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# Consequences of Specifying a Boiler Design Fuel When Source Commitments are not Firm

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# CONSEQUENCES OF SPECIFYING A BOILER DESIGN FUEL WHEN SOURCE COMMITMENTS ARE NOT FIRM

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## INTRODUCTION

Historically, steam generator and auxiliary equipment designs are based on fuel ranges. This is done because equipment design must be fixed very early in the life of a contract so that fabrication, manufacturing and construction can proceed as quickly as possible even though a design fuel has not been pinpointed.

Many architect-engineers have utilized coal constituent ranges when specifying fuel ranges for unit designs. As a boiler manufacturer and equipment supplier, we recommend that such an approach not be taken because individual ranges of constituents can be combined in ways that produce unnatural fuels which in turn leads to non-appropriate designs and equipment sizing or selections.

Therefore, we stress the importance of taking a realistic and reasonable approach to fuel specifying when the source commitment is not firm. The most desirable approach would be use of the ABMA coal guide (Fig 1) which calls for individual coal sample information and not fuel range constituents.

**RECOMMENDED ABMA***
**COAL GUIDE SPECIFICATION FORM**

SOURCE (STATE/COUNTY/COMPANY/MINE/SEAM) ____________

____________

CLASSIFICATION BY RANK____________

Proximate Analysis—as received (percent by weight)
- Volatile Matter ____________
- Fixed Carbon ____________
- Ash ____________
- Moisture (Total) ____________
- Equilibrium Moisture ____________
- ____________

Grindability—Hardgrove[b] ____________
- Feed Size (Sieve Analysis)

Sulfur
- Forms of Sulfur
  - Pyritic ____________
  - Organic ____________
  - Sulfates ____________

Heating Value—BTU/lb. as received ____________

Ultimate Analysis—as received (percent by weight)
- Moisture ____________
- Carbon ____________
- Chlorine ____________
- Hydrogen ____________
- Nitrogen ____________
- Oxygen ____________
- Sulfur ____________
- Ash ____________

Float Sink Fraction (1.6 sp.gr.) ____________

Ash Fusion Temperatures (°F)

| | Reducing | Oxidizing |
|---|---|---|
| Initial deformation | ____________ | ____________ |
| Softening (H=w) | ____________ | ____________ |
| Hemispherical (H=½w) | ____________ | ____________ |
| Fluid | ____________ | ____________ |

Ash Analysis (percent by weight)
- $SiO_2$ ____________
- $Fe_2O_3$ ____________
- $Al_2O_3$ ____________
- CaO ____________
- MgO ____________
- $P_2O_5$ ____________
- $Na_2O$ ____________
- $K_2O$ ____________
- $TiO_2$ ____________
- $SO_3$ ____________
- NAF[c] ____________
- Viscosity[d] ____________

Burning Profiles[e] ____________

Bulk Density (as delivered) ____________

Free Swelling Index ____________

Reactivity Index[f] ____________

ASTM TEST METHODS

1. Proximate Analysis—D3172,D3173,D3174,D3175,D3177,D2013
2. Ultimate Analysis—D3173,D3174,D3176,D3177,D3178,D3179, D2361
3. Heating Valve (BTU)—D2015,D3286
4. Grindability—D409
5. Moisture—D2013,D3173,D3302
6. Bulk Density—D291
7. Free Swelling—D720
8. Ash Analysis—D2795
9. Ash Fusion Characteristics—D1857
10. Classification by Rank—D388
11. Sampling Methods—D2234
12. Sampling Preparation—D2013
13. Chlorine—D2361
14. Forms of Sulfur—D2492
15. A Test for Sieve Analysis of Crushed Bituminous Coal—311-30

[b] Note: Grindability for at least three moisture levels should be determined when low rank coals are analyzed (e.g. Sub—C or Lignite).

[c] Not accounted for.

[d] Corey, Richard C., "Measurement and Significance of the Flow Properties of Coal Ash Slag," Bur. Mines Bull, Vol. 618, 1964.

* Please use one form for *each* coal specification; do not list property ranges or composite properties.

[d] Moore, G. F. and Ehrler, R. F., Western Coals—Laboratory Characterization and Field Evaluations of Cleaning Requirements, ASME paper No. 73-WA/FU-1 Detroit, Mich., November 1973.

[e] Wagoner, C. L. & Winegartner, E. C., "Further Developments of the Burning Profile," Journal of Engineering for Power, Trans ASME, Series A, Vol. 95, No. 2, April 1973.

[e] Moore, G. F. and Ehrler, R. F., Western Coals—Laboratory Characterization and Field Evaluations of Cleaning Requirements, ASME Paper No. 73-WA/FU-1 Detroit, Mich., November 1973.

[f] See *Reactivity of Solid Fuels* by A. A. Orning, "Industrial and Engineering," Pages 813, Vol. 36 (1944).

