Fuel Selection for Cofiring Biomass in Pulverized Coal and Cyclone Fired Boilers

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Abstract:

Cofiring is simply the blending of dissimilar fuels, with one being the dominant fuel (typically coal) and the other being the supplement. The principles of blending apply. Both biomass fuels and coals have wide variations in properties; these variations make some combinations of biomass and coal advantageous for the operator; other combinations can lead to significant disasters. Attention must be paid not only to the typical analyses (proximate, ultimate, ash elemental) but also to minor and trace species including halogens. Further, attention must be paid to measures of reactivity: kinetics, volatile evolution, and chemical fractionation are among these. Finally attention must be paid to the configuration of the boiler itself: wall fired vs. tangentially fired, mill capacity, fan capacity, tube spacing and tube material selection, main steam and reheat steam temperatures and—more importantly—consequent tube metal temperatures, instrumentation, presence or absence of a selective catalytic reduction (SCR) reactor for NO_x control, scrubbers, etc. If electrostatic precipitation is employed, then the characteristics of the ESP must be known. This paper considers the following biomass fuels: wood and wood waste, switchgrass, and corn stover. It considers a variety of coals including Powder River Basin (PRB) coals, Interior Province (Illinois basin) coals, Central Appalachian coals, and selected lignites. It also considers incorporation of other opportunity fuels (e.g., petroleum coke, tire-derived fuel) in the cofiring mix. It focuses upon the interactions between fuels, and the relationships between fuels and system characteristics.

Introduction

If cofiring involves 20% biomass, then it still involves 80% coal of one type or another. While the literature is replete with citations concerning the impact of different types of biomass on the process of cofiring, less attention has been given to the impact of different types of coal on the process of cofiring. Yet coals vary dramatically one from another as is shown in Table 1. Notice that the differences can come in a variety of ways:

- Heating value (Btu/lb)
- Reactivity measured either by fixed carbon/volatile matter (FC/VM) ratios from the proximate analysis, or by pyrolysis and char oxidation kinetics
- Moisture (%, lb/10^6 Btu)
- Ash (%, lb/10^6 Btu)

- Sulfur content (%, lb/10^6 Btu, lb/10^6 Btu as SO_2)
- Chlorine content (%, lb/10^6 Btu)
- Ash chemistry with particular attention to certain constituents—silica, alumina, iron, calcium, potassium, sodium

Table 1. Characteristics of Representative US Coals

Parameter	Central Appalachian (Long Fork)	Illinois Basin	Powder River Basin (Black Thunder)	Gulf Coast Lignite
Proximate Analysis (wt. % A.R.):				
Moisture	7.16	5.98	25.84	26.74
Ash	11.52	10.63	5.05	12.52
Volatile Matter	31.23	35.11	31.56	31.58
Fixed Carbon	50.09	48.28	37.55	29.16
Ultimate Analysis (wt. % A.R.):				
Carbon	66.93	60.68	51.89	31.80
Hydrogen	4.43	4.77	3.55	4.51
Oxygen	7.55	13.61	12.77	26.35
Nitrogen	1.34	1.09	0.67	0.59
Sulfur	1.07	3.24	0.23	0.84
Moisture	7.16	5.98	25.84	26.74
Ash	11.52	10.63	5.05	9.17
Chlorine (%)	0.12	0.30	0.01	--
Higher Heating Value (Btu/lb, A.R.)	12,114	10,334	8,943	7,613
Ash Elemental Analysis (% Dry):				
Al_2O_3	26.25	16.49	16.20	14.01
BaO	0.13	--	0.67	--
CaO	2.31	6.71	22.84	13.69
Fe_2O_3	8.38	20.41	6.02	7.39
K_2O	3.26	1.66	0.56	0.51
MgO	1.42	0.77	5.22	2.51
MnO	0.07	0.06	0.01	0.12
Na_2O	0.71	1.09	1.44	0.60
P_2O_5	0.56	0.45	1.57	0.39
SiO_2	51.99	39.19	32.76	38.17
SrO	0.19	--	0.36	--
TiO_2	1.07	0.84	1.28	1.15
SO_3	2.20	5.43	10.10	14.41

The various biomass fuels exhibit comparable dissimilarities as is shown in Table 2. Note that the particular wood waste sample has a very low silica content; silica in biomass ash can range from ~10% to >50%, depending upon the wood, harvesting practices, and a host of other variables. While the ranges of values are somewhat different from coals, the dissimilarities are also of considerable consequence.

