Biomass Fuel Selection for Cofiring in Circulating Fluidized Bed Boilers

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ABSTRACT

Circulating Fluidized Bed (CFB) boilers have been installed, worldwide, to burn a wide variety of biomass and biomass wastes, along with other opportunity fuels and coals. With the expansion of Renewable Portfolio Standards, many utilities and power generation companies are looking to cofire biomass with coal or other base fuels. Recent research and design studies have identified certain key issues with cofiring biomass and coal in CFB boilers. These issues involve the interplay between the various types of coal and their compositions, and the various types of biomass and their compositions. Additionally, attention must be given to the bed media being added to the blend. Not all opportunity fuels and coals are identical; for example petroleum coke contains very little ash (frequently <0.5%) and the inorganics contain high concentrations of vanadium. Coals can vary in reactivity; nitrogen, sulfur, ash, and chlorine concentrations; and the ash can contain little or significant concentrations of alkali metals. Biomass fuels—all significantly reactive—can contain varying concentrations of ash. The ash can contain significant concentrations of inorganic alkali matter including potassium and sodium. All biomass fuels are not the same. The composition of wood is fundamentally different from switchgrass, corn stover, and a host of other agricultural materials. Each type of biomass, like each source of coal, has unique characteristics that must be considered. Resulting from this analysis are some compositional guidelines to demonstrate combinations of coal and biomass [or petroleum coke and biomass] that can be successful and combinations that have the potential to create operational difficulties.

INTRODUCTION

Circulating Fluidized Bed (CFB) technology can fire many different fuels – high sulfur coals, low rank coals such as sub-bituminous and lignite, biomass, waste fuels, and other opportunity fuels. Table 1 lists some of FWNAC CFB experience and the design fuels. Higher sulfur fuels (up to 6-8% sulfur) can be burned in CFB boilers when limestone is added to the combustion process. Waste fuels with heating values as low as 4,000 Btu/lb and ash concentrations as high as 50% have been common CFB fuels. Some fuels are better suited for the technology compared to others. In addition, certain combinations of these fuels are not suitable regardless.

Fuel characteristics and combustion behaviors vary drastically from one fuel type to the next. Inherently low ash fuels such as woody biomass may require sand addition to the bed material. Certain biomasses, such as agricultural material, can increase the corrosion potential of the fuel mass by increasing the concentration of alkali metals. These differences must be considered in both the design and operation of the boiler.

Plant	Customer	Capacity	Design Fuel
CLECO, Rodemacher Power Station 3	Shaw Stone and Webster, Inc.	2 x 330 MW	Petroleum coke, Illinois #6, PRB, and Lignite
Sandow Steam Electric Station Unit 5	Bechtel Power Corp.	2 x 300 MW	Lignite
Virginia City Hybrid Energy Center, Unit 1	Stone and Webster, Inc., North Carolina	2 x 330 MW	Waste Coal, Wood
Northampton Generating Company	Cogentrix	1 x 110 MW	Anthracite Culm
Colver Power Plant	A/C Power – Colver Operation	1 x 104 MW	Bituminous Gob
Glatfelter Spring Grove	Glatfelter	1 x 70 MW	Coal, Paper sludge
Sonoco	Sonoco	1 x 120 Klb/hr Main Steam	Coal/Wood

Table 1: FWNAC CFB Experience and Design Fuels

TYPES OF FUEL CONSIDERED FOR CFB FIRING

Varying types of fuel are considered for CFB firing. CFB technology has demonstrated the ability to fire fuels with heating values that have ranged from 4,000 to over 14,000 Btu/lb. These include high sulfur coals, low rank coals such as lignite and sub-bituminous – particularly Powder River Basin (PRB), biomass, waste fuels such as waste coal and Municipal Solid Waste (MSW), and other opportunity fuels. Each fuel type varies in fuel characteristic and combustion behavior (see Tables 2, 3, and 4). Table 2 compares coal analysis of typical bituminous, sub-bituminous, and lignite. Note the variation in moisture and ash content, carbon and oxygen concentration, and heating values. Within the coal family, the variability can be drastic. And like coal, biomass and opportunity fuel properties vary significantly; see Tables 3 and 4. It is important to analyze the ash constituents; these will affect the operation of the boiler.

Certain fuels and combinations of fuels are well suited for CFB firing. Other types of solid fuels can also be fired, however the level of success can vary depending on the fuel and/or blended fuel properties. Waste coals – also known as “culm”or “gob” – can have heating values as low as 4,000 Btu/lb and ash contents as high as 50%. With high ash concentrations, the addition of bed material is not required; limestone sorbent is used primarily for sulfur capture.

A common low rank fuel considered for CFB firing in the U.S. is Powder River Basin (PRB) sub-bituminous coal. PRB can be fired with CFB technology; however certain constraints can limit the quantity used in the blend. Inherently low in sulfur and ash concentrations, PRB coal may require bed make up material such as sand. This can increase the rate of erosion on waterwall tubes. Other, more expensive options are to utilize flyash from existing boilers.

