TECHNICAL PUBLICATION

Biofuel Conversions
The First Step — Fuel Selection

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Presented at

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ABSTRACT

One of the primary focuses in legislation today is increasing the amount of electricity generated by renewable fuel sources. The EPA states that as of March 2009 33 states have developed renewable portfolio standards (RPS), which require retail electricity sellers to use some percentage of renewable energy in their overall supply. The questions arise, as legislation becomes more stringent, can the current fleet be retrofitted to burn renewable fuels and if so what would be the first step?

This paper focuses on the initial fuel selection process and the various parameters that affect plant design:

- * *Moisture content*
- * *Higher heating value*
- * *Slagging and fouling*
- * *Corrosion and erosion*

This analysis of biofuels can help prevent costly corrosion, erosion, slagging, and fouling issues from occurring.

INTRODUCTION

Various programs being implemented by the Environmental Protection Agency (EPA) are making biomass boilers and retrofits more and more appealing. The Renewable Energy Credit (REC) market has made the possibility of converting to biomass fuels financially attractive. Depending on the market the REC can be anywhere from \$0.50 to \$150 per MWh. It is predicted that this year's compliance REC market will be worth over \$600 million.[7] Renewable Portfolio Standards (RPS) are being established in thirty-three (33) states. The RPS requires retail electricity sellers to use some percentage of renewable energy in their overall energy supply. Certain states, such as Oregon, Maine, Connecticut, Illinois, and Minnesota, are aggressively pursuing these standards with requirements upwards of twenty-five percent (25%).

Biomass fuels are also starting to be considered environmentally friendly. There is no net increase in CO_2 emissions from combustion; the CO_2 absorbed during growth is released during combustion.[5,6] This is referred to as CO_2 "neutral", which is a good position to be in, since CO_2 emissions regulations are being established in many areas. Most biomass fuels have very little to no sulfur, reducing the overall SO_2 emissions as well. However, to understand firing biomass fuel and converting existing boilers, biomass as a fuel must be understood. This understanding includes how fuel selection affects plant design. The parameters discussed are moisture content, higher heating values, slagging and fouling, corrosion, and erosion.

BIOMASS FUELS

The term "biomass" refers to any organic non-fossil fuel. There are four (4) primary classes of biomass:

1. Wood and woody materials
2. Herbaceous and other annual growth materials like straw, grasses, and leaves
3. Agricultural by-products and residues including shells, hulls, pits, and animal manures
4. Refuse derived fuels (RDF/processed garbage) and non-recyclable papers

Table 1 depicts a fuel from each of the four (4) primary biomass classes. Biomass constituents can vary between primary classes and even within their own classes. However, oxygen and carbon usually comprise the most abundant elements at 20-40% by wt. and 30-60% by wt, respectively.

Table 1

Typical Properties of Various Biomass Fuels[8]

		Wood Fuels	**Herbaceous**	**Agricultural**	**RDF**
Analysis	Unit	Wood Chip (40% Moisture) (As Rec'd)	Miscanthus (As Rec'd)	Rice Hulls (As Rec'd)	RDF (As Rec'd)
H_2O	%	40.70	14.54	10.94	19.50
Carbon	%	29.49	40.41	34.58	32.59
Hydrogen	%	3.62	4.92	4.23	3.86
Nitrogen	%	0.06	0.28	0.46	0.42
Oxygen	%	25.64	37.19	31.69	30.45
Sulfur	%	0.01	0.05	0.05	0.21
Ash	%	0.50	2.61	18.05	12.97
Chlorine	%	—	0.05	0.11	> 0.04
HHV	Btu/lb	4,958	6,879	6,065	5,446

General characteristics show that woods have greater carbon content than herbaceous and agricultural biomass on a dry basis, while abundant amounts of Chlorine can be found in herbaceous and agricultural materials versus wood. Herbaceous fuels also have higher contents of Potassium (K) and Silicon (Si), which can lead to slagging and fouling issues.[5] RDF can contain significant quantities of Chlorine (Cl) due to plastics (PVCs) and other wastes that get burned.

A majority of herbaceous and agricultural biomass fuels are crops and are produced for short periods during the year, this differs significantly from fossil fuels. Additional biomass fuel sources are typically required for periods of fuel shortages or adequate fuel storage should be provided. Long-term storage can be difficult due to the different bulk densities of biomass fuels.

