Biomass Cofiring and Its Effect on the Combustion Process

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ABSTRACT

Over the last two decades, there have been many cofiring demonstrations which have evaluated the combustion of biomass with coal. These demonstrations have addressed issues of capacity, efficiency, emissions and some combustion effects. Many studies of the combustion processes associated with cofiring have exhibited a limited understanding of the fundamental chemistry and the processes by which combustion occurs. Historically, burning profiles have been used to study certain combustion properties of fuels and fuel blends. In order to increase the understanding of combustion processes in cofiring applications, a study has been undertaken to evaluate the combustion of Central Appalachian Eastern Bituminous coal with selected highly reactive biomass fuels – looking at both the parent fuels and blends. The biomass fuels utilized in this study include woody material, switchgrass, and corn stover. A thorough literature review was conducted of over 100 papers and articles to review the cofiring experiences to date and compare previously experimented fuel blends. A detailed laboratory test program and associated analysis followed. The results of this work provide additional data concerning the combustion processes of cofiring by developing and studying distinct burning profiles determined by Thermogravimetric Analysis (TGA). These findings suggest that further research may be useful for improving the blending and cofiring of biomass with coal, which is essential to assist the power industry reduce the carbon footprint of coal-fired generating stations.

INTRODUCTION

Over the last two decades, there have been many cofiring demonstrations and the experience has been substantial. Experiences have ranged from laboratory and experimental results to full scale demonstrations, the latter of which are shown below.

Representative cyclone cofiring demonstrations including plant name, owner, coal, and biomass form (Tillman, 2001):

- Allen Fossil Plant, TVA – Illinois Basin Coal/Sawdust
- Allen Fossil Plant, TVA – Utah Bituminous Coal/Sawdust
- Allen Fossil Plant, TVA – Trifire with Tire-derived Fuel (Sawdust)
- Michigan City Generating Station, NIPSCO – PRB Coal (UWW)

- Bailly Generating Station, NIPSCO – Coal Blends and Pet Coke (UWW)
- Willow Island Generating Station, Allegheny – Trifire with TDF (sawdust)
- LaCygne Generating Station, KCP&L – Railroad ties and PRB
- King Station, Northern States Power – Dry fine wood dust and PRB coal

Representative pulverized coal cofiring demonstrations including plant name, owner, coal, and biomass form (Tillman, 2001):

- Plant Hammond, Georgia Power (blended wood/coal)
- Plant Kraft, Savannah Electric (separate injection, wood)
- Kingston Fossil Plant, TVA (blended wood/coal)
- Colbert Fossil Plant, TVA (blended wood/coal)
- Shawville Generating Station, GPU (blended wood/coal)
- Seward Generating Station, GPU (separate wood injection)
- Albright Generating Station, Allegheny (separate injection)
- Blount St. Station, MG&E (separate injection, switchgrass)
- Plant Gadsden, Alabama Power (sep inj, switchgrass)
- Ottumwa Generating Station, Alliant (sep inj, switchgrass)
- Greenidge Generating Station, NYSEG (separate sawdust injection)
- Pickway Generating Station, AEP (blended wood/coal)

In general, the combustion of biomass with coal is understood. However, understanding of the detailed processes by which combustion takes place, and details of the interaction between coal and biomass, is limited. The understanding of the fundamental chemistry and the process by which combustion occurs must be strengthened if cofiring is to be optimized. This work attempts to deepen this knowledge by studying the burning profiles through Thermogravimetric Analysis (TGA) and the associated Differential Thermogravimetric Analysis (DTG).

Pursuing this analysis required both an extensive literature search and laboratory experiments. The literature search (Duong, 2010) considered research methods for evaluating fuel reactivity, cofiring research, and cofiring demonstrations. Particular emphasis was given to TGA and DTG analysis, focusing on the development of burning profiles. Both the strengths and limitations of this analytical technique were pursued. Of particular interest was research on biomass and cofiring reactivity pursued both by The Energy Institute of Pennsylvania State University and Foster Wheeler (see Bradley et. al., 2009; Tillman et. al., 2009; Tillman et. al., 2004). This research demonstrated that the biomass fuels are highly reactive, as a function of structure, and that blending them with coal in cofiring applications increases the reactivity beyond that of either parent. This research was based upon drop tube reactor (DTR) testing measuring reactivity—pyrolysis kinetics—for parent fuels and blends.