Fig. 1. ABMA Coal Guide Specification Form

## COMPROMISED VERSUS UN-COMPROMISED DESIGN (ULTRA CONSERVATISM)

One of the most controversial arguments in the industry today is how unit performance changes with fuel characteristics changes.

Invariably, the equipment manufacturers point to historical results when illustrating how and to what extent the various mechanical and performance parameters are affected by fuel difference.

The architect-engineers and utility operators question experience by pointing out design philosophies which, if instituted in initial unit design, might have minimized the adverse conditions encountered.

Designing for the worst possible conditions would be compared to "having your cake and eating it too" but it does prove costly.

The word "compromise," although often overused, couldn't fit any situation better than it does this one. Know it or not, like it or not, everyone concerned (Utility operator, Engineer and Manufacturer) consciously and sub-consciously evaluates the cost benefit of virtually every facet of unit design prior to committing to a new power plant contract.

*Uncompromised* may be considered overdesigning. As each fuel variable is analyzed and a wide range of fuels designed for, two significant adverse consequences result;

1. Initial capital cost of the unit is increased substantially.

2. Operating costs of the unit are markedly higher.

To illustrate the high cost of an uncompromising approach, consider the following general discussion which, while providing considerably greater fuel characteristic flexibility, results in an extremely costly and possibly unmarketable system. Major variables of coal fuel analyses are commented on and their accompanied impact on unit size-cost discussed. Cost comparisons are made using a cost factor terminology. A cost factor relates the extremes of fuel ranges by assuming the one end of the range is at base cost (cost factor 1.0) and the other end of the range is the factor increase.

## FUEL VARIABLES

1. *Coal Heating Value* - Since this value ranges widely between coals (see Fig. 2), it can significantly affect coal yard handling, silo storage, and coal conveying, pulverizing, and transport equipment. Steam generators of a given capacity require a fixed heat input regardless of coal heating value (moisture effects discussed later). If the actual heating value of the coal is reduced by 50%, the time rated capacity of all of the above mentioned equipment is doubled. In doubling silo capacity requirements its height and structural supports must increase; thus coal conveyors become longer.

   A similar "snowballing" effect occurs with pulverizers since the added throughput requirements would necessitate more pulverizers in turn increasing the amount of coal piping, and probably burners and furnace width, as well as associated instrumentation and controls, ash handling equipment, larger precipitators and so on. Thus, lowering coal heating value definitely has a compounded effect on the balance of fuel handling, preparation, conveying, and combustion equipment. The cost impact on the other equipment described above over the range of coal heating value, might be 2.5 times (cost factor 2.5).

2. *Coal Moisture* - Increased moisture in coal adds proportional cost factor to coal yard handling, conveying, storage, pulverizing, and transport equipment. It often requires special additional equipment such as coal dryers, ice breakers, bunker vibrations, and other special design considerations like silo hopper slope, feeder type, allowance for loss of pulverizer capacity