Table 2. Characteristics of Representative Biomass Fuels

	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 (% A.R.):			
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
Typical Bulk Density (lb/ft^3)	18	5	7

Selected performance parameters for the coals, woody biomass, and switchgrass are shown in Table 3.

Table 3. Some Performance Parameters for Coals and Biomass Fuels

Parameter	Central Appalachian	Illinois Basin	Powder River Basin	Lignite	Wood waste	Switchgrass
HHV, Btu/lb A.R.	12,114	10,334	8,943	7,613	5,028	7,002
lb/10^6 Btu of Fuel	83	97	112	131	199	143
Fe_2O_3/CaO	3.63	3.04	0.26	0.54	0.03	0.36
lb Cl/mmBtu	0.10	0.29	0.01	0.01	0.03	0.26
lb (Na_2O + K_2O)/10^6Btu	0.38	0.28	0.11	0.13	0.49	1.41
lb S/10^6Btu	0.88	3.14	0.26	1.10	0.14	0.24
lb H_2O/10^6Btu	5.91	5.79	28.89	35.12	83.53	14.05
lb ash/10^6Btu	9.51	10.29	5.65	12.05	4.59	11.55
lb fuel N/10^6Btu	1.11	1.05	0.75	0.77	1.19	0.99
VM/FC Ratio	0.62	0.73	0.84	1.08	6.05	5.35
Cl/S molar ratio	0.12	0.10	0.05	0.01	0.21	1.17

At times, individual plants or utilities will consider biomass cofiring supplemented by opportunity fuels. Both TVA (Allen Fossil Plant) and Allegheny Energy Supply (Willow Island Generating Station) supplemented woody biomass with tire-derived fuel. NiSources (NIPSCO) blended petroleum coke with wood waste in the demonstrations at Bailly Generating Station. From a fuel handling operational perspective, complexity of the system can double each time an additional fuel is being handled. Combustion is similarly made more complex.

Biomass and Coal Blends: Some Effects

The dominant cofiring experience in the US has been with wood waste or switchgrass as the renewable energy resource, and eastern bituminous coal as the base fuel. At the same time there have been tests with alternative coals; for example, testing at Michigan City Generating Station was performed with a base coal blend of Black Thunder (PRB) and Shoshone (western bituminous) coals. Numerous laboratory tests have been conducted with the lower rank coals as well.

Some aspects of fuel blending can be analyzed by averaging while others can not. Table 3 presents many of those parameters that can be analyzed by direct averaging. Table 4 provides the analysis for woody biomass cofired with Central Appalachian coal—the most common approach taken to date.

Table 4. Impact of Cofiring Wood with Central Appalachian Coal

Parameter	0% Wood Cofiring	5% Wood Cofiring (Heat Input Basis)	10% Wood Cofiring (Heat Input Basis)	20% Wood Cofiring (Heat Input Basis)
Mass Percentage of Wood	0%	11.25%	21.12%	37.59%
Heating Value of Blend (Btu/lb)	12,114	11316.57	10617.65	9450.32
Base/Acid	0.20	0.22	0.24	0.29
Fe_2O_3/CaO	3.63	2.43	1.78	1.10
lb Cl / 10^6 Btu	0.10	0.10	0.09	0.08
lb (Na_2O + K_2O) / 10^6 Btu	0.38	0.39	0.39	0.41
lb SO_2 / 10^6 Btu	0.88	0.85	0.81	0.73
lb Fuel/ 10^6 Btu	83	88	94	106
lb H_2O/ 10^6 Btu	5.91	9.79	13.67	21.43
lb ash/ 10^6 Btu	9.51	9.26	9.02	8.53
lb fuel N/ 10^6 Btu	1.11	1.11	1.11	1.12
VM/FC	0.62	0.73	0.84	1.09
Cl/S molar ratio	0.12	0.12	0.13	0.13

Note several analytical issues resulting from high percentages of woody biomass:

- Significantly higher mass flows of fuel resulting from the very high mass percentages of biomass in the fuel blend; there is a 28% increase in fuel flow to achieve 20% biomass cofiring; there is a similar decrease in the heating value of the blend.

