ENHANCING THE FUEL VALUE OF WOOD PELLETS WITH THE ADDITION OF LIGNIN

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Abstract. Because of the increased cost of petroleum-based energy production, there is renewed interest in the use of wood for energy. In particular, residential heating using wood pellets has experienced a large increase during the last decade. Manufacturers of wood pellets are interested in producing high-quality, high fuel-value pellets. In this study, lignin was explored as an additive to wood to enhance pellet fuel value. Two types of lignin were examined in the production of wood pellets, Kraft black liquor and Indulin AT (IAT). Lignin was added to a softwood furnish and pellets were prepared on a commercial California Pellet Mill. The pellets were analyzed for fuel value, moisture content, and quality. Those prepared with IAT produced better quality pellets and had a higher fuel value than with Kraft black liquor. The Kraft black liquor pellets were soft and spongy and easily fell apart. A cost analysis indicates that lignin preparation will have a major impact on the feasibility of adding lignin to wood pellets to enhance fuel value.

Keywords: Wood pellets, Lignin, Kraft black liquor, Indulin AT, fuel value, moisture content.

INTRODUCTION

Demand for residential wood pellet stoves experienced a large increase during the last decade because of increased cost for fossil fuel-based heating and a renewed interest in renewable energy. Wood pellets are typically prepared from wood residues from secondary wood processing of softwoods or hardwoods. There are voluntary pellet standards promulgated by the Pellet Fuels Institute that specify targets for pellet material properties such as bulk density, moisture content, ash content, heating value, and durability. There is active research on understanding the variables influencing the conversion process of wood residues into pellets (Nielsen et al 2009). Softwood species are often more easily pelletized than hardwoods because of lower bulk density. Although softwoods have a slightly higher average heat of combustion (White 1987), from a practical standpoint, regardless of the wood source, pellets typically have a fuel value of approximately 18.6 MJ/kg at 6% MC.

One area of inquiry receiving attention in the manufacture of wood pellets is enhancing the fuel value by functional additives. This is not novel because the combination of wood and coal has been examined (Chen and Workman 1990). Coal has a higher heating value than wood, therefore adding coal to wood pellets increases the heating value by the "rule of mixtures." It was therefore

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hypothesized that the heating value of wood pellets could be increased with the addition of lignin. Because lignin has a higher carbon and hydrogen and lower oxygen content than the polysaccharides in wood, it has a higher heating value (25.6 MJ/kg; Rowell 1984).

Lignin is extracted during the pulping process and its removal leads to better paper strength properties. The two primary industrial chemical pulping methods are the sulfite and Kraft processes, and the focus of this study was on using Kraft process lignin which is the predominant process used in Maine. In the Kraft process, extracted lignin is contained in the black liquor, which is comprised of lignin, degraded cellulose fibers, hemicelluloses, sodium hydroxide, and sodium sulfide. Black liquor goes through a recovery process, where the "cooking chemicals" are recovered to be reused in the pulping process. Black liquor is part of the waste stream and is considered to be an ideal additive to increase the heating value of wood pellets. In modern pulp mills, energy can be saved by extracting lignin to debottleneck the recovery boiler and use it to produce energy (Laaksometsa et al 2009).

The overall goal of the research was to explore the enhancement of wood pellet fuel value by the addition of lignin.

METHODS AND MATERIALS

Wood

Mixed softwood sawdust furnish, pine, spruce, and fir at 6-7% MC was obtained from a local manufacturer for processing into pellets. The wood pellet furnish was a commercial material typically used for processing, requiring no additional drying.

Lignin

A commercial lignin preparation (Indulin AT [IAT]) was obtained from Mead WestVaco, Charleston, SC, in a powder form at 5% MC. IAT is a high-purity lignin with less than 1% ash based on the Technical Data sheet. Kraft black liquor containing lignin was obtained from a local pulping manufacturer. Solids content was determined by oven-drying and an elemental composition analysis was conducted to determine inorganics. The presence of noncombustible inorganics may affect the thermal properties of the wood pellets. The total carbon and total nitrogen levels were determined using combustion analysis, while the inorganics analysis was performed using inductively coupled plasma (ICP-OES) after acid digestion by EPA Method 3010 (Edgell and Wilbers 1989) in the Department of Plant, Soils, and Environmental Sciences.