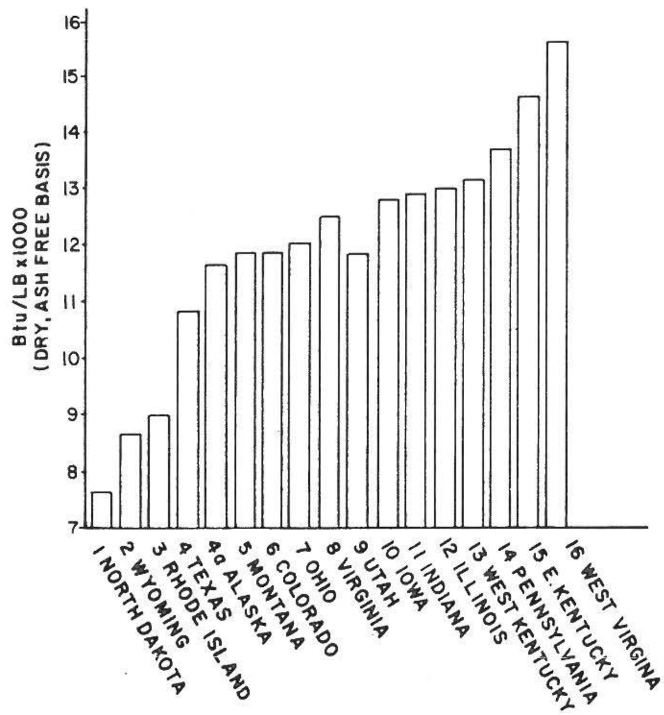


Fig. 2. Typical Heating Value of United States Coal

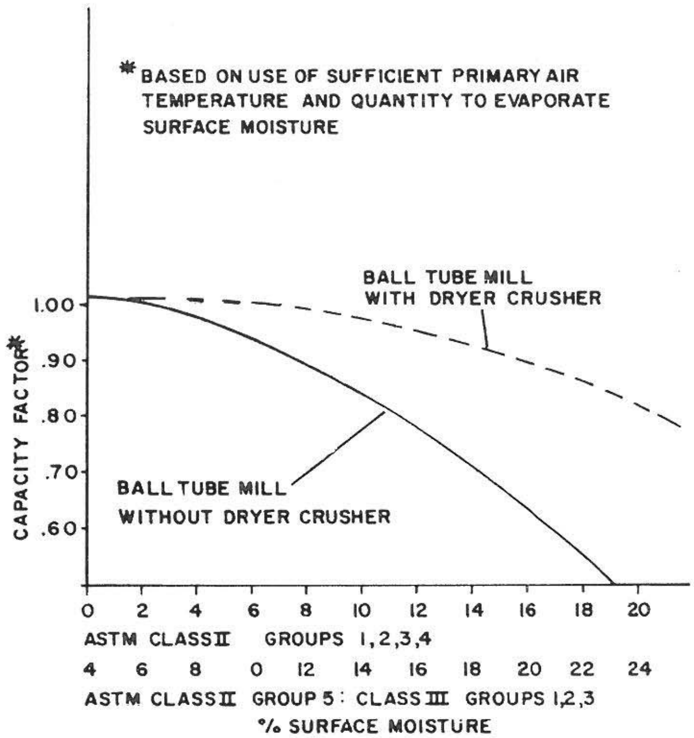


Fig. 3. Pulverizer Capacity versus Surface Moisture

(see Fig. 3), coal chute materials and geometries, air heater materials and design temperatures, precipitator velocities, temperatures and performance effects, ductwork, and stack materials. The equipment cost factor might reach 1.5. Also, every 5% moisture increase in the fuel decreases overall boiler efficiency, via vaporization loss, by approximately ½% (see Fig. 4). Considering a fuel moisture range from 5 - 30% will vary boiler efficiency at least 3%. This means,

