Premium fuel production from coal and timber waste

R.Q. Honaker
Associate professor, Department of Mining Engineering, University of Kentucky, Lexington, Kentucky

D. Taulbee
Industrial support coordinator, Center for Applied Energy Research, University of Kentucky, Lexington, Kentucky

B.K. Parekh
Associate director, Center for Applied Energy Research, University of Kentucky, Lexington, Kentucky

D. Tao
Associate professor, Department of Mining Engineering, University of Kentucky, Lexington, Kentucky

D.P. Patil
Research scientist, Center for Applied Energy Research, University of Kentucky, Lexington, Kentucky

Abstract

There is a significant amount of energy in the waste generated by the coal and timber industries. In the coal industry there is an energy loss mainly due to the discharge of fine coal to the waste impoundment. Despite the fact that the fine coal has the greatest cleaning potential, dewatering, handling and transportation concerns prevent its use as product in many cases. Likewise, sawdust generated from wood production has energy value but is only used as industrial boiler fuel when the transportation distance is relatively short. Wood waste is often discarded into cumbersome landfills due to uneconomical transportation alternatives. Recent research found that these two waste materials can be combined to provide a high-energy fuel, containing around 30.2 MJ/kg (13,000 Btu/lb), that can be easily handled and transported to end users.

Key words: Coal waste, Timber waste, Waste utilization, Briquettes, Fuel

Introduction

Kentucky has a significant concentration of industries that rank near the top in energy consumption. This is most likely due to the fact that the state has low electricity costs, which is currently 4.2 cents/kWh. Two of the industries, mining and timber, rank near the top in production when compared to all other states. Kentucky ranks third in coal production with about 136 Mt/a (150 million stpy), while also producing the largest amount of timber products east of the Mississippi River. A majority of the timber production occurs within or near the coalfields within Kentucky.

Before 1980, the ability to efficiently treat the –1-mm (-16-mesh) material in coal processing plants, which typically represents 10% to 20% of the run-of-mine feed, was limited due to the lack of effective technologies and the inability to dewater the final product to acceptable levels. Thus, vast quantities of fine, high-quality carbon material were disposed into fine-coal refuse ponds for several decades, thereby representing not only a loss of valuable energy resources but also an environmental hazard. Estimates indicate that more than 450 Mt (500 million st) of fine coal refuse are currently stored in refuse ponds in the state of Kentucky.

After 1980, lightweight polyurethane material was applied to the manufacturing of spiral concentrators. As a result, two or three spirals could be installed on a single axis, which doubled or tripled the capacity per unit of floor space. The application of spiral concentrators for cleaning the 1 x 0.15-mm (28 x 100-mesh) fraction has become a common component of fine-coal cleaning circuits, which has greatly improved energy recovery and reduced overall waste generation. In addition, froth flotation processes can be used to upgrade the -0.150-mm coal fraction.

However, according to a recent survey (Fiscor, 2000), only about 20% of the total plant capacity in Kentucky currently employs froth flotation. This is likely due to concerns related to a potential increase in the overall product moisture, the lack of an understanding of the technical aspects of the process and the operating costs. The amount of -0.15-mm (-100-mesh) material in a typical coal-preparation plant feed is about 5% (by weight). Based on a mass yield from froth flotation of 50%, the amount of high-quality fine coal that is disposed of annually in Kentucky is approximately 2.7 Mt (3 million st), which currently has a revenue value over US$100 million annually.

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In 1997, the production of all timber products in the state of Kentucky totaled 8.3 Mm^3 (293 million cu ft). However, the timber processed by the sawmills generated a substantial amount of residues, with 33% of the residues being in the form of sawdust. Sawdust has little value as a material-based product and is normally disposed of as waste. The amount of sawdust generated during 1997 was 1.0 Mm^3 (35 million cu ft) or about 12% of the total production. Nearly 47% of the sawdust was used as an industrial fuel, while the remaining was disposed of in landfills. It is a goal of the current timber industry to utilize 100% of the sawdust for autonomous energy production. However, the low bulk density of the sawdust limits the economical transportation distance to around 130 km (80 miles).

