A Coal Upgrading Technology for Sub-bituminous and Lignite Coals[1]

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ABSTRACT

Fuels Management Inc. (FMI) of Miami, Florida has developed at Western Research Institute (WRI) a low cost, low temperature process to upgrade low-rank coal by reducing moisture, sulfur, ash, and mercury. The coal upgrading process involves heating the coal in a bubbling fluidized bed-based reactor. The process heat required is derived from the coal itself. Upgrading process being a fluidized bed-based technology allows high throughputs, reducing the processing costs. Processing is carried out under controlled oxidizing conditions at mild enough conditions that compared to other coal upgrading technologies; the produced water is not as difficult to treat.

Over the past five years, WRI and FMI have constructed a nominal 400-lbs/hour pilot plant at the WRI facilities in Laramie, WY and performed a series of parametric tests to optimize the technology. Results show that the process can indeed produce a stable, high heating value product with reduced mercury content. Bulk density of the product has been determined from small samples and is typically about 88 % that of the raw coal. This paper describes the details of the technology development efforts.

INTRODUCTION

Low-rank coals account for about 50% of coal reserves and their use is limited due to low heating value and concerns regarding spontaneous combustion. Many of the low-rank coals, however, contain lower sulfur and lower ash than the bituminous coals. So if these coals could be efficiently and economically processed to yield a higher-grade, high-heating value product, there will be a beneficial impact not only on the energy supply side but also on the environmental side as well. A successful coal upgrading process has to be economical and address the issues of spontaneous combustion, decrepitation, and equilibrium moisture.

Over the years several technologies have been tested to reduce the moisture content of sub-bituminous, lignite and brown coals. Notable attempts at developing such an upgrading technology include ENCOAL, Western SynCoal and KFx processes. However, the cost of processing the coal remains high. Viability of a simple, cost effective and efficient process has not yet been demonstrated.

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FMI COAL UPGRADING TECHNOLOGY

The FMI coal upgrading process involves heating the coal in a bubbling fluidized bed-based reactor operating at near ambient pressures. The process heat required is derived from the coal itself. Upgrading process being a fluidized bed-based technology is a continuous process that allows high throughputs thereby reducing the processing costs. Maintenance costs are also low since the only moving parts are in the air blower. The FMI approach to coal upgrading is the only one using an oxidizing environment. The oxidative environment removes the more active oxygen components of the coal, thereby contributing to the stability of the product. Similarly, since the processing is carried out in air at conditions mild enough that, compared to other coal upgrading technologies, the produced water is not as difficult to treat.

A simplified basic plan of the FMI coal upgrading process is presented in Figure 1. The reactor vessel is a hollow cylindrical vessel equipped with a gas distributor plate in the bottom and a conventional cyclone separator in the top. An air blower generating about 15 psig provides the air to fluidize the coal feed. The unit operates at about 600 F. About 5% of the coal feed is needed to supply the heat of evaporation of the water in the fuel.