1. A 3½% increase in furnace to handle the greater fuel input,

2. A 3½% greater precipitator and airheater size to pass the larger flue gas volume.

3. A 4% increase in fan size when the 3½% volume adjustment is increased by test block margins.

4. A 4% increase in power requirements on the affected fans.

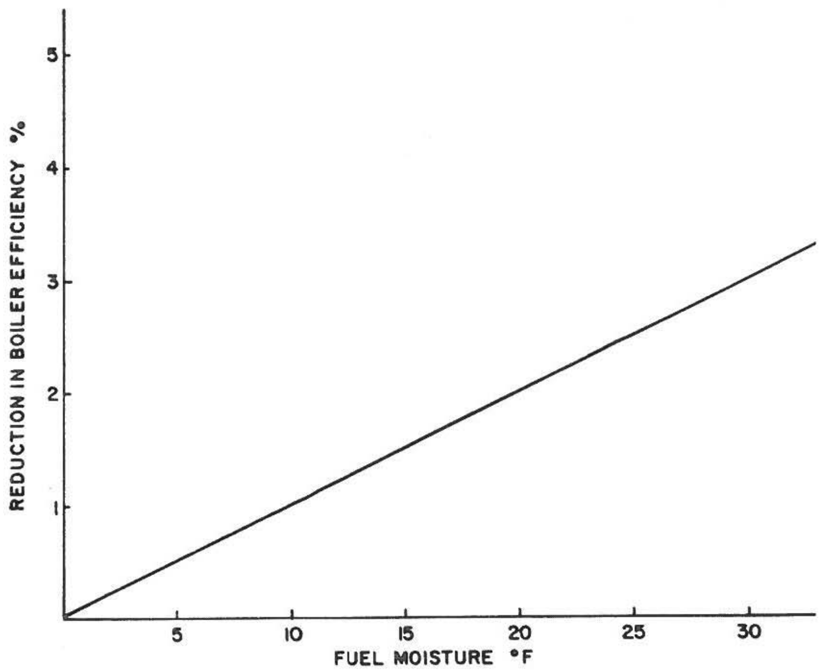


Fig. 4. Effect on Boiler Efficiency of Fuel Moisture Content

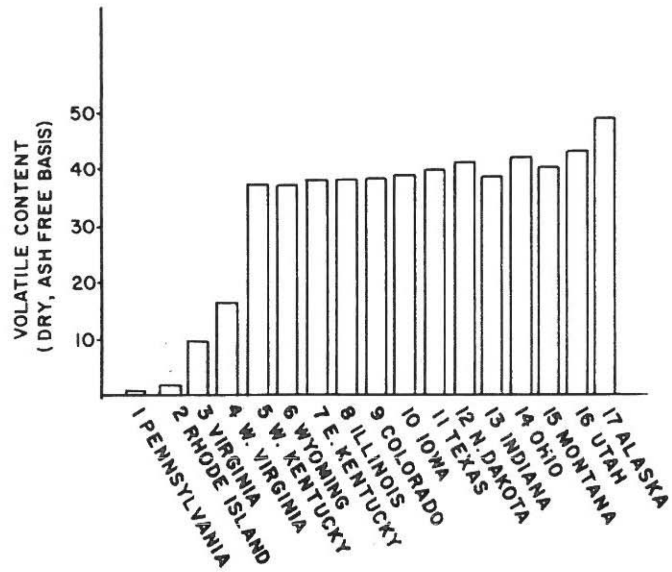


Fig. 5. Typical Volatile Content of U.S. Coals

3. *Volatile Content* - American Coals range from approximately 2 to 55% volatile content (see Fig. 5). This factor directly affects the combustability of the pulverized product. Required fineness increases as volatile content decreases resulting in significant sizing and number variations (see Fig. 6). Additionally, burner designs often must vary to accommodate low volatile coal carbon loss combustion requirements. For extremely low volatile fuel, furnace geometries, and firing methods are often drastically altered from the more conventional firing styles. This can elevate equipment costs markedly. This item can increase furnace, burner, pulverizer, conveying equipment, instrumentation and controls by an estimated 2.0 cost factor.

4. *Grindability Index (Work Index)* - Grindability (Hardgrove) index values for coals in this country can vary from approximately 35 to 110 (see Fig. 7). This results in mill sizing factors of up to 4-1. This also results, of course, in similar increases in number of pulverizers, bunkers, feeders piping, burners, and instruments and controls.

5. *Coal Abrasivity* - Although somewhat difficult to identify in advance, coals which contain relatively high quantities of quartz, feldspar, and other abrasive impurities may require special conveying system design. Abrasion resisting lined chutes, classifiers, and coal piping, while prudent from a design standpoint, can result in a cost factor of 2.3 for this equipment. Few utilities have shown the willingness to spend the necessary capital to protect these items. As coal quality continues to deteriorate, it can be expected that such expenditures will become more attractive and perhaps even commonplace in the near future.

6. *Coal Nitrogen* - Since fuel nitrogen content can significantly affect $NO_x$ emissions, even seemingly small variations in this value can have catastrophic effect on unit designs. Dry basis coal nitrogen content usually ranges from 0.6 to 1.6% (see Fig. 8), and although the exact conver-

