral-Matter-Free Basis</th>
<th>Requisite Physical Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthracitic</td>
<td>1. Meta-anthracite</td>
<td>Dry F.C., 98% or more (Dry V.M., 2% or less)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. Anthracite</td>
<td>Dry F.C., 92% or more and less than 98% (Dry V.M., 8% or less and more than 2%)</td>
<td>Nonagglomerating b</td>
</tr>
<tr>
<td></td>
<td>3. Semi-anthracite</td>
<td>Dry F.C., 86% or more and less than 92% (Dry V.M., 14% or less and more than 8%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1. Low vol. bituminous</td>
<td>Dry F.C., 78% or more and less than 86% (Dry V.M., 22% or less and more than 14%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. Med. vol. bituminous</td>
<td>Dry F.C., 69% or more and less than 78% (Dry V.M., 31% or less and more than 22%)</td>
<td></td>
</tr>
<tr>
<td>Bituminous</td>
<td>3. High vol. A bituminous</td>
<td>Dry F.C., less than 69% (Dry V.M., more than 31%); and moist c Btu, 14,000 e or more</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. High vol. B bituminous</td>
<td>Moist c Btu, 13,000 or more and less than 14,000 e</td>
<td>Either agglomerating or non-weathering {</td>
</tr>
<tr>
<td></td>
<td>5. High vol. C bituminous</td>
<td>Moist Btu, 11,000 or more and less than 13,000 e</td>
<td></td>
</tr>
<tr>
<td>Sub-bituminous</td>
<td>1. Subbituminous A</td>
<td>Moist Btu, 11,000 or more and less than 13,000 e</td>
<td>Both weathering and nonagglomerating</td>
</tr>
<tr>
<td></td>
<td>2. Subbituminous B</td>
<td>Moist Btu, 9500 or more and less than 11,000 e</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Subbituminous C</td>
<td>Moist Btu, 8300 or more and less than 9500 e</td>
<td></td>
</tr>
<tr>
<td>Lignitic</td>
<td>1. Lignite</td>
<td>Moist Btu, less than 8300</td>
<td>Consolidated</td>
</tr>
<tr>
<td></td>
<td>2. Brown coal</td>
<td>Moist Btu, less than 8300</td>
<td>Unconsolidated</td>
</tr>
</tbody>
</table>

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1. Coal Resources of the U. S. Geological Survey Circular 293J, Department of Interior.

a. This classification does not include a few coals which have unusual physical and chemical properties and which come within the limits of fixed carbon or Btu of the high-volatile bituminous and subbituminous ranks. All of these coals either contain less than 48% dry, mineral-matter-free fixed carbon or have more than 15,500 moist, mineral-matter-free Btu.

b. If agglomerating, classify in low-volatile group of the bituminous class.

c. Moist Btu refers to coal containing its natural bed moisture but not including visible water on the surface of the coal.

d. It is recognized that there may be noncaking varieties in each group of the bituminous class.

e. Coals having 69% or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of Btu.

f. There are three varieties of coal in the high-volatile C bituminous coal group, namely, Variety 1, agglomerating and nonweathering; Variety 2, agglomerating and weathering; Variety 3, nonagglomerating and nonweathering.
FIGURE 3

Heat Value of Coal of Different Ranks Compared to Proximate Analysis.

1 Coal Resources of the United States, Geological Survey Circular 2931, Department of Interior.
### TABLE 2-A

Sizes of Bituminous Coal and Their Application

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Run of Mine (ROM)</td>
<td>No screening, as if from mine. Used for domestic and power plant markets.</td>
</tr>
<tr>
<td>2.</td>
<td>5-inch lump</td>
<td>Size not passing a 5-inch round screen opening. Used for hand-fired domestic and industrial markets.</td>
</tr>
<tr>
<td>3.</td>
<td>5 x 2 egg</td>
<td>Size that passes 5-inch opening but is retained on 2-inch opening. Used in gas producers, domestic markets.</td>
</tr>
<tr>
<td>4.</td>
<td>2 x 1-1/4 nut</td>
<td>Size passing 2-inch hole screen but retained on a 1-1/4-inch screen. Used in small industrial stokers and domestic markets.</td>
</tr>
<tr>
<td>5.</td>
<td>1-1/4 x 3/4 stoker</td>
<td>Size passing 1-1/4-inch hole but retained on a 3/4-inch opening. Small industrial stokers and domestic markets.</td>
</tr>
<tr>
<td>6.</td>
<td>3/4-inch x 0 slack</td>
<td>Size passing through 3/4-inch hole screen. Used for pulverized coal units and industrial stokers.</td>
</tr>
</tbody>
</table>

### TABLE 2-B

Standard Anthracite Sizes and Trade Names

<table>
<thead>
<tr>
<th>Trade Name (larger Sizes)</th>
<th>Round Hole Mesh (Inches)</th>
<th>Trade Name (Buckwheat Sizes) Mesh (Inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broken</td>
<td>4-3/8 to 3 or 3-1/4</td>
<td>No. 1 9/16 to 5/16</td>
</tr>
<tr>
<td>Egg</td>
<td>3 or 3-1/4 to 2-7/16</td>
<td>No. 2 5/16 to 3/16</td>
</tr>
<tr>
<td>(Rice)</td>
<td></td>
<td>No. 3 3/16 to 3/32</td>
</tr>
<tr>
<td>Stove</td>
<td>2-7/16 to 1-5/8</td>
<td>No. 4 3/32 to 3/64</td>
</tr>
<tr>
<td>Chestnut</td>
<td>1-5/8 to 13/16</td>
<td>No. 5 Through 3/64</td>
</tr>
<tr>
<td>Pea</td>
<td>13/16 to 9/16</td>
<td></td>
</tr>
</tbody>
</table>
common sizes and their main uses are outlined in 2A. Anthracite is usually available in many sizes at the colliery, and Table 2B summarizes standard sizes and names.

