Technical Publication

Coal Conversion

by

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The increasing cost of the Btu, combined with the national trend toward maximum utilization of coal as an energy source, have prompted utilities and boiler manufacturers to investigate the possibility of coal conversion on utility steam generators. This paper addresses itself specifically to the topic of converting steam generating units that were originally designed for firing:

A. Oil or natural gas to pulverized coal, or
B. High-rank bituminous to low-sulfur western coals.

CONVERSION FROM OIL OR NATURAL GAS TO PULVERIZED COAL

Prior to evaluating the steam generator, it is necessary to determine whether the plant site provides adequate facilities for transportation and storage of coal. In addition, adequate space must exist to accommodate fuel handling and pulverizing, as well as ash collection and handling equipment.

Steam Generator Operation

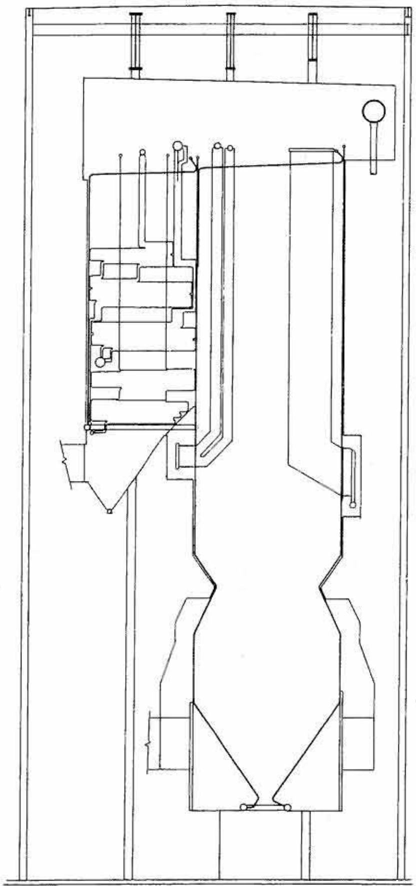
It is a well-known fact that a fuel conversion to pulverized coal on a unit designed for oil or natural gas results in deratement from the original design maximum continuous rated (MCR) steaming capacity, *if* equipment modifications are not made. A 50% reduction in MCR is typical when considering this type of fuel conversion. The magnitude of deratement is primarily dependent on the physical size of the existing steam generator. Shown in Figure 1 are two modern utility steam generating units; one designed to fire oil, the other designed for western sub-bituminous coal. The steaming capacity of each unit is approximately 4.5 million pounds per hour, at nearly 2000 psig, and 955/955F.

The difference in steam generator sizes is responsible for obvious differences in design parameters such as area and volumetric heat release, but not so obvious items such as flue gas velocity limits and ash fouling tendency are also contributing factors. A brief explanation of these terms is warranted.

Area heat release is defined as the total net heat liberated per unit projected area of radiant heat absorbing surface. This parameter is instrumental in furnace design calculations and in determining furnace exit gas temperatures. A maximum limit on area heat release for a particular coal fuel and steam generator design along with other factors, insures that furnace heat absorption is sufficient to prevent a slagging condition (dry bottom design), and that furnace exit gas temperature is well below the ash fusion temperature (h = w reducing). The plan area heat release, a parameter for proportioning furnace design, is the quotient of the gross fuel heat input divided by cross-section plan area of the furnace. The volumetric heat release is the quotient of gross fuel heat input divided by the furnace volume and is an indicator of flue gas