Problems related to the transportation and utilization of the fine coal and sawdust may be alleviated by combining the two materials into briquettes for use as fuel. A problem identified from previous fine-coal briquetting studies is the high binder cost. The cost of the binder was found to be the most critical factor with total costs being in the range of \$5 to \$8 per clean ton (Akers et al., 1999; Black, 1999). The use of sawdust waste may enhance the dewatering of the fine-coal product and may provide strength enhancements and binder cost reductions in the production of coal/sawdust briquettes that could be used as a premium fuel by utilities.

Briquetting. High-quality premium fuel can be produced from fine coal and sawdust wastes through an agglomeration process. The resulting material has characteristics that are easy to handle and transport. Briquetting is one of the most effective agglomeration processes and is widely used in agglomerating a variety of fine particles, including coal fines (Lyne and Johnston, 1981; Stambaugh, 2000). The process of briquetting often consists of applying pressure to a mass of particles with or without the addition of a binder to form agglomerate. The most common briquetter is the ring-die-type extruder in which rotation of the die in contact with the roller compresses material between the roller and the die. The resulting pressure forces the material through the die holes, producing cylindrical pellets with diameters ranging preferably from 10 to 12 mm (Leaver, 1979).

Binders are often used in pelletization of fine particles to enhance particle cohesion and the pellet strength (Young and Kalb, 1994; Olson et al., 1995; Mehta and Parekh, 1996; Baykal and Doven, 2000; Yaman et al., 2000). The most common binders include soluble salts, bentonite, inorganic chemicals and organic materials. Lime is a common inorganic binder used to agglomerate fine coal. Organic binders usually rely on adhesion and cohesion to form bridges between coal particles. Starch is an example of an organic binder. It significantly increases the strength of wet and dry pellets. Bitumen is rapidly becoming the most popular coal binder because of its unique characteristics. It is inexpensive, contributes little to the ash of pellets, produces mush less smoke than tar pitch and distributes readily on the coal surface. Also, fibrous wastes such as sawdust are also very promising coal binders (Gunter, 1993).

One of the advantages of briquetting fine coal in the presence of sawdust is that the heat produced during high-pressure extrusion may be sufficient to cause sawdust sintering, which may enhance binding between fine coal particles. It is known that the presence of even minute amounts of a liquid phase formed as a result of sintering strongly enhances the rate of the pelletizing process (Wynnyckyj and Batterhamt, 1985).

Processing strategy

Briquetting is generally considered to be a costly process for fuel production using coal. However, the process strategy is to adjoin the briquetting operation with an operating coal-preparation plant so that improved coarse circuit yields could be realized by the production of a low-inert, high-Btu product from coal and timber waste. As shown by Yoon et al. (1998), the production of ultrafine coal that has low ash and moisture contents allows the production of higher-ash content coal in the coarse cleaning circuits, which is especially beneficial for the production of steam coal requiring a specified heating value. The processing scheme shown in Fig. 1 employs advanced coal-cleaning technologies to produce low-ash coal and employs briquetting to provide a low-moisture, easy-to-handle product. Moisture content reduction in the briquetting process is achieved by compression to maximize particle packing density and the use of a hydrophobic binder that repels water from the particle surfaces and void spaces between the particles forming the briquettes.

The fine-coal refuse is upgraded using advanced technologies such as column flotation. Typical chemicals used in the froth flotation process may be replaced by binders that are applied in the briquetting process. For example, tall oil derivatives, which provide excellent collector and frothing properties, are promising binders for coal/sawdust briquette production.

Dewatering of the flotation concentrate can be accelerated and a significantly lower moisture filter cake could be obtained if the diameter of the capillaries formed in the filter cake could be increased and the porosity of the cake improved. The addition of wood fibers in the filter cake provides channeling effects as well as higher porosity to the filter cake. A high porosity significantly improves the filtration rate, which in turn increases the solids throughput in the dewatering machine. Preliminary studies by the authors confirmed the high dewatering rates and a total moisture reduction of 25%, compared to the results under the same conditions without the addition of the wood fibers.

To summarize, the processing strategy employs:

- premium fuel production from two industrial wastes that generated in significant quantities within the same region in Kentucky,
- integration of the advanced coal processing and briquetting operations with an operating coal preparation plant,
- dewatering benefits gained from the addition of sawdust and/or other fibrous wood wastes into the fine coal-processing feed stream,
- optimized reagent consumption for the production of coal/sawdust briquettes and
- production of a fuel from fine waste that is easy to handle and transport.