Like coal, biomass fuel properties vary significantly from one biomass to another. Woody biomass has been fired successfully in CFBs. However, make-up material such as sand may be required. For agricultural biomass, they can bring higher concentrations of potassium and sodium to the fuel mass. When combined with the higher alkali metal concentration, higher chlorine concentrations inherent to agricultural material will increase corrosion potential. Certain nut waste biomass are exceptions. Sodium and potassium will also contribute to agglomeration and fouling problems. Corn stover has both high chlorine and alkali metal concentrations. The initial reaction is the formation of alkali chloride followed by a sulfation reaction, provided that there is available sulfur. Sulfation is the substitution of chlorine with sulfur forming alkali sulfate. While not benign, alkali sulfates are far less aggressive than alkali chlorides. Therefore when sulfur capture is utilized, as typical in CFB firing, the sulfation reaction is minimized.

Chlorine that does not react with alkalis usually exists as HCl in the flue gas. HCl is not thermodynamically favored to be captured by limestone sorbent at normal CFB operating temperature of approximately 1600^{o}F and requires a downstream scrubber for its removal.

Opportunity fuels such as petroleum coke can be fired successfully. With the addition of limestone, high sulfur concentrations inherent to petroleum coke can be managed. The inorganic constituents of petroleum coke include significant concentrations of vanadium. When petroleum coke is completely combusted, a significant portion of the vanadium is converted to its highest oxidation state of vanadium pentoxide (V_2O_5). Vanadium pentoxide has a low melting point of 1274^{o}F and can cause fouling of convective pass surfaces. Vanadium pentoxide can also form eutectics with reactive alkalis that result in corrosion.

Typical Coal Analysis for Bituminous Coal vs. Low Rank Coals			
Parameter	**Central Appalachian (Long Fork)**	**Powder River Basin (Black Thunder)**	**N.Dakota Lignite**
Proximate Analysis (wt. % A.R.)			
Moisture	7.16	25.84	26.74
Ash	11.52	5.05	12.52
Volatile Matter	31.23	31.56	31.58
Fixed Carbon	50.09	37.55	29.16
Ultimate Analysis (wt. % A.R.)			
Carbon	66.93	51.89	31.80
Hydrogen	4.43	3.55	4.51
Oxygen	7.55	12.77	26.35
Nitrogen	1.34	0.67	0.59
Sulfur	1.07	0.23	0.84
Moisture	7.16	25.84	26.74
Ash	11.52	5.05	9.17
Chlorine (%)	0.12	0.01	--
Higher Heating Value (Btu/lb, A.R.)	12,114	8,943	7,613
Ash Elemental Analysis (% Dry)			
Al_2O_3	26.25	16.20	14.01
BaO	0.13	0.67	--
CaO	2.31	22.84	13.69
Fe_2O_3	8.38	6.02	7.39
K_2O	3.26	0.56	0.51
MgO	1.42	5.22	2.51
MnO	0.07	0.01	0.12
Na_2O	0.71	1.44	0.60
P_2O_5	0.56	1.57	0.39
SiO_2	51.99	32.76	38.17
SrO	0.19	0.36	--
TiO_2	1.07	1.28	1.15
SO_3	2.20	10.10	14.41

Table 2: Typical Coal Analysis for Bituminous Coal vs. Low Rank Coals

Typical Biomass Analysis			
Parameter	**Wood Waste**	**Switchgrass**	**Corn Stover**
Proximate Analysis (wt. % A.R.)			
Moisture	42.00	9.84	8.00
Ash	2.31	8.09	6.90
Volatile Matter	47.79	69.14	69.74
Fixed Carbon	7.90	12.93	15.36
Ultimate Analysis (wt. % A.R.)			
Carbon	29.16	42.00	42.60
Hydrogen	2.67	5.24	5.06
Oxygen	23.19	33.97	36.52
Nitrogen	0.60	0.69	0.83
Sulfur	0.07	0.17	0.09
Moisture	42.00	9.84	8.00
Ash	2.31	8.09	6.90
Chlorine (%)	0.01	0.18	0.24
Higher Heating Value (Btu/lb, A.R.)	5,028	7,002	7,000
Ash Elemental Analysis (% Dry)			
Al_2O_3	3.55	4.51	3.80
BaO	--	--	--
CaO	45.46	5.60	8.80
Fe_2O_3	1.58	2.03	1.80
K_2O	8.52	11.60	17.30
MgO	7.48	3.00	3.40
MnO	--	--	--
Na_2O	2.13	0.58	1.50
P_2O_5	7.44	4.50	2.70
SiO_2	17.78	65.18	52.10
SrO	--	--	--
TiO_2	0.50	0.24	0.13
SO_3	2.78	0.44	3.70