Although rank, grade, and size designations help identify and describe a coal in question, there still remain other characteristics such as indicated by moisture, free swelling index, grindability tests, etc. A bituminous coal information chart (Table 3) suggested for use in studying the available coals in a region, lists origin, chemical and physical characteristics. Even this more comprehensive list does not completely spell out all the characteristics of a heterogenous material like coal. For example, plastic properties, frequently referred to as the caking behavior, are lacking. Frankly, tests describing this quality or behavior have in the past defied predicted performance on the various types of combustion equipment. The Bituminous Coal Research Laboratory is currently conducting an investigation regarding the plasticity of coals' behavior during combustion in beds. Likewise the ignitibility or reactivity index of coals remains somewhat of a mystery and only limited correlation between laboratory test results and plant combustion has been obtained. The ignition temperature of coal is an empirical rather than an absolute value and depends almost entirely upon the test used and the combustion technique employed. Volatile matter on a dry-ash-free basis is itself as good an indicator of ignitibility as are most tests. Although a substantial amount of research work has been devoted to the subject of ignitibility, no ASTM method is available to calibrate this important characteristic. The Coal Combustion Laboratory, Department of Fuel Technology, The Pennsylvania State University,
TABLE 3

BITUMINOUS COAL SPECIFICATIONS FOR COMBUSTION EQUIPMENT

Utilization flexibility for the proposed combustion equipment is determined from the average characteristics shown below, which constitute the range in quality of typical coals and sizes economically available at the destination indicated. Performance guarantees are calculated on one coal and steaming capacities specified for each of the others.

<table>
<thead>
<tr>
<th>Origin</th>
<th>Producing Dist. No.</th>
<th>State</th>
<th>Coal Region</th>
<th>Seam</th>
<th>Originating Railroads</th>
<th>Transportation Charges</th>
<th>Delivering RR. or Dock</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIZE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
has recently initiated a research project to study the ignitibility of Pennsylvania bituminous coals in an effort to correlate this illusive characteristic with combustion performance.

Rose (18) recently discussed the 'Free-swelling Index of U. S. A. Coals and Causes for the Wide Range in Values.' Figure 4 shows the magnitude and distribution of the F. S. I. according to the 18 major coal producing states for 4500 coals purchased by the United States government 1948-57. (U. S. Bureau of Mines Analyses) Many combustion engineers attempt to predict performance by the use of F. S. I., a rather simple test. Extreme caution must be used, however, when this is done as close confirmation is required and then only limited success can be expected. The combination of F. S. I. and size consist is being used more and more in conjunction with combustion performance to assist in the selection of coals, particularly for traveling grate stokers. Size consist is a most important characteristic. Tate (23) ably describes this as follows: "Size consist is the proportion of each group or particles within specified size limitations, from small to large, which in the aggregate make the whole."

De Lorenzi (8) states: "The most outstanding burning characteristics of coal are the properties of caking exhibited by some coals and its opposite, free-burning, shown by others. These two properties, more than any other factors govern the selection of coal-burning equipment. As important as this characteristic is, it must be admitted that there is no test which will permit it precise evaluation in the laboratory. The free-swelling index test is an approach to describing this characteristic but it is by no means an absolute value."
Figure 4

FREE-SWELLING INDEX OF 4,500 COALS PURCHASED BY

FREE-SWELLING INDEX

BITUMINOUS COAL RESEARCH, INC.
H.J. ROSE, PGH., PA. 8-25-1958
Caking coals, when heated in a furnace, pass through a plastic state during which the individual pieces fuse together. Free-burning coals do not fuse together when heated but tend to burn in separate pieces. Thus it is apparent that there are many gradations between the two extremes of caking and free-burning and for lack of something better, such general terms as heavy, moderately coking and matting are used.

Unquestionably, the constituents of the ash are coming more and more under the scrutiny of the coal customer, equipment designer and combustion engineer. The maintenance of furnace walls and tubes as a result of fireside deposits has captured the attention of all who are affiliated with such troublesome problems. While ash characteristics fall into a class by itself and are separate from burning characteristics, nevertheless they must be considered in the overall operation of the steam generator. No attempt will be made to cover this complex problem which still requires much additional investigative work.

Cyclone firing has emphasized the importance of slag viscosity of coal ash. The Babcock and Wilcox Company has released instructions for "Evaluation of Slag Viscosity Characteristics of Coal for Cyclone Firing". (3)

Barkley (4) compiled information supplied by an ASTM D-5 Coal and Coke Subcommittee XVII on the Significance of Laboratory Tests of Coal and Coke for Combustion. This comprehensive study spells out the importance of laboratory results with types of firing. In many cases, however, certain test results do not have any definite significance for the type of firing under discussion. Barkley states:
"The purpose of these papers is to answer, in so far as practicable, questions as to the significance of ASTM laboratory tests in the combustion of coal and coke. Attempt is made to show in what way these tests may be of value in connection with the use of the fuel. It should be realized that the subject matter is not scientifically clean-cut and definite, and in many instances the best that can be written is only relative or indicative." The laboratory tests and classifications that were considered by Barkley et al are shown in Table 4.

The most important characteristics of coal then are: degree of caking, size consist, moisture content, physical hardness, ash characteristics, volatile matter, and ash content. These affect combustion and the selection of a combustion technique best suited for a particular coal. Admittedly, fuel costs often strongly influence the selection of the type of coal or equipment, and coal users are sometimes willing to sacrifice optimum performance to gain an economic advantage.