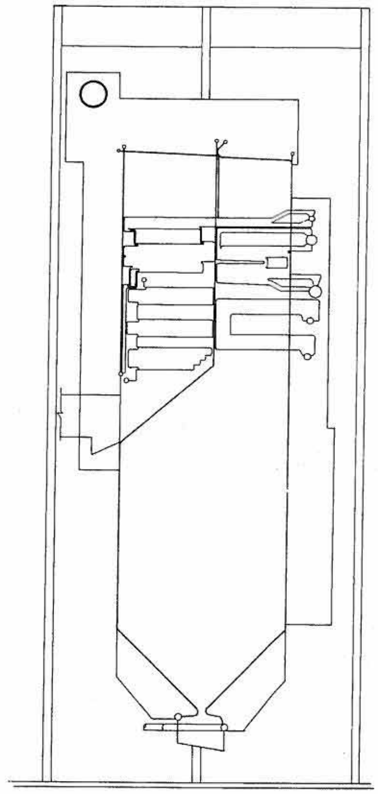
UTILITY STEAM GENERATORS

COAL FIRED



40'-1" FURNACE DEPTH
x 91'-3¼" FURNACE WIDTH
576,000 Ft^3 FURNACE VOLUME
ERS - 102,570 ϕ

OIL FIRED



40'-0" FURNACE DEPTH
x 80'-0" FURNACE WIDTH
242,000 Ft^3 FURNACE VOLUME
ERS - 37,780 ϕ

Figure 1

residence time. The limit on this value for a given design insures adequate time to complete combustion in the furnace cavity.

Normal range of heat releases are as follows:

Area Heat Release: 60,000-75,000 Btu/hr./sq. ft.
Volumetric Heat Release: 10,000-13,000 Btu/hr. cu. ft.
Plan Area Heat Release: 1.25×10^6-1.90×10^6 Btu/hr./sq. ft.

The maximum heat release(s) for a particular conversion depends largely on ash fusion temperatures and the slagging tendency of a given coal. Slagging is the accumulation of plastic or liquid deposits on radiant heat exchange surfaces.

Fouling is defined as the accumulation of deposits on heat exchange surfaces located in the convective portions of the steam generator and/or auxiliary equipment. The net effects on the operation of a unit improperly designed or maintained for ash fouling properties encountered are: reduced heat transfer (which leads to reduced boiler efficiency), increased draft loss, and increased probability of pluggage and subsequent equipment damage caused by erosion due to excessive flue gas velocity.

The slagging and fouling tendency must be predicted accurately to achieve a reliable, economical design, whether the project is a new construction or a fuel conversion in existing plant. To accurately predict these, as well as other properties, it is imperative that the ABMA Coal Guide Specification Form, as shown in Figure 2, be completed for each coal considered. Figure 3 lists criteria used in establishing slagging and fouling properties for special type(s) of coal under study.

Just as slagging tendency affects furnace design, fouling tendency influences convection pass design. Depicted in Figure 4 are the criteria used, along with other factors, to determine the clear space required between tubes as a function of flue gas temperature and fouling tendency.

Flue gas velocities with pulverized coal fuels are limited to approximately half of that designed for oil or natural gas fired steam generators because of the erosive property of flyash entrained in the gas stream.

Main steam and hot reheat temperatures are, of course, reduced because of reduced thermal head (furnace exit gas temperature) allowed at MCR. The exact amount of reduction depends on the original design and steam temperature control range.

Not affecting boiler operation *per se,* but germane to the topic of fuel conversion, is the subject of NO_x formation. EPA regulations state that when a fuel change is made on a utility steam generator not originally designed to accommodate such a fuel, new source limits on emissions will apply. State and local ordinances may further restrict emissions. Results obtained from a study we are presently undertaking on the convertibility of selected units, indicate that EPA NO_x limits are generally exceeded, unless the combustion process is modified.

Steam Generator Modification

Slagging, fouling, gas velocity and NO_x emissions are parameters which can adversely affect steam generator availability and reliability.

The practicality and feasibility of performing required modifications to minimize or eliminate load deratement on a fuel conversion project of this type are evaluated by the manufacturer and utility, respectively. Each project presents problems which are unique to that particular plant. It is beyond the scope of this paper to define and describe each possible situation which may arise; however, the key factors will be discussed in general terms.

Heat Releases: Reduced area and volumetric heat releases require larger furnace cavity surface and volume, generally on the order of 50%. In some instances, this can be accomplished by deepening and/or increasing the height of the furnace in combination with the addition of waterwall platens or radiant superheater surface. Excavating and dropping the furnace hopper is a viable approach in some cases where column foundation design permit.