Experimental

Coal sample. Fine coal slurry discharged to an impoundment at an operating coal preparation plant was collected over a period of one operating shift. The plant was processing coal from the Hazard No. 4 coal seam, which is a high-volatile bituminous coal with a dry-based heating value of around 33.0 MJ/kg (14,200 Btu/lb). As shown in Table 1, the coal slurry sample contained mostly ultrafine coal with 77% (by weight) having a size below 37 µm. The particles coarser than 37 µm were very clean, with an ash content of less than 6% and a heating value of 33.585 MJ/kg (14,439 Btu/lb) on a dry basis.

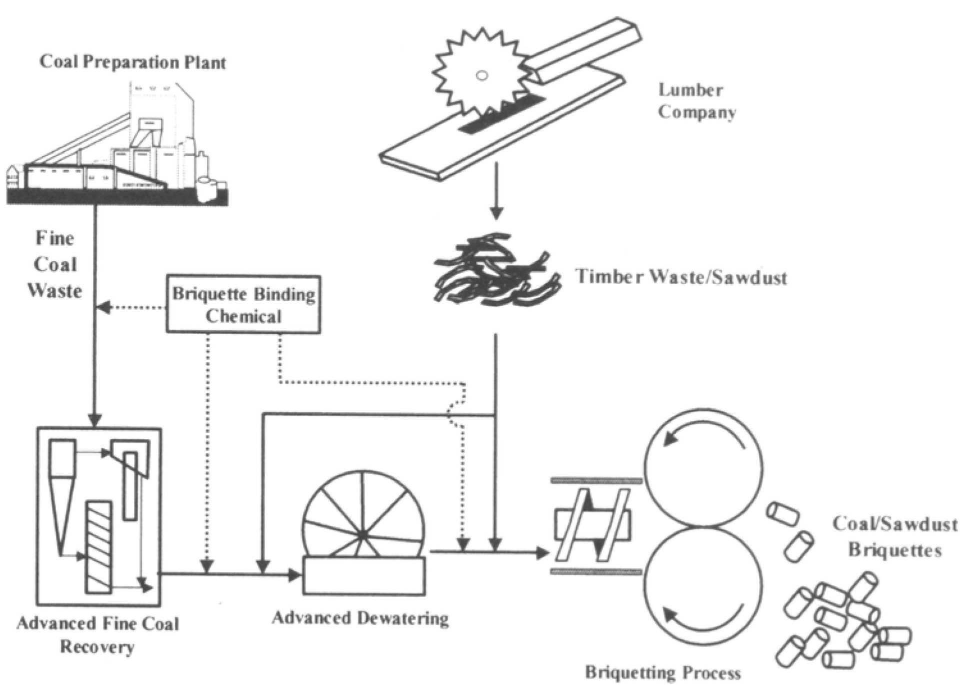

Figure 1 — Schematic of the proposed concept of coal/sawdust premium fuel production.

As such, efficient classification of the material could provide a high-quality product representing 23% of the total mass of the waste coal.

Froth flotation of the entire fine-coal sample reduced the ash content from 48.53% to 6.03% while recovering 57.4% of the total mass, as shown in Fig. 2. The flotation results were produced from a release analysis, which approximates the optimum separation performance achievable by any flotation process. Fuel oil was used as a collector and a polyglycol was used as a frother. The heating value of the 6.03% ash product was greater than 32.5 MJ/kg (14,000 Btu/lb) on a dry basis.

For a small number of briquette tests, a second fine coal sample was utilized, which was collected from the thickener feed stream of a plant treating Elkhorn No. 3 seam coal. The coal is ranked as high-volatile bituminous with an air-dried heating value of 30.0 MJ/kg (12,940 Btu/lb). According to release analysis results, froth flotation has the potential of reducing the ash content to about 6% while recovering 30% of the feed weight.