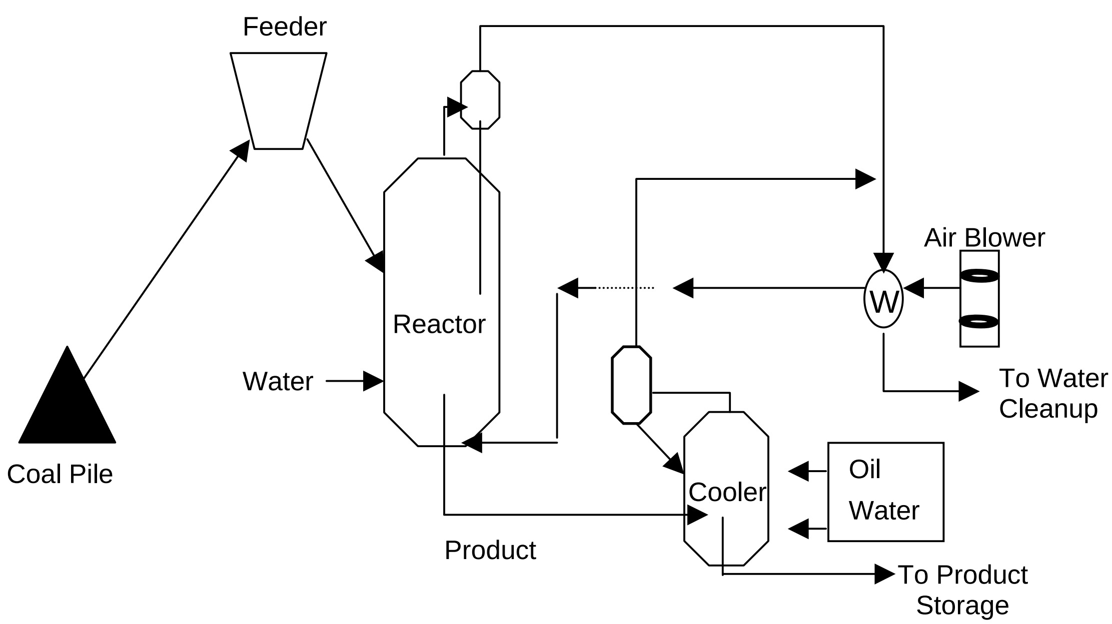

Figure 1. A schematic depiction of the FMI coal upgrading process

As a part of the technology development efforts, FMI has constructed a Pilot Test Facility at WRI. The pilot tests facility (see Figure 2) consists of a 12-inch diameter fluidized bed reactor where all coal-drying reactions occur. The fluidized bed reactor is assembled from flanged spool pieces such that the aspect ratio can be changed. The reactor is well instrumented so that temperature of the bed can be monitored at every 3 inches. Similarly, pressures and differential pressures can be monitored at several locations in the reactor. The reactor is also equipped with a 3-inch diameter feed port, whereby a screw feeder can feed coal into the reactor at rates up to

400 lbs/hour. Two drain ports are installed on the reactor at an elevation of 18 inches. These ports are used for withdrawing the dry coal, and/or for collecting samples.

A refractory-lined propane-fired burner is used for start up. The burner heats the fluidizing gas to the desired temperature to start the drying process.

A 3-inch screw feeder transports the coal from a hopper into the reactor. A variable speed motor drives the screw.