EXPERIMENTAL METHODOLOGY

Pursuing the measurement of reactivity by burning profiles, numerous experiments were conducted. Three types of biomass were used: mixed hardwood-softwood wood waste, corn stover, and switchgrass. A single coal—an eastern bituminous coal—was selected as the primary fuel. Blends containing 10, 20, and 30 percent biomass, on a mass basis, were tested. Table 1 presents the proximate and ultimate analysis of these fuels.

Table 1: Standard Analysis of the Parent Fuels (Dry and As Received Basis)

Parameter	**Wood Waste**		**Corn Stover**		**Switchgrass**		**Eastern Bituminous Coal**	
Proximate Analysis	Dry Basis	As Rec'd	Dry Basis	As Rec'd	Dry Basis	As Rec'd	Dry Basis	As Rec'd
Total Moisture	--	45.54	--	5.25	--	14.23	--	6.53
Ash	3.14	1.71	13.73	13.01	2.25	1.93	17.28	16.15
Volatile Matter	77.99	42.48	70.32	66.63	80.88	69.37	30.40	28.42
Fixed Carbon	18.87	10.28	15.95	15.12	16.87	14.47	52.32	48.90
Total	100.00	100	100.00	100	100.00	100.00	100.00	100.00
Ultimate Analysis								
Carbon	50.42	27.46	43.68	41.39	49.09	42.10	72.19	67.48
Hydrogen	6.78	3.69	6.71	6.36	6.86	5.88	5.13	4.80
Nitrogen	0.30	0.17	3.73	3.54	0.21	0.18	1.33	1.24
Sulfur	0.06	0.03	1.42	1.35	0.09	0.08	0.74	0.69
Oxygen	39.30	21.40	30.72	29.11	41.50	35.59	3.33	3.11
Ash	3.14	1.71	13.73	13.01	2.25	1.93	17.28	16.15
Total Moisture	--	45.54	--	5.25	--	14.23	--	6.53
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Higher Heating Value (Btu/lb)	10,766	5,863	7,224	6,845	8,149	6,989	12,020	11,235
Typical Reactivity Measures								
VM/FC		4.13		4.41		4.79		0.58
H/C		1.600		1.830		1.663		0.847
O/C		0.585		0.527		0.634		0.035

All coal samples were pulverized to <60 mesh, and biomass fuel samples were pulverized to <200 mesh; samples were then characterized according to ASTM procedures and then blended as required by the testing. Samples were placed into a platinum pan; sample sizes in the range of 15 – 30 mg were used for each test run. The fuel samples were then heated within the furnace from ambient temperature to the range of 800°C (1470°F) to 1000°C (1830°F), dependent on how fast the fuel burned to completion. Precise weight loss measurements were conducted by the TGA instrument, heated at 20°C/min. The TGA analysis was evaluated at 10°C/min, 20°C/min, and 50°C/min. The 20°C/min rate was chosen as the most appropriate. Heating was terminated at 800 – 1000°C depending upon burnout completion of the sample. Based on the weight loss curve derived from TGA analysis, derivative thermogravimetric analysis (DTG) was calculated. DTG is essentially the slope of the weight loss curve. DTG curves are the burning profiles of the fuels and are essential to clearly observing the onset and behavior of each of the combustion processes. Two, and periodically three tests were conducted of the same blend in order to ensure reproducibility of results.

In addition to the DTG curves, this experimentation documented the temperature of initiation (T_{init})—when pyrolysis or devolatilization commenced—for each blend. T_{init} provides yet another measure of reactivity, and a measure of the ease of ignition of the fuel or fuel blend.

RESULTS

The results for woody biomass are shown in Figures 1 – 5. These show the comparative TGA and DTG curves. Table 2 presents the T_{init} values for both the parent fuels and blends. Similar curves and data have been developed for coal/corn stover and coal/switchgrass blends.