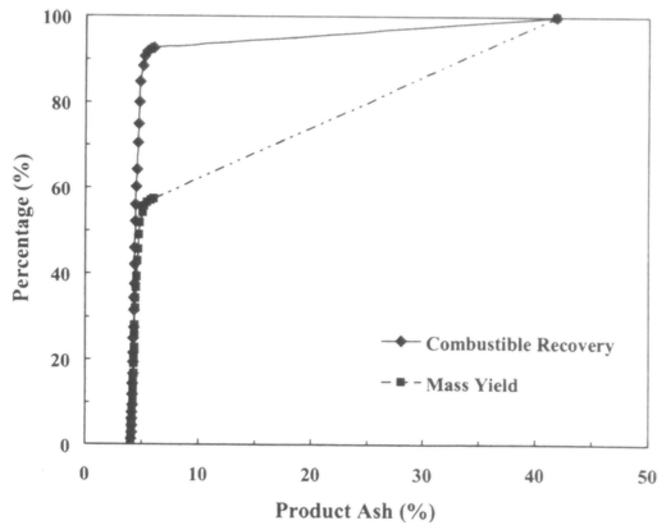

Figure 2 — Flotation release analysis conducted on the fine coal waste slurry sample.

Wood sample. A 200-L (52.8-gal) drum full of sawdust was collected from a timber mill that uses a circular saw in eastern Kentucky. The sample consisted of a typical mixture of the tree species being harvested in eastern Kentucky, primarily white oak, red oak and poplar. The entire sample was screened through a 9.5-mm (3/8-in.) sieve, manually mixed to ensure homogeneity, split and then stored in sealed quart jars. These splits were frozen to minimize aging. Several other samples were collected from different sources and treated in the same manner.

Particle size analyses conducted by dry screening on the as-received sample revealed an average particle size of around 1 mm based on a wet screen analysis and 0.86 mm using dry screening (Table 2). The increased particle size when wet screening is believed to be due to water absorption and swelling. The swelling causes some cracking and reduced strength during briquetting Less than 10% of each sawdust sample had a particle size less than 0.21 mm (60 mesh), while

Table 1 — Particle size-by-size analysis results of the fine coal waste slurry sample on a dry basis.

Size fraction, μm	Weight, %	Ash, %	Total sulfur, %	Heating value, Btu/lb
+210	0.17	2.99	0.77	14,520
210 x 150	0.62	3.00	0.77	14,515
150 x 75	8.00	3.03	0.77	14,431
75 x 44	9.26	6.39	0.74	13,878
44 x 37	4.33	11.05	0.70	13,101
-37	77.62	60.80	0.35	4,850
Total	100.00	48.53	0.44	6,886

Table 2 — Particle size distribution of the sawdust sample as determined from dry screening.

Size fraction mm	Weight, %	Oversize, %
+1.68	10.00	10.00
1.68 x 1.18	11.31	21.30
1.18 x 0.85	19.02	40.32
0.85 x 0.60	20.79	61.11
0.60 x 0.425	16.21	77.32
0.425 x 0.30	10.89	88.21
0.30 x 0.25	3.82	92.03
-0.25	7.97	100.00

Table 3 — As-received heating values of several saw dust types.

Sawdust sample	Moisture, %	Heating value, Btu/lb
Poplar	21.43	6,390
White oak	15.83	6,835
Oak	16.27	7,014
Mixture	17.85	6,751
Hickory	22.65	6,493

the amount of +1.68-mm (+12-mesh) material was highly dependent on the lumber production technique.

Characterization of sawdust samples from five different sources, which varied by location and tree type (i.e., popular and oak), was conducted. As shown in Table 3, the average energy value was 15.6 MJ/kg (6,696 Btu/lb) on an as-received basis with a minimum of 14.9 MJ/kg (6,390 Btu/lb) and a maximum of 16.31 MJ/kg (7,014 Btu/lb). The average moisture content was 18.8% (by weight).

Froth flotation. Clean coal was generated for the briquette study using a laboratory flotation column from which the concentrate was collected and dewatered using a vacuum filter. The flotation column was installed to treat a split stream of the thickener feed at an operating preparation plant. All thickener reagents added prior to entry into the thickener were turned off during the collection of the flotation concentrate. The feed solids concentration varied during the tests from 3% to 5% (by weight). Fuel Oil No. 2 was added as a collector at a concentration of 0.5 kg/t (1.0 lb/st), while 15 ppm of polyglycol was used as a frother. Wash water was added internally into the froth phase while adjusting the pulp level to ensure that 60% of the wash water reported to the tailings stream. The ash and total moisture contents of the dewatered flotation concentrate were 4.85% and 26.8%, respectively.