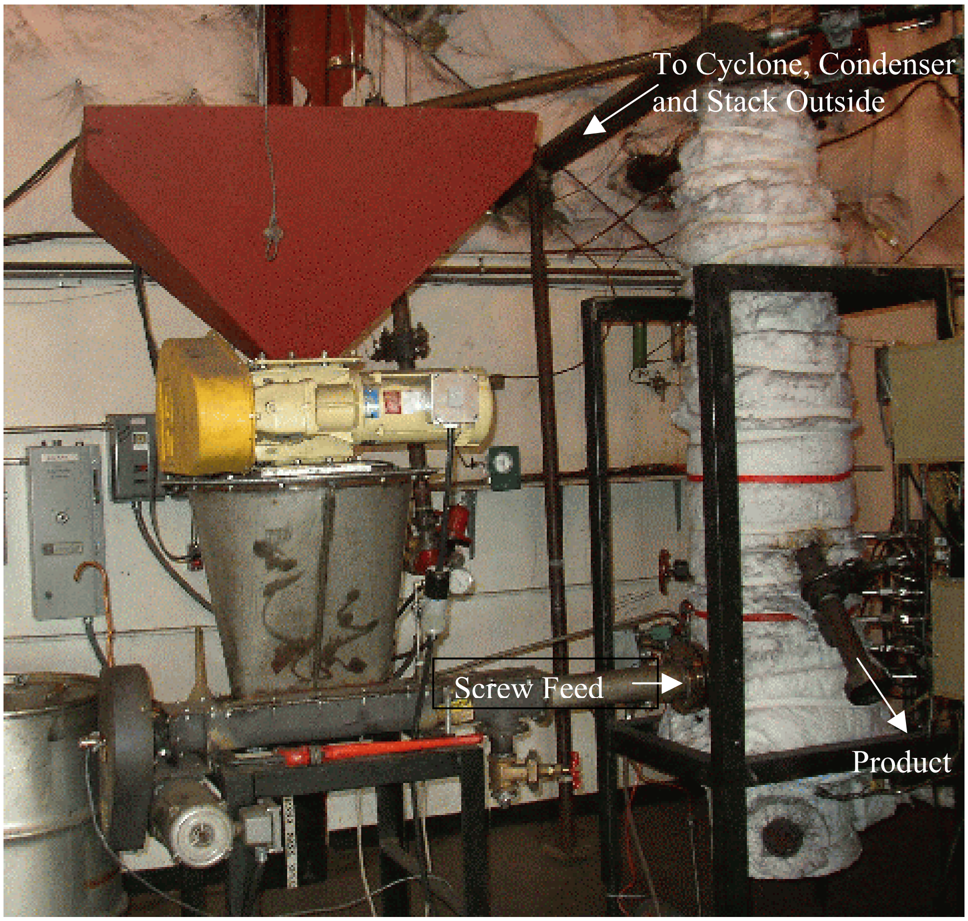

Figure 2. A photograph of the Pilot Test Facility at WRI

Off-gases from the reactor are sent to a cyclone separator, and then to a forced-air condenser. The water removed from the coal is condensed and drains into a storage drum. A blower is used to recycle a portion of the gases back to the reactor. A second blower provides air for the process. This air is heated by the propane burner and then mixed with the recycle gas to fluidize the bed of coal.

The FMI coal drying process requires a precise control of the bed temperature, and of the amount of oxygen present in the fluidizing gas. A PC-based control system employing LabTech Control software is used to control the process temperature, partial pressure of oxygen, and the coal feed-rate. The system also serves as a data logger whereby all flows, temperatures, and pressures are logged every five seconds.

The reactor is also equipped with provisions for adding water to control the processing temperature. Water injection is also controlled by the process control PC by alarming one of the bed thermocouples.

A typical test involves reactor warm-up by lighting the propane burner and by starting the air blower. Recycle blower is then started. The system controls are then transferred to Auto mode and the fluidizing gas volume set to 100 scfm. The propane-firing rate is slowly increased until the onset of exothermic reactions in the reactor. This is typified by a sudden drop in the oxygen concentration in the off gases from the reactor, and typically occurs at about 400 F. At this time, coal feed is initiated and slowly increased as the reactor temperature increases. When the desired coal feed rate and bed temperature are achieved, the system oxygen level controls are also transferred to the Auto mode. Under these conditions, any temperature excursions are compensated by either the coal feed rate adjustment and/or by water injection.

The bed can be fluidized with a recycle gas/air ratio from zero (no recycle) to about four (higher the recycle gas/air ratio, smaller the amount of throughput). The control system accommodates slight mismatches in the amount of heat produced in the reactor and that needed to evaporate the water from coal by injecting small amounts of water.

RESULTS

Over the course of the technology development efforts, several technology optimization tests were conducted with Powder River Basin sub-bituminous coals, and with Montana and Alaska lignites. All testing to date has employed ¼ x ⅛-inch feed. The limitation is a direct result of the design of the feed equipment assembled at the pilot test facility and not a technology limitation. In all cases, a stable upgraded product was indeed produced. Some of the results are described below.

Product Quality: An independent laboratory routinely analyzes samples of parent coals and resultant products. Representative data from Wyodak coal and Usabelli coal are displayed in Tables 1 and 2 respectively. Each table shows the ultimate and proximate analyses for the coal and respective product. It should be noted that the analyses show sampling variability in ash content and therefore data should be used for comparison purposes only. Nevertheless, from the data presented in the two tables, it is quite evident that the product as produced by the FMI process is water free and has a high heating value.

Bulk Density: Bulk density of the feed coal and the product were measured. As expected, the bulk density of the product was lower. For Wyodak coal the bulk density of the product was determined to be 43.41 lbs/ft^3 whereas the value for the parent coal was 48.77 lbs/ft^3.