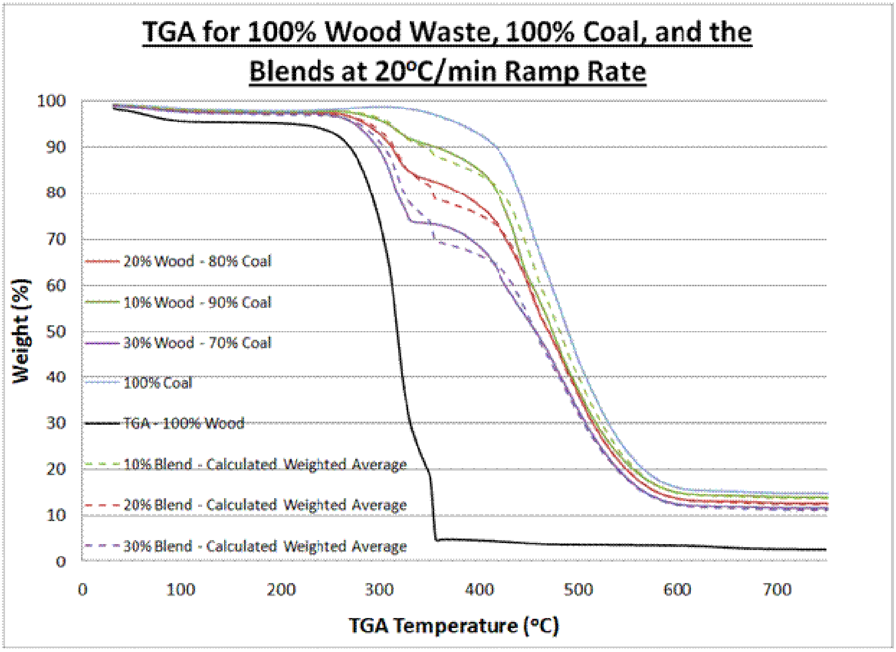

Figure 1. TGA Curves for wood waste, coal, and the blends.

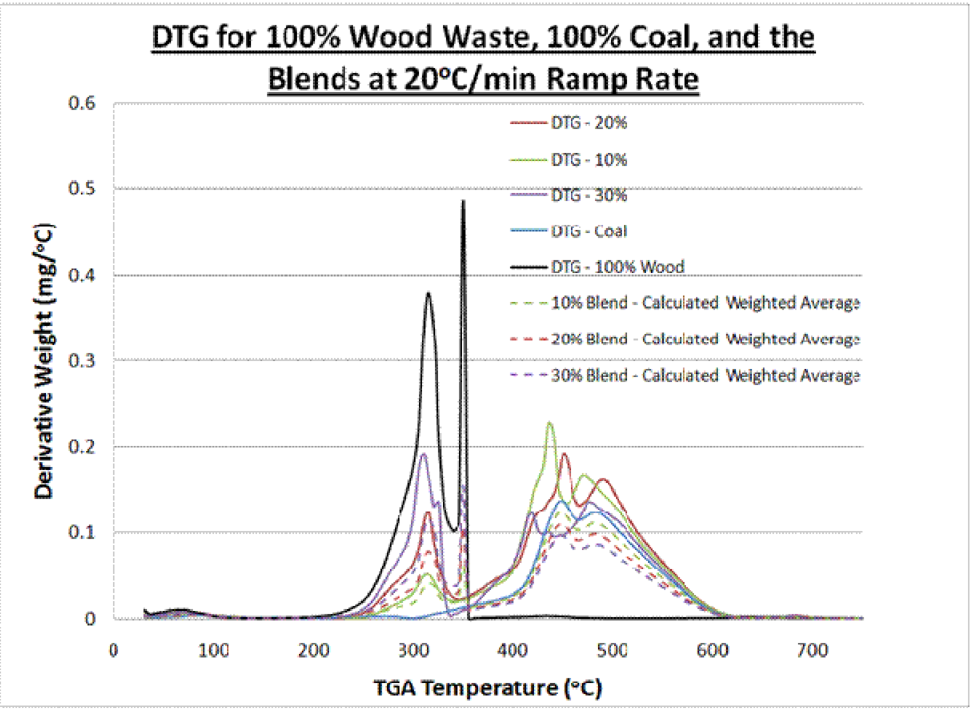

Figure 2. DTG curves for wood waste, coal, and the blends.