Briquetting. Briquettes in each test were prepared using essentially the same conditions and the same proportions by weight of coal, sawdust (10%), binder (5%) and water (5%). The 5% (by weight) water was added prior to briquetting to facilitate the dispersion of the binder. After thoroughly mixing, briquettes were formed by compressing 17.0 ± 0.05 g of each blend in a 28.6-mm-diam cylindrical dye. Briquette lengths were variable depending on the packing density achieved using 27,580-kPa (4,000-psi) pressure for three seconds in an automated press. Sixteen briquettes were formed from each blend. Five of the briquettes were crushed 30 minutes after preparation, and the remaining briquettes were placed in a curing chamber from which five were removed and crushed 24 hours after preparation. A third set of five briquettes was crushed seven days after preparation. The curing chamber was maintained at a constant 22°C (72°F) and 80% relative humidity.

Compressive strength measurements were made after time periods of 30 minutes, 24 hours and 7 days using a Mark-10, Model EG200, compressive-strength meter mounted on a Chatillon automated test stand. The flat side of each briquette was pressed with a 19-mm-diam plunger at a speed of 25.4 mm/min until the briquette shattered. The average strength of five briquettes was reported at each of the time intervals.

In addition to testing compressive strengths, tests were conducted using standard techniques that assess the ability of the briquettes to remain intact during transportation and weathering. Briquettes that were cured in the environmental chamber for seven days at 22°C (72°F) and 80% relative humidity were subjected to drop tests, water resistance and attrition studies. For the drop tests, four briquettes were dropped from a height of 450 mm (18 in.) until significant cracks were observed. The average number of drops to failure was recorded and averaged.

An attrition index was determined by tumbling approximately 100 g of briquettes (about seven to eight briquettes) in a 300-mm-diam Plexiglas cylinder equipped with 50-mm lifters. The briquettes were tumbled for five minutes at a rotational speed of 40 rpm. Afterward, the material inside the cylinder was wet screened through a 300-μm (50-mesh) sieve and the percentage by weight of +300-μm material reported as the attrition index.

To test water resistance, four briquettes were submerged in water for eight hours and then (if still intact) placed back into the environmental chamber overnight and subjected to compressive strength analysis the following day.

Results and discussion

Numerous binder types were evaluated at a dosage equivalent to a cost of $8.00/st of coal treated based on the current price of each binder. During the initial tests, no lime was added to the mixture. The data in Table 4 represents the compressive force needed to bring the briquette to failure. As shown, no single binder provided both the highest green and 7-day strengths. However, some of the binders tested well at all three of the time levels.

Lime is commonly used to enhance the strength of coal briquettes in commercial operations. Tests results indicate that the benefit of lime addition is a function of the primary binder type. As shown in Table 5, the strengths obtained under all time intervals were significantly enhanced by the addition of lime at a concentration of 2% (by weight) for two primary binder types. However, for a third binder type, the addition of the lime appears to weaken the strength of the briquette.

Results from tests utilizing the best binders based on compression strength evaluations are provided in Table 6. A significant reduction in the strength of the briquettes from a 24-hr water submersion period is noted by comparing the strength values with the one-day strength numbers. However, briquettes formed using two of the binder types retained significant strength that may be satisfactory for transportation and handling under wet conditions. The same two binders also result in briquettes that resist attrition and breakage during repetitive drops.

Table 4 — Average compressive strength of five briquettes produced for several binder types after varying lengths of curing time; Hazard No. 4 coal.

Binder type	Binder weight, Wt.%	Green strength, N	1-day strength, N	7-day strength, N
1	0.4	7.7	8.0	40.6
2	6.7	7.8	7.9	15.9
3	3.4	8.8	8.5	28.3
4	7.2	9.6	9.6	36.3
5	6.7	6.9	9.0	16.0
6	2.9	8.8	11.5	27.2
7	6.4	7.4	8.3	11.2
8	5.0	9.8	9.0	16.5
9	17.8	9.2	6.6	7.6
10	8.0	10.3	7.3	15.1
11	4.8	7.4	5.1	5.2
12	8.0	7.0	15.5	16.5
13	6.2	6.8	7.6	12.5
14	9.4	5.8	7.7	10.3
15	1.0	9.8	15.8	32.1
16	1.5	12.3	8.0	7.7
17	17.8	9.3	9.1	16.6
18	1.0	8.0	8.5	21.0
19	2.9	10.2	12.0	31.8
20	4.8	7.1	7.8	13.7
21	12.3	7.4	6.4	na
22	4.8	8.8	7.0	na
23	4.8	6.7	6.0	na
24	0.0	6.9	4.3	na

Table 5 — Effect of lime addition on the average compressive strength of five briquettes; Elkhorn No. 3 coal.