Equilibrium Moisture: Samples of product were tested for equilibrium moisture content. The procedure used involved exposure to moist air for 48 hours followed by a 24-hour drying period in room air. The data showed that depending on the processing conditions, the product has equilibrium moisture content in the six to ten percent range.

Table 1. Ultimate and Proximate Analyses of Wyodak Coal and Associated Product

	As Received Wt%		Moisture Free wt%		MAF Basis wt%	
	Raw Coal	Product	Raw Coal	Product	Raw Coal	Product
Proximate Analysis:						
Moisture	23.79	0.00				
Ash	4.38	7.34	5.75	7.34		
Volatile Matter	34.00	39.46	44.61	39.46	47.33	42.59
Fixed Carbon	37.83	53.20	49.64	53.20	52.67	57.41
Ultimate Analysis:						
Moisture	23.79	0				
Hydrogen	5.99	3.39	4.37	3.39	4.64	3.66
Carbon	51.97	68.28	68.19	68.28	72.35	73.69
Nitrogen	1.26	1.26	1.65	1.26	1.75	1.36
Sulfur	0.3	0.35	0.39	0.35	0.41	0.38
Oxygen	36.1	19.38	19.65	19.38	20.85	20.91
Ash	4.38	7.34	5.75	7.34		
Heating Value, Btu/lb	8,686	11,178	11,397	11,178	12,092	12,063

Table 2. Ultimate and Proximate Analyses of Usibeli Coal and Associated Product

	As Received Wt%		Moisture Free wt%		MAF Basis wt%	
	Raw Coal	Product	Raw Coal	Product	Raw Coal	Product
Proximate Analysis:						
Moisture	25.11	0				
Ash	14.05	13.36	18.75	13.36		
Volatile Matter	33.77	33.24	45.1	33.24	55.51	38.37
Fixed Carbon	27.07	53.4	36.15	53.4	44.49	61.63
Ultimate Analysis:						
Moisture	25.11	0				
Hydrogen	3.26	3.27	4.35	3.27	5.35	3.77
Carbon	48.51	73.32	64.77	73.32	79.72	84.63
Nitrogen	1.1	1.4	1.47	1.4	1.81	1.62
Sulfur	0.5	0.12	0.66	0.12	0.81	0.14
Oxygen	7.47	8.53	9.97	8.53	12.27	9.85
Ash	14.05	13.36	18.75	13.36		
Heating Value, Btu/lb	7,518	11,024	10,038	11,024	12,354	12,724

Spontaneous Combustion Test: The pilot test facility was operated for extended periods of time so as to produce nearly 3,000 lbs of material for forming an instrumented coal pile. A covered and insulated 4' x 4' plywood structure was constructed and filled with product to a depth of 4'. The pile was instrumented in that a series of thermocouples were buried in the pile and a pc-based data logger continuously recorded the temperatures for a period of thirty-three days. The temperature data recorded from the coal pile are displayed in Figure 3.