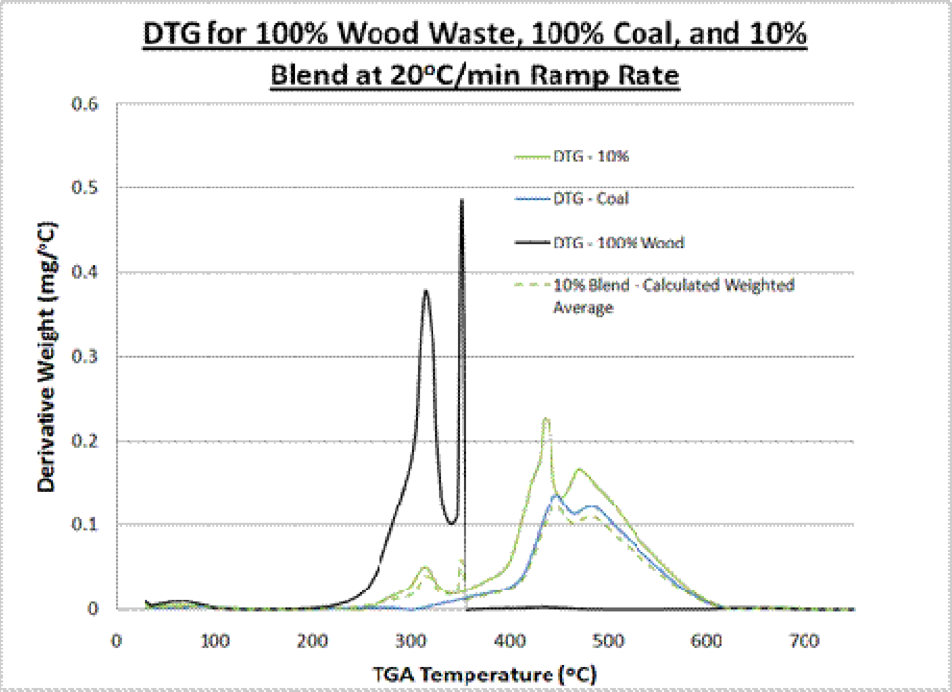

Figure 3. DTG curves for wood waste, coal, and the 10% cofiring blend.