**COMBUSTION TECHNIQUES**

The fundamental combustion techniques are fuel bed burning, suspension burning and cyclone burning. Basic fuel beds may be defined as follows: (20) An underfeed bed is one in which the fuel and air move in the same direction, in contrast with an overfeed bed in which the fuel and air move in opposite directions, and the cross-feed bed in which the fuel moves in a direction normal to the flow of air. Some combustion engineers prefer to classify the traveling stoker fuel bed as the front-feed method, while others call it an overfeed bed. Thus, there exists
TABLE 4

LABORATORY TESTS AND CLASSIFICATIONS

Laboratory Tests on Bituminous Coal

2. Ultimate analysis (C - H - O - N - S - ash).
3. Calorific value (B.t.u.).
4. Fusibility of ash (initial deformation - softening - fluid).
5. Analysis of ash (phosphorus).
6. Fineness of powdered coal (size consist).
7. Grindability.
8. Drop-shatter test (size stability and friability).
10. Screen analysis (size consist).
11. Weight per cubic foot of crushed coal.
12. Dustiness of coal.

Classification

15. Rank (low- and medium-volatile bituminous, high-volatile A bituminous, etc.).
16. Variety (common banded, splint, cannel, and boghead).

Laboratory Tests on Anthracite

2. Ultimate analysis (C - H - O - N - S - ash).
3. Calorific value (B.t.u.).
4. Fusibility of ash (initial deformation - softening - fluid).
5. Analysis of ash (phosphorus).
6. Fineness of powdered coal (size consist).
7. Grindability.
8. Screen analysis (size consist).

Laboratory Tests on Coke

2. Ultimate analysis (C - H - O - N - S - ash).
3. Calorific value (B.t.u.).
4. Fusibility of ash (initial deformation - softening - fluid).
5. Analysis of ash (phosphorus).
6. Volume of cell space of lump coke.
7. Drop-shatter test (property to withstand breakage).
8. Tumbler test (resistance to degradation by abrasion).
9. Sieve analysis (size consist).
10. Weight per cubic foot.
11. Dustiness of Coke.
a difference of opinion and terminology among combustion engineers.

There are few decisive examples of these basic fuel beds in the modern industrial stoker. The single and multiple retort stokers are examples of the underfeed bed; the spreader stoker, the overfeed bed; and the traveling grate, the cross-feed type. In reality, most stoker fuel beds embody more than one basic type.

The spreader stoker combines suspension burning with overfeed fuel bed firing and the amount of each present will vary according to the percentages of fines present in the coal. Pulverized coal firing, on the other hand, employs true suspension burning. Cyclone firing falls into a class by itself. Crushed coal (1/4 x 0) is introduced tangentially into an inclined water-cooled cylinder, where a high speed whirling action of the heated combustion air and entrained coal attains very high furnace temperature and heat releases. The cyclone furnace does not have a conventional fuel bed but the coal is partly burned in suspension and partly as it adheres to the molten slag-lined cylindrical furnace.

**REVIEW OF INDUSTRIAL COAL BURNING EQUIPMENT**

There are six basic industrial coal burners marketed today. (19, 20) They are: single retort underfeed stokers, multiple retort underfeed stokers, spreader stokers, traveling stokers, pulverized coal burners, and cyclone furnaces. There is considerable overlapping of both the generating capacity and the type of fuel that these machines will handle. All factors must be weighed carefully and even then the experts cannot always agree what is best for a given situation. Recently,
special kinds of small stokers such as the Fire-Jet stoker and the oscillating or vibrating stoker have reached the market. Intended for the commercial and small industrial market, they employ the cross-feed type bed, and will compete with the single retort stokers. These new stokers will not be discussed in this paper.

**Single Retort Underfeed Stokers (side-dump)** This well known machine is the oldest member of the family. It employs the underfeed bed and is characterized by a single retort. In addition to the primary feeder which may be either a screw or a ram, there is also a secondary distributing ram. Moreover, the machine may have a moving or fixed grate bar with or without a dump grate. The mechanical interpretation of this method of burning coal differs in constructional details among the various manufacturers. Although this method of combustion has been established for over fifty years, constant advances have been made in the simplification of machinery, drives, and the use of modern metals. There has also been a special effort to reduce maintenance through improved design. The single retort stoker has been built to serve boilers up to 40,000 lbs steam per hour but they are now generally sold for capacities of less than 30,000 lbs steam per hour. Anthracite stokers are most popular in the range of 1,000 to 10,000 lbs steam per hour and use #1 and #2 buckwheat coal. Bituminous stokers with stationary grates usually handle boilers up to 10,000 lbs steam per hour, while the moving grate bars which allow a better distribution on wider width of furnace, will go up to 35,000 lbs steam per hour with caking and free burning coals. The importance of the single retort stoker in the overall combustion picture cannot be minimized and numerically, they exceed
all other stokers. For certain types and sizes of boilers and load conditions, there is no other machine which can be substituted for it. Table 5, a Guide to Stoker Application, summarizes data for all stokers. Table 6, Industrial Combustion Equipment Applications, summarizes the relationship of ranks of coal to method of firing.

**Multiple Retort Underfeed Stokers (end-dump)** These heavy duty stokers, once the top favorite in central heating and power stations, have been pushed to the background in new sales. First, pulverized firing supplanted these machines in the large capacities of 200,000 lbs steam per hour up. Later the spreader stoker followed and because of its lower first cost, lower maintenance and greater flexibility, was given preference in the 200,000 lbs steam per hour down category. However, numerous multiples are still consuming large quantities of coal.

The fundamental principle of underfeed firing is preserved to a large extent in the multiple machine but the construction of the single and the multiple stokers is decidedly different. Coal fired in the multiple machine flows from an elevated point at the front boiler to a lower point at the bridgewall. Thus the flow of coal is in a straight line whereas in the single retort, the coal not only flows from front to back, but from side to side. The multiple retort also operates with rather thick fuel beds, the depth varying from 12 to 24 inches. The steaming range of the multiple retort stoker extends anywhere from 30,000 to 500,000 lbs steam per hour.