Binder type	Binder weight, Wt.%	Green strength, N	1-day strength, N	7-day strength, N
4	0	8.5	11.2	45.2
4	2	8.9	9.4	28.5
7	0	4.7	5.3	6.3
7	2	10.0	11.6	20.2
19	0	5.0	5.7	23.7
19	2	8.1	11.1	45.0

Table 6 — Materials handling parameter test results for the Hazard No. 4 coal-sawdust briquettes.

Binder type	1-day strength, N	Drop test	H_2O resistance strength, N	Attrition index
15	19.4	51.25	9.4	81.06
25	13.9	27.25	4.0	56.80
26	17.6	46.75	5.4	67.45
27*	19.4	51.25	9.4	81.06

*2% by weight lime added.

Table 7 — Briquettes qualities including heating value produced from Elkhorn No. 3 coal and mixed wood waste.

Binder type	Ash, %	Moisture, %	As received, Btu/lb	Dry Btu/lb
1	4.78	2.71	13,807	14,192
13	4.94	5.37	13,199	13,948
8	4.61	2.3	14,027	14,357
21	4.82	3.12	13,457	13,890
23	4.62	4.62	13,537	14,193

Randomly chosen briquettes produced during the binder screening study were evaluated for their energy value. As shown in Table 7, the ash contents of the briquettes are below 5%, which is reflective the efficiency achieved during the cleaning process. More importantly, the moisture contents are also about 5% or lower. These values are about 20 absolute units lower than the ultrafine clean coal produced in commercial plants. The majority of the moisture reduction occurs during the briquetting process. Intense compression of the wet solids significantly increases packing density, which reduces the amount of void volume existing between the particles. As a result, water is forced outward and through the surfaces of the briquette. Further reduction in moisture occurs during the curing process, especially when a hydrophobic binder is employed. As such a result of the coal cleaning and briquetting processes, the combined low ash and total moisture contents (i.e., total inerts) can be utilized to significantly impact the overall coal preparation plant performance by allowing for greater total inert and, thus, mass recoveries from the coarse cleaning circuits, as previously discussed (Yoon et al., 1998).

The average energy value for the briquettes produced was 31.65 MJ/kg (13,605 Btu/lb) on an as-received basis, with the high value being 32.63 MJ/kg (14,027 Btu/lb) and a low of 30.70 MJ/kg (13,199 Btu/lb). This high-energy product was generated using coal that is currently being discarded due to concerns related to product moisture and handleability.

Conclusions

The coal and timber industries generate fine wastes that have significant heating value. In some cases, these waste streams are effectively exploited for energy purposes. However, handling and transportation of these materials is generally technically and economically unfeasible. In addition, moisture concerns also limit the ability to utilize the ultrafine coal despite the high quality (i.e., low ash and total sulfur contents and high dry-base energy value) that is typically associated with this material.

Briquetting of ultraclean coal and sawdust provides a premium fuel that is in a form that is easy to handle and transport. If the briquetting operation is done in conjunction with an operating preparation plant, the low total inerts produced from the briquettes could be used advantageously to increase the mass yield realized in the coarse cleaning circuits of the preparation plant. Briquettes of 90% -150-µm coal fines and 10% sawdust have been produced that have a heating value exceeding 32.6 MJ/kg (14,000 Btu/lb) on a dry basis.

Binders with and without lime have been found to provide very high compressive strengths and the ability to withstand repetitive drops without breakage. Overall strength improves with increasing cure time under standard conditions. However, submersion under water deteriorates the strength of the briquettes with the magnitude of the decrease being dependent on the binder type. However, binder cost remains relatively high at around $4 to $8 per ton of product, and this is the focus of current research.

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