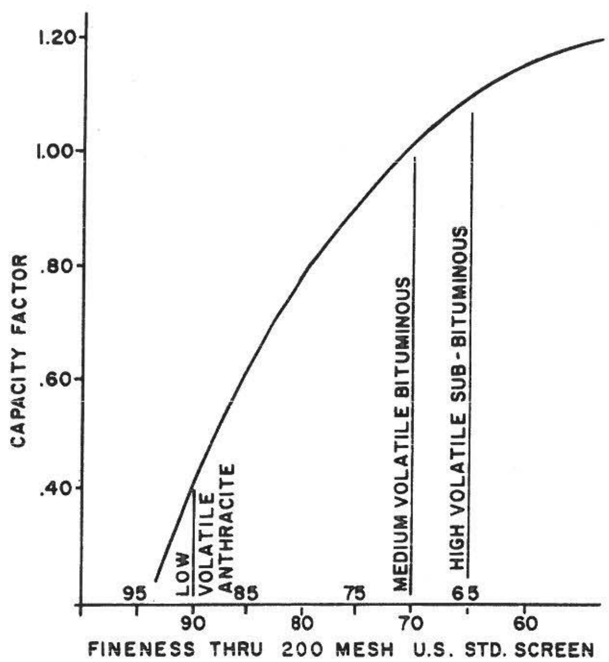


Fig. 6. Pulverizer Capacity
versus Coal Fineness

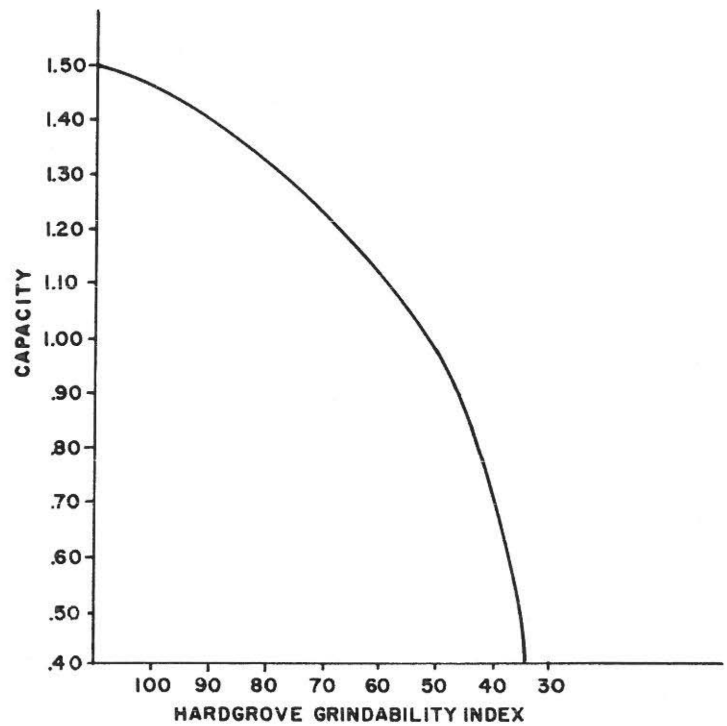


Fig. 7. Pulverizer Capacity
versus Coal Grindability

tion rates to $NO_x$ are still subject to much controversial conjecture, most sources report high resultant emission rates for high nitrogen coals. The fact that several conventional $NO_x$ control methods are ineffective in controlling fuel nitrogen generated $NO_x$ only adds to the design costs for controlling this pollutant in the combustion process. Cost factors for this fuel parameter can vary from zero increase for very low fuel nitrogen levels to doubling burner and furnace costs (cost factor 2.0) along with uncertain long term effects of staged combustion where fuel nitrogen levels are high. Staged combustion has also resulted in greater than normal furnace effectiveness (see Fig. 9). This would demand a factor of 1.2 times additional reheater and superheater heating surface to achieve design steam temperatures at the lower available thermal flue gas head.