There are three main methods of ash discharge: the older dump type, the rotary ash discharge, and the continuous ash discharge.
<table>
<thead>
<tr>
<th>Types of Coal</th>
<th>Stoker</th>
<th>Typical Recommended Coal Sizing</th>
<th>Typical Allowable Burning Rates/sq. ft. of Nominal Grate Area per Hour</th>
<th>Range of Boiler Capacity - lbs steam per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthracite and Semi-anthracites</td>
<td>Single-Retort Underfeed (Special Design)</td>
<td>No. 1 and No. 2 Buck</td>
<td>16-24 lbs depending on stoker width**</td>
<td>1,000 to 10,000</td>
</tr>
<tr>
<td></td>
<td>Traveling Grate</td>
<td>#3 or #4 Buck</td>
<td>320,000 Btu</td>
<td>10,000 to 200,000</td>
</tr>
<tr>
<td>Bituminous Coal Caking Type (Eastern Areas)</td>
<td>Single-Retort Underfeed (Stationary Grate)</td>
<td>2-in. nut and slack*</td>
<td>20-25 lbs depending on stoker width**</td>
<td>1,000 to 10,000</td>
</tr>
<tr>
<td></td>
<td>Single-Retort Underfeed (Moving Grate)</td>
<td>2-in. nut and slack*</td>
<td>20-35 lbs depending on stoker width**</td>
<td>1,000 to 35,000</td>
</tr>
<tr>
<td></td>
<td>Spreader</td>
<td>1-1/4 to 1-1/2 in. nut and slack*</td>
<td>550,000 Btu</td>
<td>5,000 to 200,000</td>
</tr>
<tr>
<td>Bituminous Coal Free-burning type (Midwestern Areas)</td>
<td>Spreader</td>
<td>3/4-in. nut and slack*</td>
<td>550,000 Btu</td>
<td>5,000 to 200,000</td>
</tr>
<tr>
<td></td>
<td>Chain Grate</td>
<td>1-in. nut and slack*</td>
<td>500,000 Btu</td>
<td>10,000 to 200,000</td>
</tr>
<tr>
<td></td>
<td>Single-Retort Underfeed</td>
<td>1-in. to 1-1/2-in. nut and slack*</td>
<td>500,000 Btu</td>
<td>10,000 to 200,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20-30 lbs depending on stoker width**</td>
<td></td>
</tr>
<tr>
<td>Western sub-bituminous Coals and Lignites</td>
<td>Spreader</td>
<td>1-1/4 or 1-1/2-in.</td>
<td>550,000 Btu</td>
<td>5,000 to 200,000</td>
</tr>
<tr>
<td></td>
<td>Traveling Grate</td>
<td>1-in. nut and slack*</td>
<td>500,000 Btu</td>
<td>10,000 to 200,000</td>
</tr>
</tbody>
</table>

* Not more than 50 percent slack should pass through 1/4-in. round mesh screen.

** Allowable burning rate varies with stoker width.

<table>
<thead>
<tr>
<th>Method of Firing</th>
<th>Anthracite</th>
<th>Bituminous-Caking (Eastern Area)</th>
<th>Bituminous, Free-burning (Midwestern)</th>
<th>Sub-bituminous and Lignites (Western)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-Retort Underfeed</td>
<td>1,000-10,000</td>
<td>1,000-35,000</td>
<td>5,000-30,000</td>
<td></td>
</tr>
<tr>
<td>Multiple-Retort Underfeed</td>
<td>30,000-500,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spreader Stokers</td>
<td>5,000-200,000</td>
<td>5,000-200,000</td>
<td>5,000-200,000</td>
<td></td>
</tr>
<tr>
<td>Traveling Grate</td>
<td>10,000-200,000</td>
<td>10,000-200,000^1</td>
<td>10,000-200,000</td>
<td></td>
</tr>
<tr>
<td>Chain Grate</td>
<td></td>
<td>10,000-200,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulverized Coal^3</td>
<td>60,000-1,000,000</td>
<td>60,000-1,000,000 and over</td>
<td>60,000-1,000,000 and over</td>
<td></td>
</tr>
<tr>
<td>Cyclone Furnace^2</td>
<td>75,000-350,000 per furnace</td>
<td>75,000-350,000 per furnace</td>
<td>75,000-350,000 per furnace</td>
<td></td>
</tr>
</tbody>
</table>

NOTE:  
^1 Limited case.  
^2 Certain coals with proper ash fusion.  
^3 Steaming range may exceed maximum figures shown.  

Many existing plants are modernizing or rehabilitating these machines. Such important accessories as armored sidewall cooling tuyeres, over-fire air, zoning of air, rear arches, preheated air, and automatic ash removal are being added. One very decided advantage of this stoker is its very low stack discharge.

**Spreader Stokers** The spreader stoker reached the market some thirty years ago, and it has soared rapidly in sales. Spreader stoker firing combines the principle of suspension burning and the non-agitated fuel bed. The coal is mechanically thrown or pneumatically blown from a point above the bed so as to spread the fuel evenly over the grate. The ultra-fines are burned in suspension while the larger particles reach the grate in an oxidized condition, there to be consumed by under grate air. Due to this preoxidation or partial burning of the coal during the feeding operation, caking or non-caking characteristics have little or no effect on the performance of this stoker.