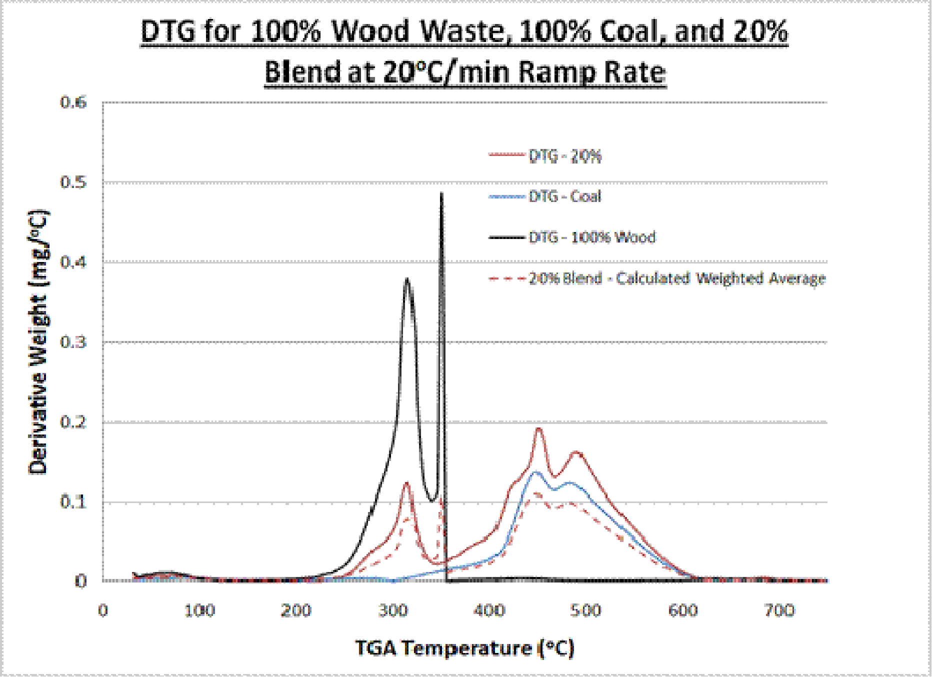

Figure 4. DTG curves for wood waste, coal, and 20% cofiring blend

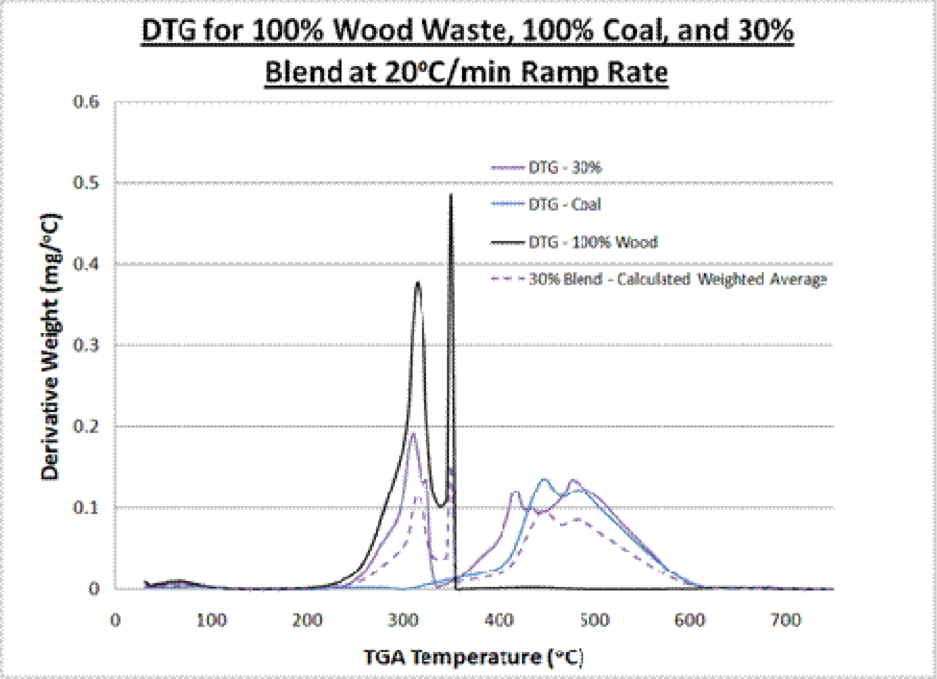

Figure 5. DTG curves for wood waste, coal, and 30% cofiring blend

Table 2. Temperature of Initiation Values for Wood Waste, Coal, and Cofiring Blends

Fuel/Blend	**Temperature of Initiation for Pyrolysis (^{o}C)**	**Calculated Weighted Average Temperature (^{o}C)**
100% Wood Waste	250	--
10% Wood Waste, 90% Coal	260	322
20% Wood Waste, 80% Coal	265	314
30% Wood Waste, 70% Coal	270	306
100% Coal	330	--

The results for corn stover virtually paralleled the results for woody biomass. The results for switchgrass were somewhat different as is represented by Figure 6. The results for T_{init} did parallel those of wood and corn stover as is shown in Table 3.