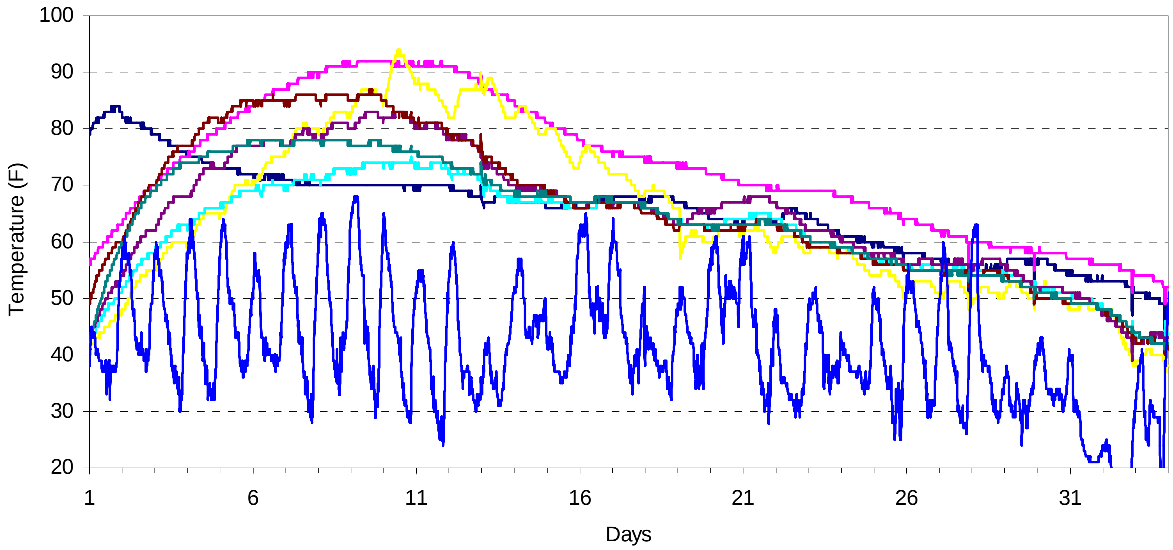

Figure 3. Temperature Data from the Coal Pile Exposed to Ambient Air for Thirty-three Days

The data presented in the Figure 3 clearly show that the temperature of the coal pile after showing an initial increase of twenty to forty degrees over a period of seven to ten days then steadily decreased. Daily temperature variations over this time period ranged from a low of twenty-five degrees to a high of about sixty-seven degrees.

At the end of this test, samples were collected from the top of the pile and from near the center of the coal pile and analyzed. The data for two such samples are displayed in Table 3. From the data presented in Figure 3 and the product analyses displayed in Table 3, it is concluded that the product is stable and not prone to self-heating and thereby resistant to spontaneous combustion.

Mercury Removal: It is well established in the literature that when coals are heated that there exists a temperature regime in which substantial quantities of mercury present in the coal is liberated in gaseous forms. In that regard, all thermal coal-upgrading processes lead to a beneficiated product with respect to mercury. Recently, tests were performed to quantify the mercury removal effected by the FMI process. Over a four-hour period nearly 900 lbs of a Powder River Basin sub-bituminous coal was processed at 600 F. Samples of the parent coal, processed fines elutriated from the fluidized bed, and product were analyzed for their mercury content. The data are summarized in Table 4. It appears that the FMI coal upgrading process removes approximately seventy percent of the mercury present in the sub-bituminous coal. Similar tests conducted with Alaskan lignite showed nearly ninety percent removal of mercury.

Table 3. Ultimate and Proximate analyses of samples from the coal pile

	As Received Wt%	
	Top	Center
Proximate Analysis:		
Moisture	2.27	1.39
Ash	7.44	7.53
Volatile Matter	30.97	31.96
Fixed Carbon	59.32	59.12
Ultimate Analysis:		
Moisture	2.27	1.39
Hydrogen	3.02	2.95
Carbon	72.46	73.43
Nitrogen	1.3	1.38
Sulfur	0.21	0.22
Oxygen	15.57	14.49
Ash	7.44	7.53
Heating Value, Btu/lb	11622	11794

Table 4. Mercury analysis data for PRB coal samples

	Hg Concentration, ppm	
	As-Received	Dry Basis
Parent Coal	0.0504	0.0657
Processed Fines	0.0561	0.0561
Product 1	0.0258	0.0258
Product 2	0.0213	0.0213
Product 3	0.0240	0.0240

Process Economics: Most competing coal processing technologies are proprietary. Accordingly it is difficult to get definitive information on competitive process economics. However, a major competitor has published information showing, a capital coat of $70/ton of product. Our estimate is that the FMI process will have a capital cost of less than $35/ton of product. Similarly, the processing costs for the FMI process are expected to be lower because of the simplicity of the process. FMI therefore believes that its coal upgrading technology is in a very competitive economic position.

CONCLUSIONS

Fuels Management Inc. has developed a fluidized-bed-based coal upgrading technology that dries low-rank coals using air as a fluidizing medium. The FMI coal-upgrading technology is capable of producing a high heating value, stable product that is not only low in its moisture content but also is low in its mercury content. The process economics, although not presented in any detail are far superior to those of the other technologies developed to date and tested.