Spreaders may be purchased in capacities from 5,000 to 200,000 lbs steam per hour and up. In the smaller units pneumatic firing dominates, while in the larger ones the mechanical spreaders prevail. The grates for this machine may be of the stationary, dumping, or continuous discharge type. The stationary type is most generally used when the ash content of the coal is low and the steaming capacity in the low range. The middle range uses the dump-type grate, whereas the larger range uses the continuous ash discharge grate. About 1939, the combination of spreader firing with the reverse traveling grate resulted in an extremely successful development. The furnaces for these stokers must be large enough for the fines and volatile matter
to burn out before entering the tube passages, and the furnace unit heat liberation must not be too low else poor ignition and smoke result during low load.

Poor engineering and lack of adequate dust collectors have often resulted in very disappointing performance. With some installations the cinder loss is so great that unless it is collected and reinjected into the furnace, not only will efficiency suffer but a definite public dust nuisance will result. Overfire jets have been applied with great success using either steam or compressed air to increase the turbulence and thus reduce smoke. Most of the new stokers today are installed with built-in overfire jets.

**Traveling Stokers** The traveling type stoker resembles and is, in fact, an endless conveyor. The topside supports the fuel bed and is composed of cast iron sections or keys attached to carrier bars which are in turn connected to the drive chain. The coal is uniformly spread on the flat, slow moving grate carrying the green coal from the hopper through zones of drying, heating, distillation, ignition, intense combustion, and finally the burning out zone. The ashes are spilled over the opposite end of the firebox from the feed hopper. The thickness of the bed is adjusted by the depth feed regulator near the hopper and the speed is so regulated as to allow the fuel to be completely spent before it leaves the furnace. There even seems to be renewed interest in the traveling stoker for the caking coals with swelling indexes up to 7-1/2 with proper size consist—usually a coarse coal. Freedom from acute fly ash problems is a very desirable feature. This stoker is the only one suitable for the large industrial anthracite-fired boilers which range from 10,000 up to 200,000 lbs steam per hour.
The relationship of furnace and boiler design is very important in all stokers but especially so with the traveling grate. Furnaces should be designed to give prompt ignition and stabilization of the bed and to prevent stratification of gases as they leave the beds and enter the furnaces and boiler tube passages on different sections of the grate. Boilers should be designed to eliminate high carbon losses in the refuse and incorporate reinjection when the fly material carry-over is substantial. Perhaps the most important feature of the furnace design is the front and rear combination arches. These indispensable accessories perform the important function of accelerating ignition through radiation and reflection of heat, deposition of incandescent fuel from the rear portion to the incoming fuel, and bringing flame and gas at high temperatures in contact with the entering fuel. Recent trends in furnace design, however, eliminate the arch by the use of air jets to accelerate ignition and simulate arch conditions. This is an important development which lowers initial cost and eliminates arch maintenance.

**Pulverized Firing** The first successful commercial application was made to a cement kiln in 1895 in a plant of the Atlas Portland Cement Company. Although this was a guarded trade secret until 1900 as was the practice in those days, yet it proved so successful that by 1903, practically all the cement kilns in coal burning areas had been converted to coal. The burning of pulverized coal actually can be traced back to 1867; however, from that date until 1913 practically every effort to burn it under steam boilers was a failure. The first complete pulverized-fired central station was the Lakeside station of the Milwaukee Electric Railway and Electric Light Company which was completed in 1920.
Prior to 1925, almost all pulverized coal firing was the storage system type in which the coal was pulverized, stored, then refed as needed into the air stream for the burners. However, in 1925 the first direct system was installed, in which the coal, after pulverization, is kept in the air stream until injected into the furnace. Since that time, the trend has increased to direct firing until now all new systems use this method. Many advancements related to this method quickly followed and by 1935, pulverized coal firing for power boilers had reached such wide acceptance that it largely supplanted underfeed stoker firing for new boilers larger than 200,000 lbs steam per hour.

Today more coal is consumed by this type of firing than by any other method. Pulverized firing is true suspension burning and more nearly approaches gaseous combustion than any other method of burning coal.

For good results, the coal must be ground almost to the fineness of face powder. Coal should be 98% through 50 mesh and between 65 and 85% through 200 mesh screen depending upon the volatile matter of the coal, types of furnaces, length of flame travel, furnace temperature, and other factors. Before coal is ready for the pulverizer it should pass through a primary crusher and over a magnetic pulley and other suitable means of removing the tramp iron. The upper size of the coal bed to the mill will vary with the type and size of the mill and usually ranges from 3/4 to 1-1/4 inches. Coal cannot be satisfactorily pulverized until it is dry. Modern pulverizers combine drying, pulverization, and classification phases in one integrated piece of equipment.
Furnaces for pulverized firing are divided into the wet-bottom (slag tap) or the dry-bottom types, and the selection depends largely upon the ash characteristics of the fuel to be fired. The quantity of the ash leaving with the furnace exit gases is from 40 to 60% of the total ash fired for the wet bottom units, compared to 80 to 90% for the dry-bottom furnaces. Recently a special kind of slag tap furnace called the Turbo-Furnace (7, 9, 12) was developed which has reduced fly ash emission drastically. By reinjection of fly ash recovered from the combustion gases, all the ash becomes slag, eliminating a costly disposal problem. Many advantages are claimed for the Turbo-Furnace including low furnace exit temperature and pressurized operation.

The Cyclone Furnace The cyclone furnace is essentially an inclined cylinder of watercooled construction, the interior surface of which is lined with plastic chrome ore. Burning crushed coal, its basic principle of operation utilizes the slagging characteristics of the coal ash. Coal is introduced with primary air to the furnace at a velocity of 250 mph. Entering the primary burner through a tangential inlet, the fuel particles are whirled into the furnace and discharged into the larger cylinder (5 to 10 feet in diameter, with a length approximately one and one-third times the diameter) of the cyclone burner where the whirling effect is increased by tangential admission of secondary air at high velocity.