Example:

Assume the following:

100,000 lb/hr boiler requiring a 1 week on site supply of fuel. The two fuels being burned will be from Table 1, Wood Chips and Rice Hulls.

Bulk density of wood chips = 28 lb/ft3

Bulk density of rice hulls = 8 lb/ft3

Wood chip fuel flow = 30,700 lb/hr

Rice Hull fuel flow = 23,000 lb/hr

Assume a 20ft diameter by 500ft high silo will be used for storage. The total number of silos required to store the rice hulls is 3 as compared to the wood chips at 1. Wood chips have a higher bulk density and there for take up less space than certain types of agricultural and herbaceous fuels.

Currently, industrial and utility plants alike monitor their fuels to make sure that they are in compliance with the contract specifications. They typically monitor moisture, ash, and higher heating value. The elemental ash composition is another fuel characteristic that needs close monitoring in the case of biomass fuels. The ash composition allows the plant to monitor the content of alkali in the fuel, which can indicate a propensity for a fuel to slag and foul a unit. The alkalis typically consist of potassium “K” and sodium “Na”, in the forms of K_2O and NaO.[4]

MOISTURE AND HIGHER HEATING VALUE (HHV)

The amount of moisture a fuel has can severely affect a boilers performance in several ways. The three primary impacts are on fuel flow, combustion airflow, and boiler efficiency.

Fuel Flow

The moisture of a fuel directly impacts the High Heating Value (HHV). The greater the moisture the lower the HHV and the more fuel needed to achieve the same steaming capacity.

Table 2

Fuel Analysis Varying Moisture Content

Fuel Analysis							
H_2O	%wt.	0.00	40.00	45.00	50.00	55.00	60.00
C	%wt.	51.22	30.74	28.17	25.61	23.05	20.49
O_2	%wt.	41.94	25.16	23.07	20.97	18.87	16.78
N_2	%wt.	0.22	0.13	0.12	0.11	0.10	0.09
H_2	%wt.	5.56	3.34	3.06	2.78	2.50	2.22
Cl	%wt.	0.00	0.00	0.00	0.00	0.00	0.00
Ash	%wt.	1.02	0.61	0.56	0.51	0.46	0.41
S	%wt.	0.04	0.02	0.02	0.02	0.02	0.02
Total	—	100.00	100.00	100.00	100.00	100.00	100.00
HHV	Btu/lb	7,649	4,589	4,207	3,824	3,442	3,059

Table 2 uses a typical 50% moisture fuel analysis to show the affect moisture variation has on fuel constituents. The moisture was then varied to show the change in HHV as the moisture increased and decreased over a 60% moisture range, shown in Figure 1. The moisture in the fuel dilutes the % by wt. of the other components causing the HHV to go down, which in return increases the total amount of fuel fired, shown in Figure 2.

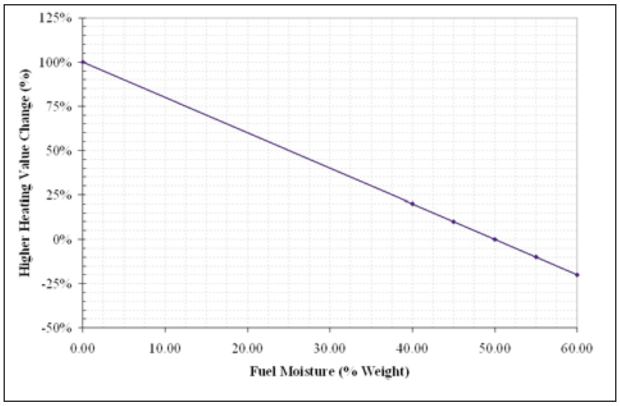

Figure 1: Effect of Moisture on HHV

COMBUSTION AIR FLOW

The increase in fuel consumption increases the combustion air required in order to obtain “complete” combustion. Cases of high moisture fuels require hotter undergrate air to assist in the evaporation of the fuel moisture and improve the combustion process.

Boiler Efficiency

When the moisture in a fuel increases the boiler efficiency decreases. The root cause of the decrease in efficiency is the loss of heat converting fuel bound liquid water to vapor. A 10% increase in fuel moisture can decrease the boiler efficiency by 7% and the reverse is also true, shown in Figure 2. The change in boiler efficiency directly effects the fuel flow requirements.