- Slagging and fouling is apt to increase. The base/acid ratio climbs from 0.2 to almost 0.3; while this is not dramatic for slagging and fouling it indicates possible problems; the lb alkali metals (Na_2O and K_2O) expressed in lb/10^6 Btu do climb over 0.4, indicating a possible slagging condition; and the Fe_2O_3/CaO ratio drops from 3.63 to 1.10—putting the fluxing ratio in the heart of the most difficult area to manage.

- Because the heating value decreases, the fuel flow increases, and the volatility increases, it is expected that the 20% cofiring case will fill the primary furnace with flame. Flames will be pushed upward to—and possibly past—the nose of any boiler designed for Central Appalachian coal.

It becomes interesting to compare the results of wood cofiring with switchgrass cofiring, as can be seen from Table 5. Note that Table 5 does not show the effects of bulk density; for the woody biomass the density is ~18 lb/ft^3 while for switchgrass the density is ~5 lb/ft^3.

Table 5. Calculated Results Cofiring Switchgrass and Central Appalachian Coal

Parameter	0% Cofiring	5% Switchgrass Cofiring (Heat Input Basis)	10% Switchgrass Cofiring (Heat Input Basis)	20% Switchgrass Cofiring (Heat Input Basis)
Mass Percentage of Switchgrass	0%	8.35%	16.12%	30.19%
Heating Value of Blend (Btu/lb)	12,114	11687.37	11289.76	10570.54
Base/Acid	0.20	0.21	0.22	0.23
Fe_2O_3/CaO	3.63	3.19	2.82	2.24
lb Cl / 10^6 Btu	0.10	0.11	0.11	0.13
lb (Na_2O + K_2O) / 10^6 Btu	0.38	0.44	0.49	0.59
lb SO_2 / 10^6 Btu	0.88	0.85	0.82	0.76
lb Fuel/ 10^6 Btu	83	86	89	95
lb H_2O/ 10^6 Btu	5.91	6.32	6.72	7.54
lb ash/ 10^6 Btu	9.51	9.61	9.71	9.92
lb fuel N/ 10^6 Btu	1.11	1.10	1.09	1.08
VM/FC	0.62	0.73	0.85	1.10
Cl/S molar ratio	0.12	0.14	0.16	0.19

What becomes more interesting is the impact of changing coals on the various analytical parameters. This is shown for 10% and 20% cofiring in Tables 6 – 9. Not all parameters are shown.

Table 6. Cofiring 10% Woody Biomass with Various Coals

Parameter	Central App	Illinois Basin	PRB	Lignite
Mass Percentage of Wood	21.12%	18.59%	16.50%	14.40%
Heating Value of Blend (Btu/lb)	10617.65	9347.56	8296.97	7240.74
Fe_2O_3/CaO	1.78	2.29	0.23	0.49
lb Cl / 10^6 Btu	0.09	0.26	0.01	0.01
lb (Na_2O + K_2O) / 10^6 Btu	0.39	0.33	0.15	0.17
lb SO_2 / 10^6 Btu	0.81	2.84	0.25	1.01
lb Fuel/ 10^6 Btu	94	107	121	138
lb H_2O/ 10^6 Btu	13.67	13.56	34.36	39.96
lb ash/ 10^6 Btu	9.02	9.72	5.54	11.30
lb fuel N/ 10^6 Btu	1.11	1.07	0.79	0.82
VM/FC	0.84	0.92	1.05	1.30
Cl/S molar ratio	0.13	0.10	0.06	0.02

Table 7. Cofiring 20% Woody Biomass with Various Coals

Parameter	Central App	Illinois Basin	PRB	Lignite
Mass Percentage of Wood	37.59%	33.94%	30.78%	27.46%
Heating Value of Blend (Btu/lb)	9450.32	8533.03	7737.98	6903.19
Fe_2O_3/CaO	1.10	1.75	0.20	0.44
lb Cl / 10^6 Btu	0.08	0.24	0.01	0.02
lb (Na_2O + K_2O) / 10^6 Btu	0.41	0.35	0.19	0.20
lb SO_2 / 10^6 Btu	0.73	2.54	0.23	0.91
lb Fuel/ 10^6 Btu	106	117	129	145
lb H_2O/ 10^6 Btu	21.43	21.34	39.82	44.81
lb ash/ 10^6 Btu	8.53	9.15	5.44	10.56
lb fuel N/ 10^6 Btu	1.12	1.08	0.84	0.86
VM/FC	1.09	1.14	1.29	1.54
Cl/S molar ratio	0.13	0.10	0.07	0.02