Combustion takes place within the large cylinder with final discharge of gases through a re-entrant water-cooled throat at the front of the secondary furnace. The coal burns at a high rate of heat release, the ash constituents being melted to liquid slag at approximately 2800°F.
The film of slag, which adheres to the cylindrical wall of the furnace, flows gradually to the slag taps at both sides of the furnace. The rate of heat release is very high, about 500,000 Btu per cu. ft. per hour in the primary furnace, the furnace temperature being more than 3000°F. Approximately 15% of the total combustion air enters at 250°F as primary air with the coal; 80% enters at 750°F, as secondary air; 5% enters as tertiary air. Secondary air enters the cyclone burner at tangential velocities of 20,000 to 30,000 ft. per minute. The small quantity of tertiary air is admitted along the longitudinal axis of the primary burner to prevent recirculation of fine coal at this point. This also provides adequate air for combustion of fine particles which may travel along the axis of the burner vortex. This technique eliminates coal pulverizers and minimizes the fly ash collection system because 85 to 90% of the ash is removed as slag.

THE RELATIONSHIP OF COAL CHARACTERISTICS TO THE COMBUSTION TECHNIQUE (8, 20)

Single Retort Underfeed Stokers The single retort stoker has burned everything from anthracite to lignite although it was primarily designed for burning caking bituminous coal. It is most widely used for burning the eastern caking and semi-caking bituminous coals and midwestern free burning coals. Despite its versatility, peak performance is not obtainable with coals having extreme characteristics, such as excessively high ash content, low ash fusion temperatures, very fine size consist, and with strongly caking coals which are difficult to ignite.

Size consist (5) is one of the chief factors influencing the performance of these machines and is as important as the nature of the
coal itself. If there is a high concentration of fines (minus 1/4-in.), combustion will be retarded. Nut and slack coal, with a top size of 1-1/4 to 2-in., is most commonly used, and not more than 40% of the coal should be below 1/4-in. When the coal is friable, larger top sizes, even mine-run, have been used without difficulty. The use of double screened coal is not usually required and occasionally, when too coarse, is inadvisable. Some fuels, however, are so stubborn to the combustion process that the removal of fines becomes mandatory, especially with stationary grates and high burning rates. Ash content of bituminous coal should be not less than 4% and not more than 15% for good operation. Number 2 buckwheat seems to be the popular size for anthracite stokers. The free burning nature of anthracite allows a continuous discharge of ash over the side of shortened side dump grates into the pits. The size of anthracite is much more critical than that of bituminous coal and the coal preferably should contain a limited amount of undersize and oversize material. The distribution of coal on the grates is chiefly affected by moisture content and size consist. Well prepared coals which are more inclined to be uniform from shipment to shipment, give best results and eliminate frequent adjustment of the distributing ram.

**Multiple Retort Underfeed Stokers** The ideal fuel for multiple retort stokers is coal that tends to coke but will break into porous fuel beds when agitated by the machine. The ash content should not be below 4 percent because some ash is necessary for protection of the grates against high temperatures; and conversely, the ash content should not be too high. Ash fusion temperature of 2400°F. is preferred and the iron oxide content of the ash should be below 15 percent for low ash fusion coals.
Obviously the ideal fuel is not always obtainable or economical. A wide range of coals is therefore being used, and with proper precautions, good operation is possible. A non-agglomerating coal should be avoided as this will cause drifting of coal on the fuel bed resulting in high carbon losses and generally poor performance. During periods of fuel shortages, anthracite and coke have been mixed with caking bituminous coal up to about 35 percent. Medium and high-volatile coals are preferred. Although low-volatile bituminous coals can be burned, they require more grate area due to the fact that less of the coal is burned as volatile matter in the combustion space.

Segregation of sizes is serious and affects the overall operation. In mixing several types of coal, it is important that segregation be held to a minimum, otherwise the drifting coals may separate from the caking ones and concentrate in certain areas. The size range of the fuel is likewise important. Coal with a top size ranging from 3/4 to 2-in. is preferable and it should not contain more than 50 percent of fines that will pass through a 1/4-in. round-hole screen. Volatile matter between 20 and 30 percent and ash content of 6 to 8 percent are additional specifications for the ideal fuel.

**Spreader Stokers** The outstanding feature of the spreader machine is its ability to burn a wider range of coal than any other stoker. Although the performance of any burner is best when quality coal is used, this method of firing was developed primarily to utilize the lower grades of coal with high ash content and low fusion. Its performance with heretofore troublesome coals has been very successful. It can burn everything from semi-anthracite to lignite and even
anthracite has been burned successfully on spreader stokers in mixtures of 25 to 50 percent.

Of all the coal characteristics, size of fuel is probably the most important with this stoker. The thin, quick burning fuel bed of the spreader stoker requires a small size coal. Since only part of combustion occurs on the stationary bed, it is necessary to provide sufficient burning volume for the volatile matter and fines which burn in suspension. They must have ample time to be completely consumed before entering the boiler passage. If the coal is too coarse, it will require a burnout period that will be too long prior to dumping of the ash, and this will result in high carbon losses in the ash pit. An ideal top size for the fuel is 3/4-in. with sizes up to 1 or 1-1/2-in. within the range of suitability. Coarse or closely sized fuel is not desirable, since it has a tendency to pile up on one portion of the grate. The coal should be of such size that the largest pieces can be burned in about one minute. The smaller the top size, the greater the percentage of fines (unless the size consist is modified) and more suspension burning. The use of extremely fine coal may produce satisfactory burning conditions but it may also lead to a very high cinder carryover. Fly-cinder (part ash and part carbon) will be deposited in the boiler passes and the remainder discharged with the flue gas. The combustible matter in the cinder carryover may vary from 20 to 60 percent being almost in direct proportion to the rate of burning. From 25 to 50 percent of the material collects in the boiler passes, from whence it may be recovered if some type of cinder removal system is provided. With adequate cinder recovery and other favorable conditions, the carryover heat loss may be
reduced as low as 2 to 3 percent rather than the customary 10 to 15 percent.