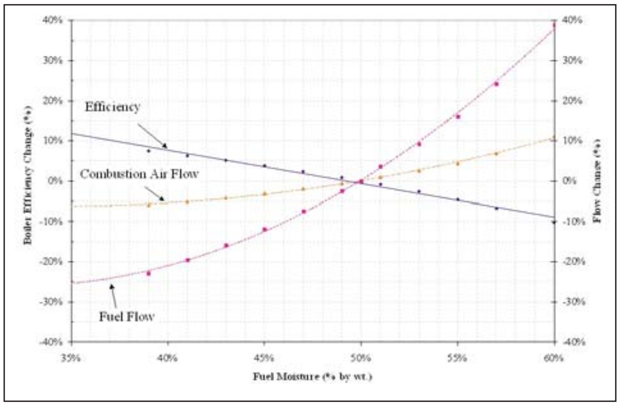

Figure 2: Moisture effect on Fuel Flow, Combustion Air Flow, and Boiler Efficiency

SLAGGING AND FOULING

The slagging and fouling characteristics of biomass ash can not be compared to those of coal because the constituents can vary significantly. The alkali index method for determining slagging and fouling has become the most popular and fairly accurate indicator. [3, 10, 11] Table 3 shows the corresponding elemental ash composition to the fuels shown in Table 1. It also shows the calculated alkali index for these fuels. The ash's tendency to slag and foul increases as the alkali index increases. Along the same lines, the greater percent ash in the fuel in conjunction with a greater quantity of alkalis in the ash increases this tendency as well.

Table 3

Elemental Ash Analysis[8]

		Wood Fuels	Herbaceous	Agricultural	RDF
Analysis	Unit	Wood Chip (40% Moisture) (As Rec'd)	Miscanthus (As Rec'd)	Rice Hulls (As Rec'd)	RDF (As Rec'd)
SiO_2	%	1.44	61.84	91.42	33.81
Al_2O_3	%	0.41	0.98	0.78	12.71
TiO_2	%	0.11	0.05	0.02	1.66
Fe_2O_3	%	0.15	1.35	0.14	5.47
CaO	%	31.00	9.61	3.21	23.44
MgO	%	6.81	2.46	< 0.01	5.64
Na_2O	%	0.35	0.33	0.21	1.19
K_2O	%	26.60	11.60	3.71	0.20
SO_3	%	1.53	2.63	0.72	2.63
P_2O_5	%	4.47	4.20	0.43	0.67
Undetermined	%	23.33	4.95	0.00	12.58
Total	%	100	100	100	100
Alkali Index	%	0.27	0.45	1.17	0.33

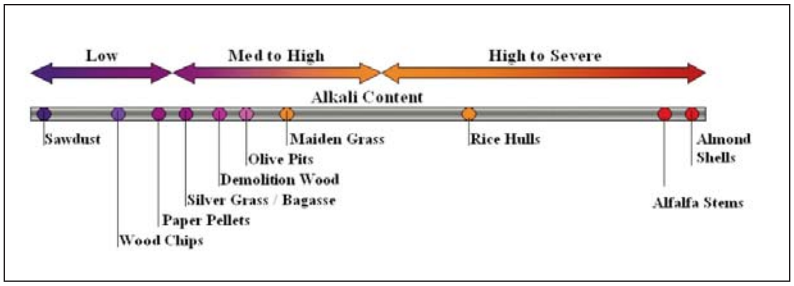

Figure 3: Various Biomass Fuels Slagging and Fouling Tendencies

If co-firing of various biomass fuels is considered, each fuel's alkali index should be evaluated. The co-fired mixture should then be evaluated on a fuel weight percentage basis. [10, 11, 12] Figure 3 represents the slagging and fouling tendencies for various biomass fuels going from low to severe, based on alkali content. Note that the woody biomass fuels are near the lower end and the agricultural and herbaceous fuels are closer to the high/severe end. This is consistent with the fact that agricultural and herbaceous fuels have high K and Na contents as previously stated.

Fuels with higher quantities of sodium oxide (Na_2O) and potassium oxide (K_2O), have lower the ash fusion temperatures. The reduction in ash fusion temperature increases the propensity for molten ash deposits to form on the heat transfer surfaces.[2, 5] This ash "blanket" decreases heat transfer, increases flue gas temperature, which ultimately decreases boiler efficiency. Deposits can be controlled by more frequent sootblowing or installation of new sootblowers for better coverage.[1, 4] In new boiler designs this would be considered and the tube spacing to make cleaning easier. Severe fouling can also lead to tube bundle pluggage, high flue gas flow stratification, and tube erosion.