Table 3: Typical Biomass Analysis

Example of Waste Fuel (Waste Coal and MSW) and Opportunity Fuel (Petroleum Coke)			
Parameter	**Waste Coal**	**‘Typical’ Composite MSW**	**Petroleum Coke (Fluid Coke)**
Proximate Analysis (wt. % A.R.)			
Moisture	7.00	25.20	2.24
Ash	41.60	24.40	1.32
Volatile Matter	19.80	25.40	4.94
Fixed Carbon	31.60	25.00	91.50
Ultimate Analysis (wt. % A.R.)			
Carbon	41.70	25.6	84.41
Hydrogen	3.10	3.40	2.12
Oxygen	4.70	20.30	0.82
Nitrogen	0.90	0.50	2.35
Sulfur	1.00	0.15	6.74
Moisture	7.00	25.2	2.24
Ash	41.60	24.4	1.32
Chlorine (%)	0.04	0.45	--
Higher Heating Value (Btu/lb, A.R.)	7,677	4,450	14,017
Ash Elemental Analysis (% Dry)			
Al_2O_3	22.80	--	9.40
BaO	--	--	--
CaO	1.46	--	8.90
Fe_2O_3	12.00	--	31.6
K_2O	3.45	--	1.20
MgO	1.92	--	0.40
MnO	--	--	--
Na_2O	0.60	--	0.10
P_2O_5	0.27	--	--
SiO_2	56.90	--	23.6
SrO	--	--	--
TiO_2	1.02	--	0.40
SO_3	1.18	--	2.0

Table 4: Example of Waste Fuel (Waste Coal and MSW) and Opportunity Fuel (Petroleum Coke)

ADVANTAGES OF CFB FIRING

Circulating fluidized bed combustion has several advantages. With longer residence times when compared to a typical pulverized coal boiler, larger fuel particles can be used. This eliminates the need for coal pulverizers thus reducing auxiliary power consumption. By adding limestone, sulfur emissions can also be minimized and in-situ sulfur capture may eliminate the need for a downstream scrubber. Flue gas NOx emissions are inherently low due to the relatively low combustor temperature.

A wide variation of fuels can be burned. The fuels considered include high sulfur coals, low rank coals, biomass, waste fuels, and other opportunity fuels. Many of these fuels can be fired successfully in CFB boilers. This flexibility includes fuels with a very wide range of heating values that can be combusted with the hot circulating solids in a CFB. However, certain combinations of these fuels or other fuels cannot be fired successfully in CFB boilers, regardless.

ADDITIONAL DESIGN CONSIDERATIONS FOR BIOMASS COFIRING

CFB firing has certain inherent limitations with respect to fuel properties such as chlorine, alkalis and ash contents. Chlorine content can limit final steam temperature since it influences metal temperatures and the potential for corrosion. The chlorine limitation is driven by sulfur capture through limestone addition. The flue gas SO_2 concentration may not be sufficient to yield less corrosive alkali sulfates, depending upon the degree of in-furnace sulfur capture. When sulfur is removed from the combustion process, the sulfation reaction is minimized. As a result, chlorine can then exist as corrosive alkali chlorides that condense on tube surfaces.

The chlorine content of the fuel can also impact the configuration of heat transfer surfaces. For high chlorine fuels, high temperature surfaces (finishing superheat or reheater) may need to be placed out of the gas path in order to prevent corrosion. For these high chlorine fuels, Foster Wheeler incorporates these high temperature surfaces in its patented Intrex™ in the solids recirculation loop. Corrosion is minimized by having the heat transfer driven by the hot circulating solids instead of flue gas flow.

In addition, high concentrations of sodium and potassium will increase both the agglomeration and fouling potential and also the corrosion potential. Fuel alkalis that are readily released into the vapor phase during combustion can undergo complex reactions with flue gas constituents and fly ash and form low melting species. The concentration of these reactive alkalis is determined by their solubility during weak acid leaching of the fuel and can be used as an index of agglomeration and fouling potential. For biomass fuels, most of the alkalis are typically in a reactive form. Fuel ash content can influence the ability of these reactive alkalis to promote agglomeration and fouling. For high ash fuels the resultant alkali species tend to be diluted and may not reach sufficient concentrations in the bed to cause agglomeration. These alkalis will also tend to be diluted by the sorbent material for high sulfur fuels.

Fuel ash content can also have other important impacts on CFB operation. In order to have enough fluidizing bed material, the ash concentration cannot drop below a certain level. When firing fuels with lower ash concentrations, additional bed material may need to be added. Limestone sorbent can provide the sole source of bed material for low ash fuels such as petroleum coke that are high in sulfur content. These factors mentioned above, along with a few others, will determine the type of fuel and fuel blends that can be fired in CFB boilers.

CONCLUSIONS

Circulating Fluidized Bed (CFB) technology can fire many different fuels – high sulfur coals, low rank coals, biomass, waste fuels, and other opportunity fuels. The variation in fuel characteristics and combustion behaviors can vary drastically. When blended, the combination of the fuels will exhibit different combustion behaviors and should be treated as a brand new fuel. Certain fuels and fuel blends are better suited while others should not be fired, regardless. CFB firing has demonstrated and will continue to fire a variety of fuels, however proper considerations must be accounted for in both the design and operation of the boiler.

REFERENCES

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