**Traveling Stokers** The chain-grate and traveling-grate are probably the most versatile stokers in regard to fuel choice. Every type of solid fuel of suitable size, such as wood, peat, lignite, bituminous coal, anthracite, coke breeze, and carbon can be burned on these machines with the exception of strongly caking bituminous coal. Caking coals need agitation of the fuel bed, which the traveling stoker does not provide. Fuels most widely used on this burner are as follows:

1. Anthracite produced at mines, reclaimed from rivers, silt and culm from slurry dams;
2. Semi-anthracite;
3. Bituminous coal (non-caking or free burning);
4. Sub-bituminous coal;
5. Lignite;
6. Coke breeze.

1. **Anthracite.** The traveling stoker is almost the exclusive machine for industrial use of small sizes of anthracite such as No. 2, 3, and 4 buckwheat, river bed anthracite, silt and culm.

2. **Semi-anthracite.** This coal is not quite as hard as true anthracite and its volatile content is higher. It makes excellent fuel for traveling grate and chain grate stokers. The higher volatile matter expedites ignition and combustion so that No. 2 buckwheat and larger sizes may be used, whereas the burnable sizes of true anthracite usually stop at No. 2 buckwheat for these machines. The extent of the semi-anthracite deposits is relatively small and the coal is used, for the most part, near the localities where it is found.

3. **Bituminous Coals.** Non-caking and free burning bituminous coals are generally used. Practically all of the coals west of the Appalachian region are excellent fuels for the traveling stoker. A few
coals east of the Appalachian range, which form a weak coke structure, are also satisfactory. Border-line coals should have a top size of 3/4-in. with no fines. Best results with bituminous coal are accomplished through "tempering" of the fuel. The addition of water to raise the moisture content up to 14 to 18 percent reduces carbon losses in the ash pit. "Tempering" is sometimes done by means of steam lances, but best results are obtained by wetting the coal for at least 12 hours before it is burned. A suitable moisture content increases bed stability by agglomerating the fines, but this is accomplished at the expense of retarded ignition.

Proper sizing of bituminous coals is important for best all-around performance. To allow sufficient air to travel through the bed on a natural draft stoker, coal should be sized to pass a 1-1/4-in. to 1-1/2-in. or even a 2-in. round-hole screen. With the forced draft stoker, best results are accomplished with coal that passes a 3/4 or 1-in. round-hole screen. Most suitable midwestern coals are those prepared to pass a 1-in. round-hole screen with not more than 25 to 30 percent undersize below 1/4-in. Waste type fuels do not give the best performance but they do provide cheap steam. For example, a stoker in the midwest is burning washery slurry with 18 percent moisture up to 30 percent ash and 10 percent sulfur. The size of this muck is minus 1/16-in. Despite the unfavorable fuel characteristics, De Lorenzi (8) reports that it was possible to develop a continuous capacity of 45,000 lbs per hour using a grate area of 160-sq. ft., even though at times water from the fuel bed actually ran out of the first stoker compartment.
(4) Sub-bituminous Coals. This type of coal is often called black lignite although it does not possess woody texture and structure. This rank of coal varies greatly in its chemical composition, but nevertheless is suitable for use on chain and traveling grate stokers. These coals ignite easily and burn freely, because of high volatile content. For this reason, larger sizes can be burned than with other coals.

(5) Lignite. With proper furnace design and good sizing of fuel, excellent results are obtained by burning lignite in the rear arch type furnace. Top size for lignite should be 1-1/4-in. with all the fines left in the fuel. Coal bed thickness may be from 8 to 12 inches. Poor grades of lignite, with moisture content of 36 to 40 percent, are difficult to ignite. They should be prepared with a top size of 3/4 to 1-inch.

(6) Coke Breeze. The size of this waste coke produce varies from operation to operation. The volatile matter also varies and these factors must be accounted for in furnace design. Best results are obtained with coke breeze if it is screened to pass through a 1/2-in. round-hole screen, with not less than 20 percent of minus 1/8-in. Minimum size of the breeze is important because it affects the carbon losses. Coke breeze is lower in density than coal and the fines have a tendency to drift off with the gases.

**Pulverized Firing** This combustion technique permits the use of all ranks of coal from anthracite through lignite and thus might be termed our most universal coal burner. Precautionary design measures must be taken, however, to insure that optimum performance is secured. Perhaps the most important characteristics to be scrutinized are: moisture content, relative hardness of the coal, volatile matter, ash
content and ash characteristics. The moisture content, particularly the so-called surface moisture, affects the flowability of the coal through the coal handling system, the flame stability and the combustion efficiency. The ease of pulverization as determined by the grindability index is an important factor affecting mill capacity in addition to other things such as moisture and size of fuel feed to the mill. Ultimately the degree of hardness influences the fineness of the coal supplied to the furnace. The volatile matter affects ignition and flame patterns, and influences the relationship of primary air to secondary air. Low volatile coals require less primary air as the carrying medium of the coal, and lower velocity secondary air for complete combustion in the furnace. Conversely, the high volatile bituminous coal is generally more difficult to grind. The ash content and ash characteristics influence design as well as the degree of undesirable fireside fouling of the furnace walls and heat absorbing surfaces. The slagging behavior of the coal is most important from a design viewpoint. The ash constituents plus a background of operating experience assist the designer in predicting slagging tendencies, although sometimes only actual furnace performance will divulge the true character of the ash.