Pellet Furnish Preparation

Samples of the lignin pellets were prepared by mixing the wood with 2-10 wt% lignin. The samples were mixed using a power hand-drill mixing attachment in a 20-L container and sealed to retard ambient moisture uptake. For each lignin loading level, six 20-L containers of furnish were prepared with 3.2 kg of material. Black liquor pellet material was also prepared using softwood flour using the same process as with the powdered lignin pellets. The black liquor was extremely viscous and had to be scraped from the secondary container into the 20-L container to be mixed with the wood furnish. Six containers of 3.2 kg of wood–black liquor furnish were prepared. The resulting pellets were analyzed for fuel content by combustion calorimetry in the Department of Chemical and Biological Engineering. The lignin pellet formulations are listed in Table 1.

Pellet Preparation

For the preparation of pellets for each of the different wood pellet formulations, a commercial scale California Pellet Mill (CPM) was used with the cooperation of a local wood pellet manufacturer. The pellet mill had a die with 4200 openings, all with an effective 6-mm dia and 37-mm depth. The lignin–wood samples were pelletized and the current draw of the 3-phase, 480 VAC of the CPM was recorded. Before and

Table 1. Lignin pellet furnish formulations.

Pellet	Wood (%)	Lignin (%)	Black liquor[a] (%)	Wood (kg)	Additive (kg)
Control	100			3.20	
2% Lignin	98	2		3.12	0.06
4% Lignin	96	4		3.05	0.13
6% Lignin	94	6		2.99	0.19
8% Lignin	92	8		2.93	0.25
10% Lignin	90	10		2.86	0.32
2% Black liquor	97.1		2.9	3.09	0.09
4% Black liquor	94.3		5.7	3.00	0.18
6% Black liquor	91.4		8.6	2.91	0.27
8% Black liquor	88.6		11.4	2.82	0.36
10% Black liquor	85.7		14.3	2.73	0.45

[a] Sixty-eight percent solids adjusted to 70% for processing losses.

after each loading level was pelletized, several containers of control sawdust were run through the CPM to ensure an uncontaminated sample. The control wood was taken from the sawdust at the plant, which was dried and ready to be pelletized for commercial pellets. This ensured the control pellets would be representative of standard pellets used for home heating. The moisture contents of the pellets were measured.

RESULTS AND DISCUSSION

The fuel values for the lignin-enhanced wood pellets are shown in Table 2. The IAT wood pellet samples increased in fuel value as a function of loading level. This was expected because lignin has a fuel value of 25.6 MJ/kg and adding more to the wood should increase the fuel value. However, the black liquor pellets decreased fuel value with increased loading levels. This was initially unexpected, but after a closer examination of the data, the reduction in fuel value is a reflection of the composition of the black liquor. The black liquor contained 68% solids, therefore as the loading increased so did the moisture. Another factor was the presence of inorganic salts, which would not contribute to heat content during combustion. The combination of these may have caused the steady decrease in heating value with increased levels of loading. It should be pointed out that the use of higher solids black liquor in the wood pellets also may have provided for better pellet properties. However, the goal was to use black liquor directly from the pulping process without further processing.

Table 2. Fuel values for lignin-enhanced wood pellets and current draw on the California Pellet Mill.

Pellet	Fuel value (MJ/kg)	Current draw (A)	Pellet MC (%)
Softwood control	20.0	110	2.5
2% Indulin AT	20.9	125	2.8
4% Indulin AT	21.0	113	2.8
6% Indulin AT	21.0	110	2.9
8% Indulin AT	21.2	109	2.3
10% Indulin AT	21.2	121	2.1
2% Black liquor	20.8	128	5.0
4% Black liquor	20.5	122	4.6
6% Black liquor	19.8	126	5.0
8% Black liquor	19.6	123	6.3
10% Black liquor	18.5	127	9.2

The elemental composition of the black liquor as a weight percentage is shown in Table 3. Because of the quantity of lignin, degraded cellulose, and hemicelluloses in the mixture, carbon should be the main element. The value of 21% carbon was much lower than an anticipated 50% value. These values indicate the amount of each element present in the black liquor after combustion and acid digestion analyses, which may explain why the elements totaled only 38%. The ICP test provides the values of the inorganic materials (metals) present in the black liquor and inorganics will not combust when combined with the wood, therefore reducing the resultant heating value. Therefore, the black liquor inorganics will contribute to the ash content in the pellets. In addition, the moisture content of the black liquor pellets was higher than the control and IAT pellets, reducing the fuel value.

Table 3. Black liquor elemental composition.