Table 8. Cofiring 10% Switchgrass with Various Coals

Parameter	Central App	Illinois Basin	PRB	Lignite
Mass Percentage of Biomass	16.12%	14.09%	12.43%	10.78%
Heating Value of Blend (Btu/lb)	11289.76	9864.58	8701.78	7547.14
Fe_2O_3/CaO	2.82	2.79	0.27	0.53
lb Cl / 10^6 Btu	0.11	0.29	0.04	0.04
lb (Na_2O + K_2O) / 10^6 Btu	0.49	0.42	0.25	0.25
lb SO_2 / 10^6 Btu	0.82	2.85	0.26	1.02
lb Fuel/ 10^6 Btu	89	101	115	133
lb H_2O/ 10^6 Btu	6.72	6.61	27.41	33.02
lb ash/ 10^6 Btu	9.71	10.41	6.24	12.00
lb fuel N/ 10^6 Btu	1.09	1.05	0.77	0.80
VM/FC	0.85	0.92	1.05	1.30
Cl/S molar ratio	0.16	0.11	0.15	0.04

Table 9. Cofiring 20% Switchgrass with Various Coals

Parameter	Central App	Illinois Basin	PRB	Lignite
Mass Percentage of Biomass	30.19%	26.95%	24.20%	21.37%
Heating Value of Blend (Btu/lb)	10570.54	9435.95	8473.23	7482.42
Fe_2O_3/CaO	2.24	2.53	0.27	0.53
lb Cl / 10^6 Btu	0.13	0.28	0.06	0.06
lb (Na_2O + K_2O) / 10^6 Btu	0.59	0.54	0.38	0.35
lb SO_2 / 10^6 Btu	0.76	2.56	0.25	0.93
lb Fuel/ 10^6 Btu	95	106	118	134
lb H_2O/ 10^6 Btu	7.54	7.44	25.93	30.91
lb ash/ 10^6 Btu	9.92	10.54	6.83	11.95
lb fuel N/ 10^6 Btu	1.08	1.04	0.80	0.82
VM/FC	1.10	1.14	1.29	1.54
Cl/S molar ratio	0.19	0.12	0.26	0.07

The influence of corn stover is similar to that of switchgrass and is not shown in tabular format. Note, however, that the significantly higher chlorine and potassium contents of the corn stover relative to the switchgrass. This will create more significant deposition and corrosion issues. Note, also, that the deposition and corrosion issues for switchgrass can be far more significant than for woody biomass as has been noted previously in the literature. What becomes interesting, and obvious, is that the effects of cofiring on fuel properties are largely diminished as the rank of coal decreases; this is obvious and much to be expected. The comparison between Central Appalachian bituminous coal and Illinois Basin coal is more fascinating and is caused by the sulfur, iron, and chlorine concentrations in the Illinois Basin coal.

When comparisons are made, the biomass fuels do not reduce the slagging and fouling characteristics of Illinois Basin coal significantly, nor do they contribute dramatically to the deposition and corrosion parameters of such fuels.

Blending with Other Opportunity Fuels

The Bailly Generating Station cofiring demonstration incorporated petroleum coke into the fuel blend. Petroleum coke is known to have high concentrations of vanadium and nickel, depending upon the source of the crude oil. The biomass was a low ash wood waste. Because the ash concentration in wood waste is typically low, this cofiring program was successful. However combinations of vanadium and potassium, or sodium, in ash streams of significance, can lead to the formation of vanidates that are significant problems. Given the concentrations of alkali metals and ash in switchgrass and corn stover, such practices would be harmful.

Alternatively, wood waste was fired with tire chips and coal at both the Allen Fossil Plant of TVA and the Willow Island Generating Station of Allegheny Energy Supply, LLC. In both cases, the tire-derived fuel increased the heat content of the blend without causing deleterious consequences.

Conclusion

Because all fuels vary as a function of source—coal deposit or specific source of biomass—the simplified analysis performed above needs to be performed for every project, and reasonably frequently. More attention needs to be paid to the characteristics of the coal—the base fuel—if cofiring is to be maximized and successful.

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