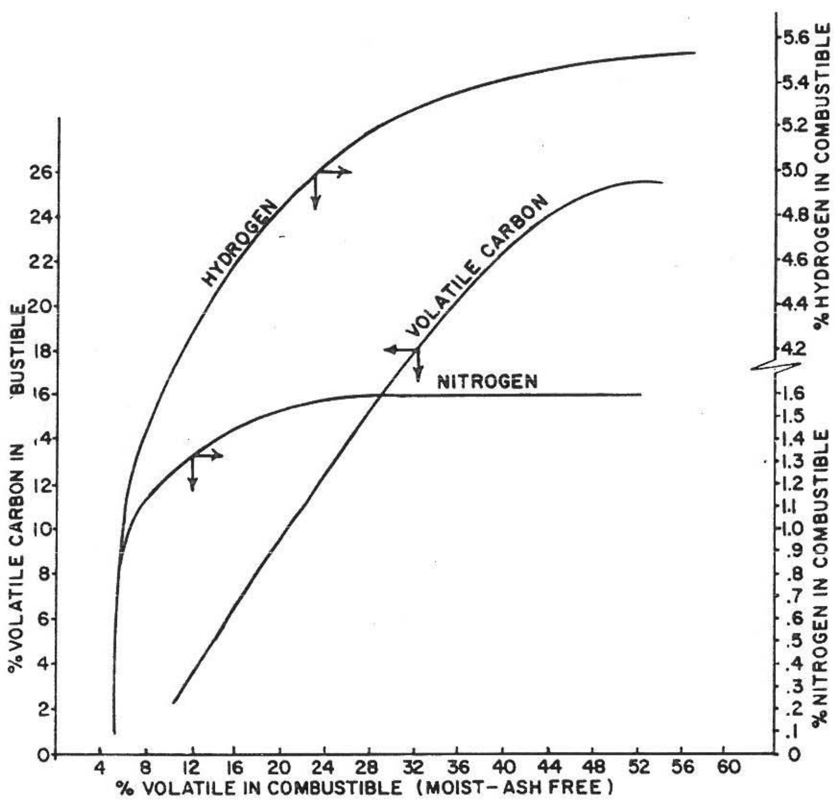


Fig. 8. Typical Proximate to Ultimate Relationship of U.S. Coals

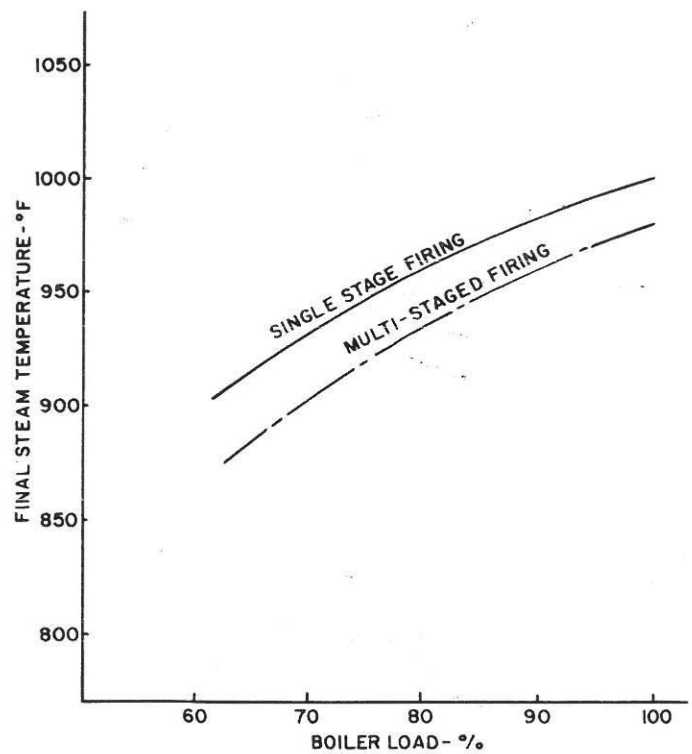


Fig. 9. Effect of Staged Burner Firing on Steam Temperature

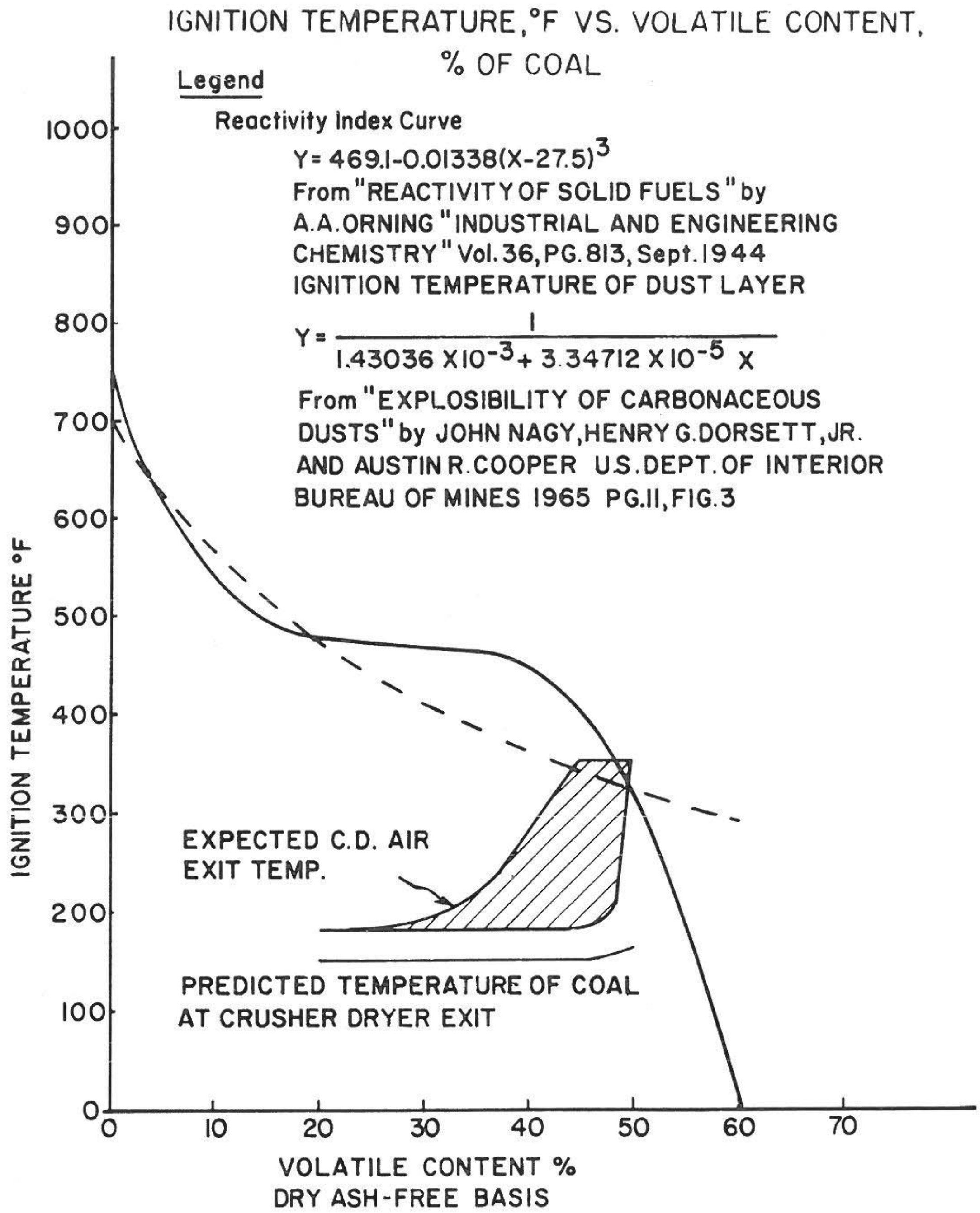


Fig. 10. Coal Reactivity Index

7. *Coal Sulfur* - The vast majority of fuel sulfur converts into gaseous pollutants in the combustion process. When attempting to control $SO_2$ emissions to the current limit of 1.2 pounds per million Btu, the relative costs of controlling $SO_2$ over the range of sulfur contents can be from zero, when fuel sulfur is less than approximately 0.7%, to well in excess of $100 per KW for a high sulfur coal. Proposed legislation to require 90% removal rates will raise the lower end of the cost scale to such a level that only the operating costs will differ significantly, regardless of sulfur content.