Element	Weight (%)
Carbon	21
Nitrogen	0.064
Calcium	0.008
Iron	0.001
Potassium	2.8
Magnesium	0.001
Manganese	0.001
Sodium	11.7
Sulfur	3.04
Total	38.7

The increase in moisture content also affected pellet quality and appearance. After the pelletizing process, one of the major differences among formulations was pellet quality. The desired pellets for burning in a wood stove have a shiny exterior and vary in length from 6 to over 12 mm. These are produced using 6-7% MC sawdust (oven-dry basis), which produces the desired finished pellets. The moisture helps lubricate the pellets to move through the die and simultaneously keeps the samples dry enough for frictional force to compact the pellets for the desired density and length (Nielsen et al 2009).

The control and IAT pellets were all high quality and showed desired properties (Fig 1). They were well formed, dry to the touch, and had a shiny exterior finish, a result of friction and heat as the pellets were formed. Black liquor pellets were often soft and spongy and appeared to have poor adhesion character, causing them to easily fall apart.

As the amount of IAT was increased, the pellets increased in length and became darker, most likely attributable to the brown color and to an increase in friction in the die. The increased friction can be partially linked to the increase in current during processing (Table 2). The longer length means that more material had to push harder to create the pellet and that residence time and friction may have caused darker pellets. This production of longer pellets was most evident at 8 and 10% IAT. However, based on appearance, the best quality pellets were achieved at 2 and 4% levels.

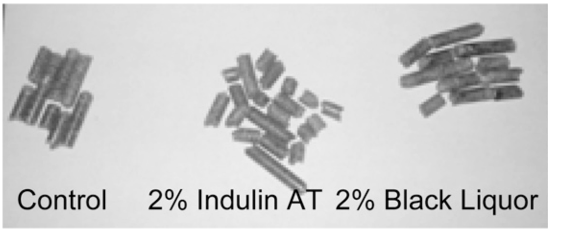

Figure 1. Control, 2% Indulin AT, and 2% black liquor pellets.

Material as well as processing costs are important considerations in the commercial manufacturing process. Although it was shown that Kraft lignin enhanced the fuel value of wood pellets, there would be an additional material cost (lignin) as well as a processing unit operation (mixing lignin with wood). The material cost analysis for adding lignin to wood pellets is shown in Table 4. The cost of wood was estimated at $120 or $160/t. The price for IAT was estimated on purchasing either small quantities at $0.68/kg or large quantities at $0.57/kg from Mead WestVaco (Personal Communication 2008). The price for Kraft lignin of $0.054/kg was estimated based on $150/t for technical lignin from black liquor and a cost of $83/t for ultrafiltration processing based on literature values (Jonsson and Wallberg 2009; Voitl and von Rohr 2010). The cost for adding IAT to wood pellets raises the price of wood pellets $48-58/t which is a 40% price increase even at the low addition rate of 2% lignin. On the contrary, if the cost of producing a technical lignin from black liquor at $0.054/kg could be realized, then the incremental cost of adding lignin to the wood pellets ranges from $2-12/t over an addition range of 2-12% lignin.

It should be pointed out that IAT is a highly purified lignin preparation that is often used as an experimental "lignin control" in research projects, and high-purity lignin may not be required for wood pellet production. The fuel price of technical lignin is often cited as about $0.054/kg but this price does not include the processing costs required to make it suitable for such uses as wood pellet production. If lignin is to be used as an additive, the processing cost of a suitable

Table 4. Cost analysis for adding lignin to wood pellets.

Pellet furnish	Indulin AT ($0.68/kg)	Indulin AT ($0.57/kg)	Kraft lignin ($0.054/kg)	Indulin AT ($0.68/kg)	Indulin AT ($0.57/kg)	Kraft lignin ($0.054/kg)
	Material cost of pellets ($/t)					
Control	120	120	120	160	160	160
2% Lignin	178	168	122	217	207	162
4% Lignin	235	215	125	274	254	163
6% Lignin	293	263	127	330	300	165
8% Lignin	350	310	130	387	347	166
10% Lignin	408	358	132	444	394	168

lignin preparation will likely have to be considerably less than the $0.57/kg for IAT, but the actual lignin cost will likely be greater than the reported price of $0.054/kg for technical lignin.

CONCLUSIONS

The addition of lignin to wood in the production of pellets enhances the fuel value of the pellets. However, the increase in fuel value has to be balanced with the cost of adding lignin. Pellets prepared with IAT were better quality and had a higher fuel value than those from Kraft black liquor. Kraft black liquor pellets were soft and spongy and easily fell apart. The results of this work suggest that opportunities exist for the production of cost-effective lignin preparations in the production of wood fuel pellets. More research work is needed to address this issue.

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