Fouling and Gas Velocity: These parameters are related to some degree. Increasing the clear space between tubes reduces the probability of a serious fouling problem, and also reduces gas velocity. However, higher flue gas quantities, coupled with design considerations regarding heat transfer, pressure drop, and tube bundle depth, may require the convection pass to be deepened and/or heightened to maintain the performance level. One approach that we consider to have merit is to relocate the economizer section outside of the existing setting to facilitate installation of additional superheat and reheat surface.

Steam Temperatures: Because of furnace and convection pass modifications, combined with other factors, increases in both superheater and reheater heat exchange

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 ____________

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] ____________

Float Sink Fraction (1.6 sp.gr.) ____________

Ash Fusion Temperatures (°F)

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

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).

Figure 2

	SLAGGING TENDENCY				Lignite	Western	Eastern
	LOW	MEDIUM	HIGH	SEVERE			
B/A X S (DRY)	0 - 0.6	0.6 - 2.0	2.0 - 2.6	2.6 -	■	■	
T250, °F.	- 2430	2430 - 2160	2160 - 2100	2100 -			
% ALKALI IN ASH	0 -	- 2.0	2.0 -	-		■	■
B/A	- 0.5	0.5 - 0.9	1.0 - 1.75	1.75 -			■
ASH FUSION, °F, H=W REDUCING	- 2330	2330 - 2130	2130 - 2025	2025 -			
	FOULING TENDENCY						
	LOW	MEDIUM	HIGH	SEVERE			
STRENGTH OF SINTERED ASH, PSI	- 1000	1000 - 5000	5000 - 16000	16000 -	■	■	
B/A X Na_2O (WATER-SOLUBLE IN LOW TEMP. ASH)	0 - 0.1	0.1 - 0.25	0.25 - 0.7	0.7 -	■	■	
B/A X Na_2O (IN HIGH TEMP. ASH)	0 - 0.2	0.2 - 0.50	0.50 - 1.0	1.0 -	■	■	
% Na_2O IN ASH	- 1.0	- 3.0	-	-	■	■	
% Na_2O IN ASTM COAL ASH	- 1.0	1.0 - 2.0	2.0 - 3.0	3.0 -	■		■
% Na_2O IN ASTM COAL ASH	- 3.0	3.0 - 6.0	6.0 - 8.0	8.0 -		■	■
% Na_2O IN DRY COAL	-	-	- 0.30	0.30 -	■	■	
% ALKALI AS Na_2O IN DRY COAL	-	-	- 0.60	0.60 -	■	■	
% ALKALI IN ASH	- 3.0	3.0 -	- 5.0	5.0 -	■	■	
% ALKALI IN DRY COAL	- 0.3	0.3 - 0.4	0.4 - 0.5	0.5 -	■	■	
CHLORINE/ASH	- 0.1	0.1 - 1.7	1.7 - 2.5	2.5 -	■	■	
% CHLORINE IN COAL	- 0.3	0.3 -	- 0.5	0.5 -	■	■	