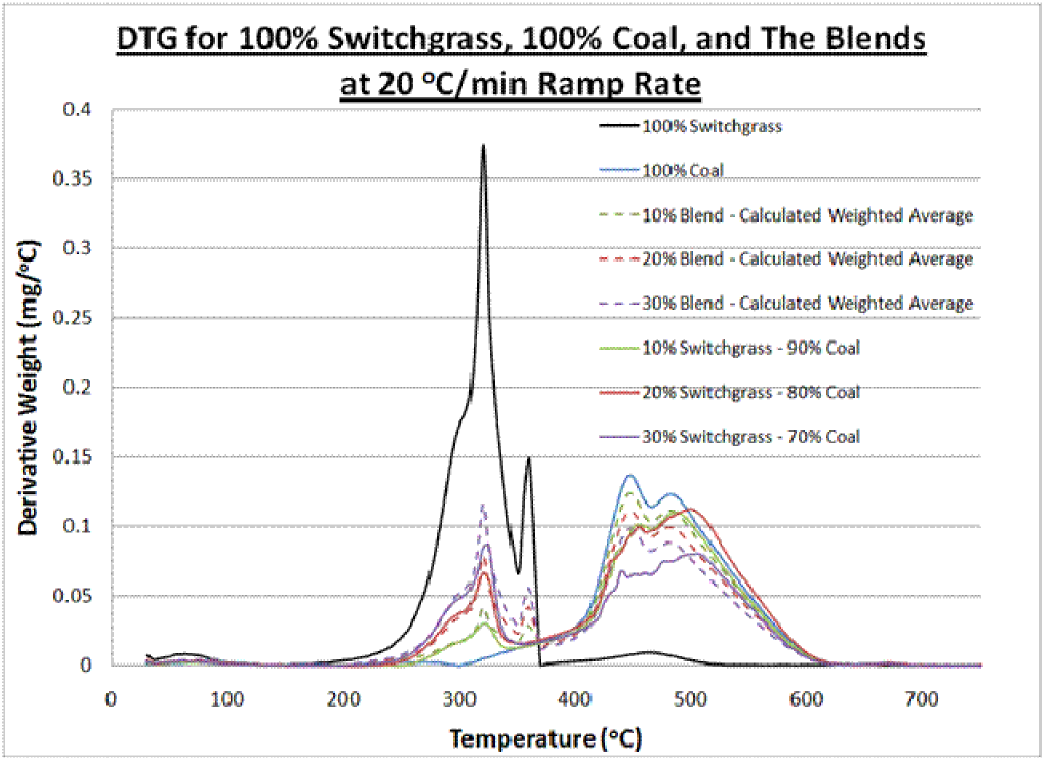

Figure 6. DTG Curves for coal, switchgrass, and the cofiring blends

Table 3. Temperature of Initiation for Switchgrass, Coal, and Associated Cofiring Blends

Fuel/Blend	**Temperature of Initiation for Pyrolysis (^oC)**	**Calculated Weighted Average Temperature (^oC)**
100% Switchgrass	240	--
10% Switchgrass, 90% Coal	260	321
20% Switchgrass, 80% Coal	265	312
30% Switchgrass, 70% Coal	270	303
100% Coal	330	--

DISCUSSION

The data in Figures 1 – 5 clearly show that blends of woody biomass and bituminous coal exhibit significant reactivity as a function of the blending or cofiring process. The blends are significantly more reactive than the weighted average of the two parent coals would suggest. Similarly the T_{init} values show the influence of blending or cofiring on the reactivity and the ease of ignition of the fuel mass. This is consistent with the results from the drop tube reactor at Pennsylvania State University (see Tillman et. al., 2009).

The data in Figure 6 show that the blending of switchgrass with coal suppresses the reactivity of the blend, relative particularly to the switchgrass but also with respect to the weighted average of the fuels. The switchgrass, as supplied, was old and perhaps exhibited the consequences of weathering when subjected to TGA analysis. At the same time the T_{init} values do support the concept that blending improves reactivity beyond that which would be expected by weighted averaging.

High reactivity of blends, relative to parent fuels, is not unusual. This has been shown for blends of bituminous coal and Powder River Basin (PRB) coals previously (see Tillman et. al., 2009). It has been suggested that this is a consequence of oxygen concentrations in the low rank coals or biomass fuels. It also may be that the lower rank coals slightly increase the hydrogen/carbon atomic ratios of the blends. As yet, no mechanisms have been elucidated to explain why this disproportionate increase in reactivity exists.

CONCLUSION

The blending of biomass with bituminous coal has, for the most part, increased the reactivity of the blends beyond that which would be predicted by weighted averages. There are some notable exceptions, however, including the DTG curves associated with the coal/switchgrass blends tested. The anomaly of switchgrass merits further investigation. At the same time more research needs to be performed in order to determine the mechanisms creating this reactivity.

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