**Cyclone Firing** The cyclone furnace has not yet attained the ability of the pulverized furnace to burn all kinds of coals. However, it has handled various kinds of coal, including medium and high volatile bituminous and lignite. Tests have indicated that the low volatile coals require higher temperature air from the preheaters which in itself, may be a prohibitive cost factor. Perhaps the two most rigid requirements are the ash fusion characteristics and the size consist. Originally,
coals up to 3/4-in. top size were used, but now the preferred size is four mesh down.

The manufacturer of the cyclone furnace gives a preliminary classification of the coal, made on the basis of the ash fusion temperatures as determined by the (reducing atmosphere) ASTM Method, D-271-48, Sections 27 to 31, inclusive:

1. If the ash softening temperature is below 2400°F., the coal can be considered suitable for cyclone furnace firing from the slag viscosity viewpoint without further information.
2. If the ash softening temperature is within the range 2400°F. to 2600°F., calculation of the viscosity of the ash is necessary to determine whether the coal is suitable for cyclone firing.
3. If the ash softening temperature is above 2600°F., the coal would normally be considered unsuitable.

**CONCLUSION**

The foregoing analyses of coal characteristics versus combustion techniques indicate the following:

(1) The single retort stoker will burn all coals from anthracite to lignite but not necessarily with equal success. Characteristics such as size consist, ash fusibility, and degree of caking nature are important and tend to influence the performance.

(2) The multiple retort stoker performs best with the eastern caking bituminous coals. As in the single retort stoker, size consist, ash fusibility and degree of caking are important characteristics.

(3) Spreader stokers will handle all ranks of coal except anthracite. The size consist appears to be the most important single
characteristic for this stoker. Other characteristics are of secondary importance in coal selection.

(4) Traveling stokers can handle every type of solid fuel with the exception of strongly caking bituminous coals. Recent experiments with careful sizing to eliminate fines indicate that even these coals may be used with proper precautions. The combination of the degree of free burning versus size consist has been carefully studied in selecting coal for this stoker.

(5) Pulverized firing appears to be the most universal method of firing coal because all ranks of fuels may be used. Admittedly, the customer prefers coals which are easiest to burn, most economical to use, and which require the minimum capital outlay. Ease of grindability and ash fusion characteristics are probably the two most important characteristics to watch. The choice of wet or dry bottom furnace and the selection of suitable unit furnace heat release, extend the latitude of the ash fusibility range while still securing optimum performance.

(6) Thus far, cyclone firing has not attained the versatility of pulverized firing in handling as wide a range of coals. The ash characteristics and size consist appear to be the most important fuel characteristic. In spite of the limitations cited above, the manufacturer states (2) that of the 512 million tons of bituminous and lignitic coals mined in the United States in 1950, approximately 70% are considered suitable for use in cyclone furnaces.

Despite the difficulty encountered in trying to correlate the many characteristics of coal with actual performance, an attempt has
been made to summarize the significant relationship in Table 7. The author is well aware of the hazards involved in such an effort, but feels that at least it will stimulate future consideration of this matter. The values in the chart are intended to indicate the relative importance in the overall picture of a given combustion technique. The quality of the characteristics considered is for the average range instead of the extremes. Moreover, the chart should be used more as a "rule of thumb" for design considerations than as a guide for an existing plant, where obviously certain characteristics are of paramount importance due to limiting design deficiencies. Actually, the combination of two or more characteristics change the significance of a single item. For instance, size consist and caking qualities, or size consist and moisture content often present an entirely different degree of relative importance than when considered separately.
TABLE 7
COAL CHARACTERISTICS SIGNIFICANCE CHART FOR COMBUSTION PERFORMANCE

<table>
<thead>
<tr>
<th>Stokers</th>
<th>S.R.</th>
<th>M.R.</th>
<th>T.G.</th>
<th>S.S.</th>
<th>P.F.</th>
<th>Cyclone</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Size consist (as fired)</td>
<td>V</td>
<td>I</td>
<td>I</td>
<td>V</td>
<td>V(^1)</td>
<td>V</td>
</tr>
<tr>
<td>2. Moisture(^2)</td>
<td>M</td>
<td>M</td>
<td>N</td>
<td>M</td>
<td>V</td>
<td>M</td>
</tr>
<tr>
<td>3. Caking Index(^3)</td>
<td>I</td>
<td>I</td>
<td>V</td>
<td>M</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>4. Ash Fusibility</td>
<td>I</td>
<td>I</td>
<td>M</td>
<td>M</td>
<td>I</td>
<td>V</td>
</tr>
<tr>
<td>5. Grindability</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>V</td>
<td>N</td>
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<td>6. Friability</td>
<td>M</td>
<td>M</td>
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<td>M</td>
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<td>7. Volatile Matter</td>
<td>M</td>
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<td>M</td>
<td>M</td>
<td>I</td>
<td>M</td>
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<td>8. Fixed Carbon</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
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<td>9. Ash Content</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
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<td>10. Calorific Value</td>
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<td>N</td>
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<td>11. Ash Viscosity</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>I</td>
<td>V</td>
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<td>12. Ash Composition</td>
<td></td>
<td>- See Footnote 4 -</td>
<td></td>
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<td>13. Sulphur</td>
<td></td>
<td>- See Footnote 5 -</td>
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Rating Code:  
- V = Very important  
- I = Important  
- M = Minor importance  
- N = Little or no importance

Footnotes:  
\(^1\) Degree of fineness is a better term for P.F.

\(^2\) Surface moisture is more critical than inherent moisture. Moisture is very important from the standpoint of plant flowability.

\(^3\) Some engineers are attempting to use the F.S.I. as an index of the degree of caking.

\(^4\) Ash composition is very important as it affects fireside fouling, but not important to combustion.

\(^5\) Sulphur is important from a corrosive standpoint, but not important to combustion.
BIBLIOGRAPHY

1. ASTM - Standards on Coal and Coke.

2. Babcock and Wilcox Company, "Steam - Its Generation and Use".