Figure 3

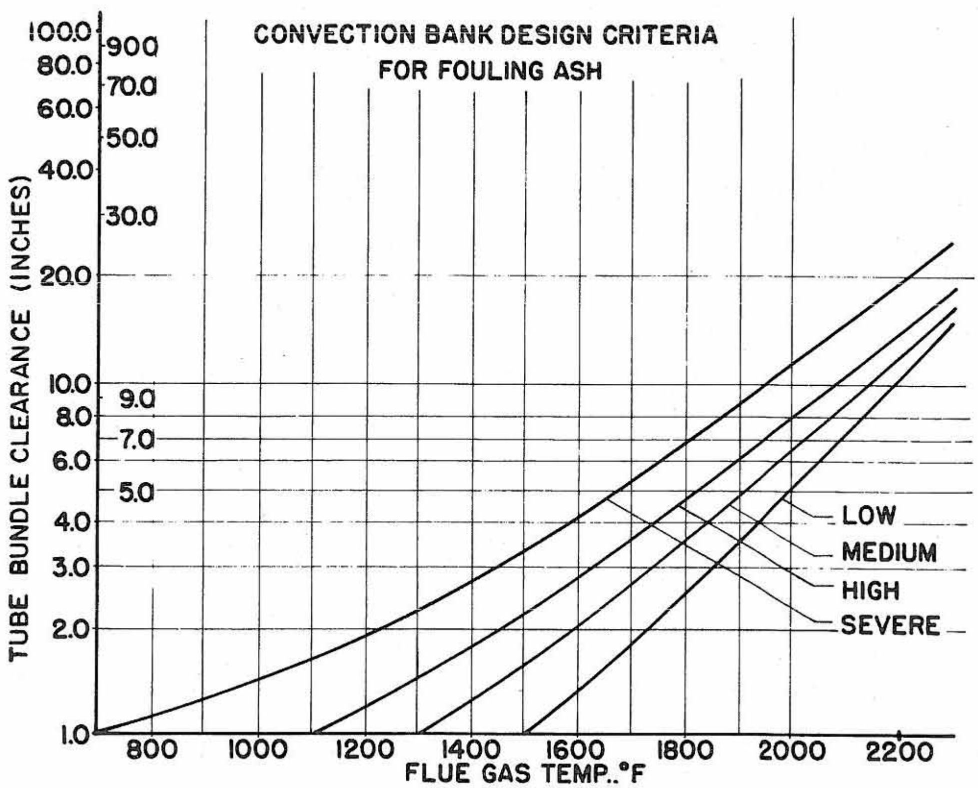


Figure 4

surfaces are required to achieve designed terminal temperatures. The economizer surface requirement is reduced because of increased evaporative surface added to the furnace, and other design considerations.

Ductwork and Breeching: Addition of primary air ducts, and possible stiffening of existing secondary air ducts, is necessary. The breeching design must incorporate ash collection hoppers at vertical bends along with larger sizing due to gas velocity limitations.

Fuel Burning Equipment and NO_x Emissions: Burners must be replaced or modified to accommodate pulverized coal. Although furnace modifications will aid in reducing NO_x formation, off-stoichiometric firing or installation of overfire air ports may be necessary to comply with EPA emission standards.

Structural Steel: Furnace and convection pass modifications, along with the addition of auxiliary equipment such as sootblowers, will affect the existing structural steel (support and buckstays) and associated column foundations. Design changes are usually required.

Auxiliary Equipment

Just as important as the steam generator design modifications in evaluating a fuel conversion are the items associated with changing and adding to existing auxiliary equipment:

Fuel handling and pulverizing equipment comprised of coal feeders, crushers, mills, classifiers/distributors, and piping have to be installed.

Forced draft fan(s) and drive(s) have to be modified or changed to handle larger air quantities.

Induced draft fan(s) and drive(s) have to be modified to handle the volume of erosive flue gas, or added to convert the unit to balanced draft operation.

Airheater surface may require adjustment or replacement to provide the sufficient primary air volume and temperature for coal drying and to prevent fouling.

Precipitator(s) and/or scrubber(s) must be installed to insure that particulate and/or SO_2 emission limits are met.

Sufficient sootblowers must be added to protect the convection pass from ash fouling, and excessive ash or slag deposits on radiant heat exchange surfaces from forming.

Digital and analog control systems must be added to insure adequate monitoring and operation of the steam generator and associated auxiliary equipment.

CONVERSION FROM HIGH RANK BITUMINOUS TO WESTERN LOW SULFUR COAL

Conversion from one type of coal to another coal usually proves to be more practical than conversion of a steam generator from oil or natural gas to pulverized coal.

Coal transportation, storage and handling, as well as plant siting problems, which are normally significant stumbling blocks, are minimal or nonexistent. Also, radical changes to existing steam generator design are generally not required to achieve a steaming capability close to MCR. The magnitude of deratement, if any, as well as the modifications required to achieve MCR, if any, are then functions of differences in coal/ash properties and cost/revenue evaluations.

Steam Generator Operation

A detailed study is required to accurately predict performance and operation, but generally the effects associated with this type of conversion are less in number and magnitude; for example, major furnace and convection pass surface modifications are not usually necessary, which eliminates the need for major alterations to the existing plant.

With respect to heat releases, the lower ash fusion temperature of western coals coupled with the probability of higher slagging tendency requires more furnace heat absorption with a corresponding drop in furnace exit gas temperature. Also, the fouling tendency is usually higher, which may result in reduced heat absorption in convection pass heat exchange surfaces, if adequate design changes and/or sootblowing are not done. The amount of sootblowing will increase.