   Sulfur content also plays a key role in air preheater cold end protection. Steam coil sizing and steam consumption can double (cost factor 2.0) if coal sulfur content varies from 0.7 to 3.5%.

8. *Reactivity Index* - Separate laboratory studies of carbonaceous dusts reveal a link between volatile content of coal and the temperatures required to auto-ignite such particles (see Fig. 10). Variations in volatile content of coals in this country result in a wide spread of predicted reactivity (the temperature required to cause rapid change in particle oxidation rate). Pulverizer inlet air temperatures should be controlled so as not to exceed the reactivity index of a given coal in order to minimize the potential for mill system fires. Where pulverizer systems do not include such protection, they may be equipped with inerting systems. Normally they are used during pulverizer startups or shutdowns. Therefore, depending upon the coal characteristics in question, the added cost of an inerting gas system plus its operating costs must be debited where coal reactivity cannot be otherwise controlled. Cost factors for this are difficult to determine. However, we estimate a pulverizer system cost increase multiplier to be on the order of 1.2.

9. *Coal Impurities* - Coal Impurity constituents (ash analysis) have the most significant effect on all coal analyses variables on steam generator design. By designing a boiler for a severe *slagging* coal rather than a low slagger, furnace size (area) would be increased by approximately 1.5 while superheater and reheater surfaces would be enlarged by approximately 1.35 times. Severe slagging coals must have larger furnace cooling zones to:

   1) Cool ash particles below their liquid plastic viscosity limit temperatures before they enter close spaced convective heating surface.

   2) Prevent the formation of running (wet) slag deposits anywhere on the furnace walls.

   Dry deposits will form on the furnace cavity, however, for medium, high, and severe slagging coals, but the deposits are normally self-limiting and easily removed with furnace wall blowers.

   These dry deposits may have a significant effect on furnace effectiveness and/or resultant furnace exit gas temperatures. Tests have shown differences of 180°F. in furnace exit gas temperature between low and severe slagging coal in units of similar design (see Fig. 11). Such FEGT variations can affect steam temperature by at least 50°F.

   To control steam temperature with a high or severe slagging fuel, the furnace must have bands of wall blowers over its entire area. The function of the blowers is to eliminate the dry deposit buildup. This will result in compatibility between furnace performance and the ability of the steam temperature control system to maintain design temperature.

   By designing furnaces to handle a coal slagging range from low to severe requires soot blower selection to be made for the severe slagging coal. This would increase the cost of the sootblower system by a factor of 4.0 over the system requirements if only low slagging coal were considered.

Fouling potential of coals will dictate convective, rear pass boiler tube spacing. Fig. 12 shows a typical boiler design standard for setting tube spacing as a function of fouling index and temperature. Severe fouling coals require greater tube clearance (open area) in order to prevent bridging of coal ash, in comparison to low fouling coals.

This greater open area will result in lower gas velocities and thus lower heat transfer coefficients.

To achieve the desired heat transfer in the convection pass approximately 35 - 40% additional surface will be necessary.

As fouling potential increases so also does the number of rear pass sootblowers. Generally 50% more sootblowers are needed in the rear pass for a severe fouling coal.

10. *Ash Quantity* - Ash quantity can vary between 3 and 25% in domestic coals. Designing to the maximum of the range will result in larger, ash handling, systems, ash ponds, boiler hoppers, precipitators, pulverizers, and related coal handling equipment. The cost impact on these items for the worst ash case might be conservatively estimated at 5 to 1.