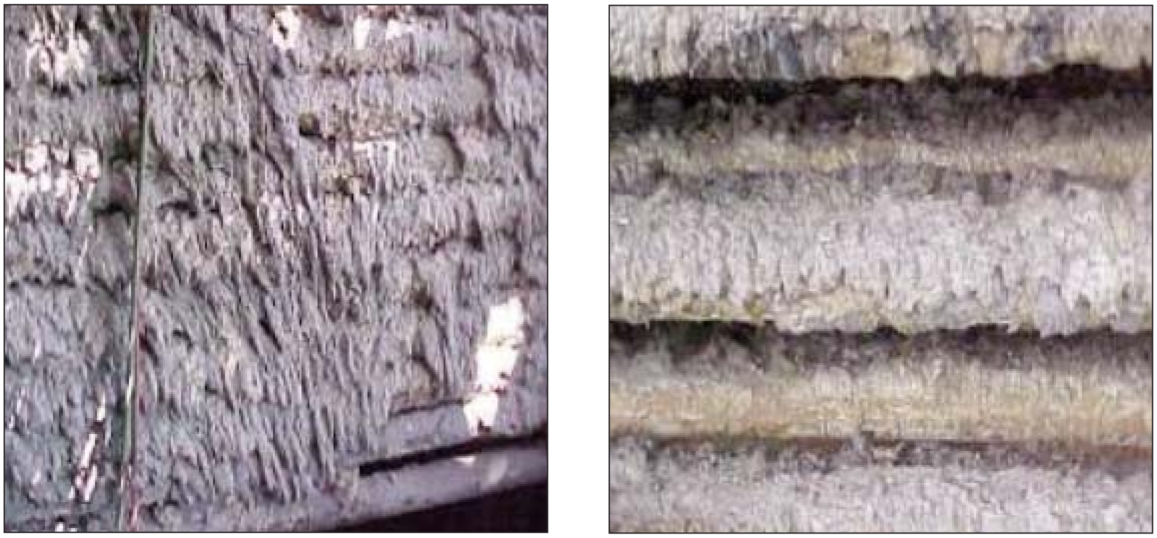

Figure 4: Examples of slagging and fouling on heat transfer surfaces

CORROSION AND EROSION

Corrosion

The two (2) major types of corrosions that occur in biomass boilers are:

- Sulfur based cold-end corrosion
- Chlorine based high temperature corrosion

Cold end corrosion issues can take place in two (2) different locations in the boiler, at the outlet of the economizer, and at the cold end of the air heater (AH). Cold-end corrosion can be controlled typically by maintaining the economizer or AH tube metal temperature above the SO_2/SO_3 condensation points.

Chlorine corrosion can be caused by components in the gas phase, by deposits on heat transfer surfaces, or by a combination of both. [9] The direct contact of chlorine on metal alloys causes the metal to oxidize and eventually the tubing will need replacement. Overlaying tubes with higher quality materials, such as Incoloys, can inhibit chlorine corrosion on furnace waterwalls and superheaters.

Erosion

Tube erosion is typically due to sand/silica imbedded in biomass fuels. Erosion can be concerning where high ash content coincides with a high Silica (Si) content in the ash composition. In general, this type of erosion can be deterred if the flue gas velocities are maintained below fifty (50) feet per second through the tube bundles.

Figure 5: Examples of corrosion and erosion prevention techniques

SUMMARY

Biomass fuel selection is a very important step in the design of a new boiler or biomass conversion. Each fuel's characteristics can affect boiler performance in significantly different ways due to the vast variations in composition. Monitoring of fuel moisture can help prevent loss in boiler efficiency, increases in fuel consumption, and increases in combustion air requirements. Requiring the analysis of the elemental ash composition can help control possible slagging and fouling issues from occurring. Fuels that have high slagging and fouling potential can reduce the effectiveness of heat transfer surfaces, increase fuel flow, increase stack temperature, and decrease boiler efficiency. Adding weld overlay can help inhibit or possibly prevent heat transfer surface corrosion and erosion, which reduces the frequency of heat transfer surface replacements. Plants can properly design for specific problematic biomass fuels by utilizing the methods outlined in this paper. Thus, adding significant weight to their renewable energy portfolio.

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