The steam generator thermal efficiency is reduced from 2-4% due to the higher fuel moisture and other factors. Air requirements for stoichiometry are increased 4-6%. Consequently, system air pressure drop and draft loss are increased significantly.

The effect on steam temperatures and attemperation requirements can vary. If a furnace evaporative heat exchange surface addition is made, steam temperatures will tend to remain the same or be reduced. Superheater spray requirements will be reduced. If the furnace is not altered, steam temperatures and attemperation will tend to increase.

Nitrous oxide formation will vary proportionately with the amount of nitrogen in the coal and the firing rate, which affects the thermal NO_x component. The sulfur dioxide emission level is reduced because of the lower sulfur content in the fuel. The particulate emission level will rise due to the higher resistivity of the flyash, which causes reduced precipitator efficiency.

Test

We have thoroughly tested a Riley steam generator equipped with Riley Ball Tube Mills, originally designed for firing Illinois coal, on Wyoming sub-bituminous coal. Test results indicated a deratement of approximately 5% caused by limitation on primary air fans. By making minor modifications to the existing mill system, full unit rating could have been attained, with sufficient reserve on the mill system.

Steam Generator Modifications

As noted earlier, major steam generator modifications are usually not required to achieve "acceptable" steaming capability or full rating. There are, however, many types of "minor" equipment alterations or replacement which would result in minimizing maintenance and maximizing steam generator capability, reliability and availability. For example:

Slagging may be prevented by the addition of waterwall platens or radiant superheater surface, in combination with additional wall blowers.

Excessive fouling can usually be prevented by additional sootblowing equipment operation and minor tube bundle redesign.

Superheat and reheat steam temperatures can usually be adjusted by relatively minor surface adjustments. The extent of the modifications depends on the magnitude of the furnace changes and the original design. Because of increased convection, primary superheater tubing and outlet header(s) may require upgrading.

Economizer modifications are also a possibility depending on fouling, extent of furnace modifications, and primary air temperature requirements.

Existing burners may need modifications or additional burners may be needed to handle the 25-50% larger quantity of coal and primary air.

Auxiliary Equipment

Because of the larger amount of high-moisture coal required, the fuel handling system usually must be up-rated to permit full rating on the steam generator. Uprating may vary from the modifications of the limiting component to the addition of one or more mill system comprised of feeders, crusher-dryers, mill classifiers/distributors, piping, primary air fan(s) and sealing air fans.

Draft equipment and respective drives may need modification or replacement to handle larger air and flue gas quantities and static pressures.

Airheater and/or economizer surface adjustments may be needed to insure adequate supply and temperature of primary air to dry the high-moisture coal.

Additional wall deslaggers and retractable sootblowers are usually installed to keep the steam generator at peak efficiency.

Steam Generator Conversion

Duplicate Riley steam generators originally designed for utility service, firing Ohio bituminous, have been successfully converted to western sub-bituminous coal. They are presently achieving original design MCR.

A summary of modifications made to the steam generators and associated auxiliary equipment follows:

1. Approximately 30% of the primary superheater and 50% of a wall-type radiant superheater were removed.
2. For each unit, a Riley Atrita® Pulverizer was added and speed was increased on three existing mills.
3. One burner was added on each unit to increase fuel burning capacity by 12%.
4. Sootblowers were added throughout the unit.
5. Airheater surface was adjusted to minimize the fouling tendency and to increase hot air temperature.

Conclusion

The problems associated with converting existing utility steam generators from oil or natural gas to pulverized coal involve siting, in addition to major steam generator and plant modifications, *if* substantial deratement is not acceptable. To date, the economic feasibility of this type of fuel conversion has proven to be marginal at best; however, if interruptions in the existing fuel supply occur or it becomes completely unavailable to a relatively new plant, then it may be economically attractive to convert to pulverized coal.

Conversely, switching from high rank to low sulfur western coals, on Riley Stoker Corporation steam generating, fuel handling, and burning equipment, *has* proven successful with little or no deratement and relatively minor equipment alterations.