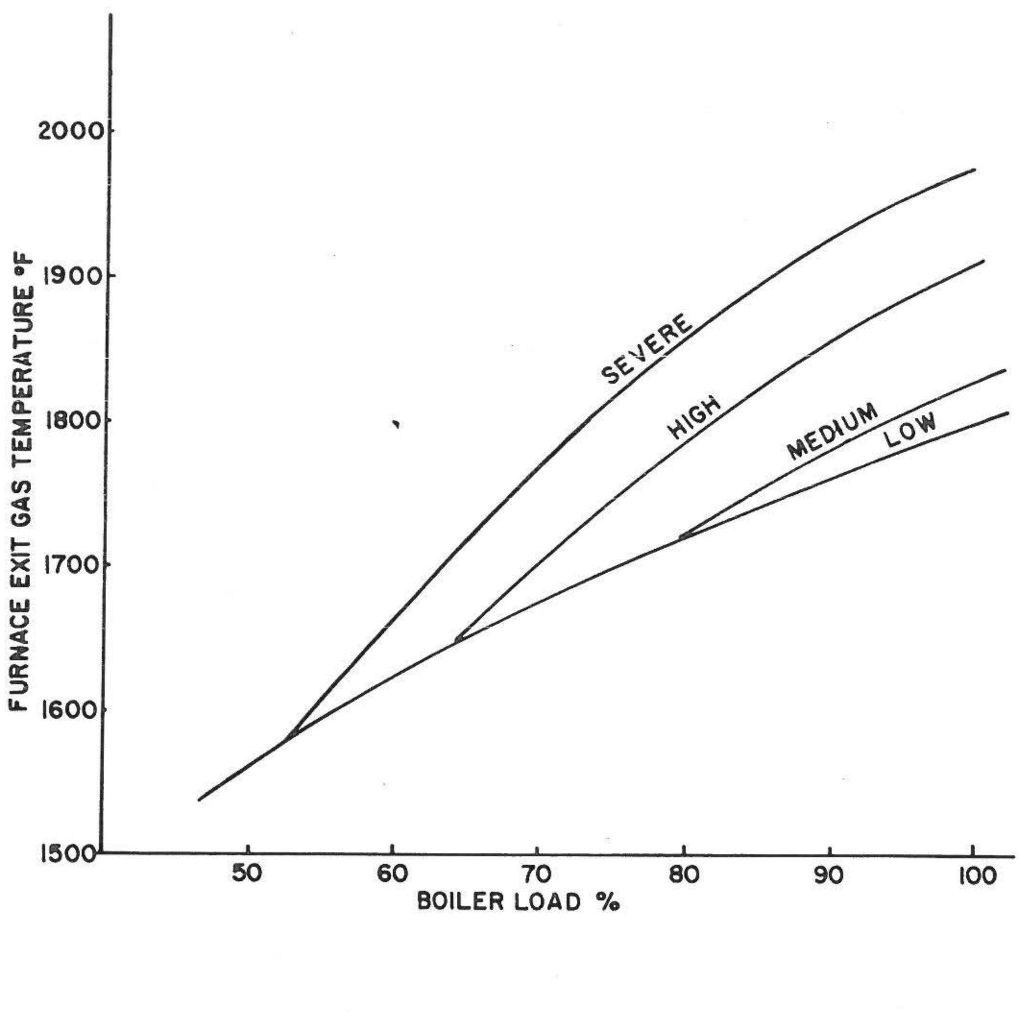


Fig. 11. Effect of Coal Slagging Characteristics on Furnace Exit Gas Temperature

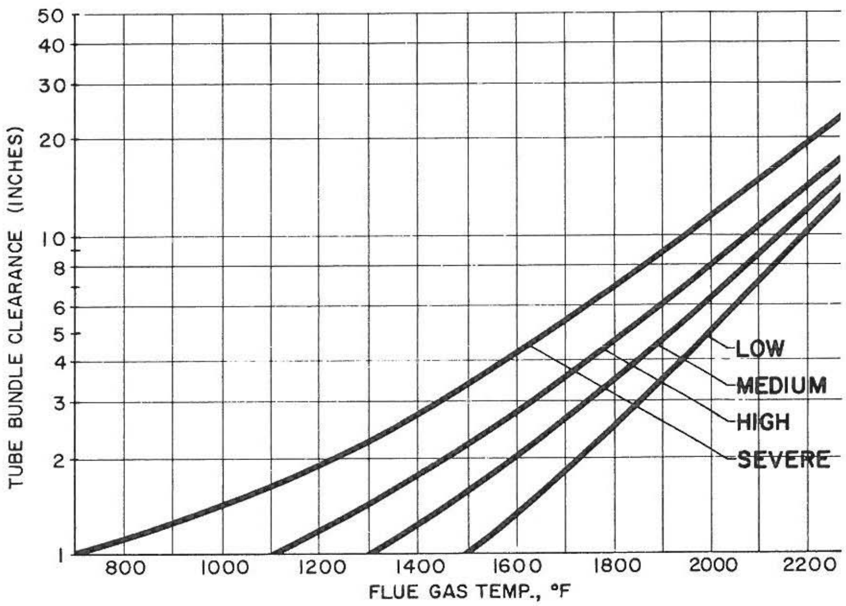


Fig. 12. Convection Tube Spacing as a Function of Coal Fouling Index and Gas Temperature

CONCLUSION

Designing to wide variations in coal analyses results in astronomically high first costs.

Since the equipment has been selected for the worst coal analysis inherent power requirements will also be very high. If a so called "good coal" is fired in the unit, inherent power requirements are not materially affected. This results in poor power-cost effectiveness.

This kind of additional cost mandates "compromise" in system design and careful attention of fuel variables.

Any utility company would be wise to firm up a fuel source prior to commitment for the generating station design. In lieu of this approach, it becomes realistic to expect to pay much more for new plant designs capable of handling wide variations in coal constituents. In such cases, customer specifications should clearly identify the condition to be designed for, and should place high dollar evaluation on offerings which provide for greater flexibility and conservatism.

This will prevent competitive bidders from designing to less flexible less conservative designs dictated by low dollar evaluations only.

This conservative approach can only be offered successfully when Industry accepts and rewards this design concept.

If this design concept is accepted, the enthusiasm of designers who have been forced to economize their offerings would be greatly enhanced.