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THE PRODUCTION OF A PREMIUM SOLID FUEL FROM POWDER RIVER BASIN COAL

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ABSTRACT

This report describes our initial evaluation of a process designed to produce premium-quality solid fuel from Powder River Basin (PRB) coal. The process is based upon our experience gained by producing highly-reactive, high-heating-value char as part of a mild-gasification project.

In the process, char containing 20 to 25 wt % volatiles and having a gross heating value of 12,500 to 13,000 Btu/lb is produced. The char is then contacted by coal-derived liquid. The result is a deposit of 6 to 8 wt % pitch on the char particles. The lower boiling component of the coal-derived liquid which is not deposited on the char is burned as fuel.

Our economic evaluation shows the process will be economically attractive if the product can be sold for about \$20/ton or more.

Our preliminary tests show that we can deposit pitch on to the char, and the product is less dusty, less susceptible to readsorption of moisture, and has reduced susceptibility to self heating.

INTRODUCTION

Western Research Institute (WRI) is presently developing a process to produce a premium-quality, solid fuel from low rank coal called the CompCoal™ process. This process is based upon our experience with the development of coal-drying and mild-gasification processes and what we have learned from the technical and economic evaluation of those processes. CompCoal focuses upon a low-cost method to produce a premium-quality fuel that is less susceptible to formation of dust, readsorption of moisture, and self heating than the parent coal. The CompCoal product must also have a high heating value as well as low sulfur and moisture content and must exhibit good combustion characteristics.

During the period from 1987 through 1991, WRI worked on the development of coal-drying and mild-gasification processes. This work was done using minus 8 mesh and minus 28 mesh Wyodak and Usibelli coals in specially-designed, plug-flow, fluidized-bed reactors. Bench-scale reactors at feed rates of 10 lb/hr with 8-hr tests and a process research unit (PRU) fed at 100 to 150 lb/hr for 24-hr and 5-day tests were used. Both processes were subjected to economic evaluation. The drying process (Boysen et al. 1990) uses a recycle flow of carbon dioxide, derived from the coal, as a heating medium. While the use of carbon dioxide avoids the potential hazards of fires and explosions in the drying system, its use also requires that condensers be used to separate water from the recycle gas. The U.S. Department of Energy (DOE) also required that the drying process be developed for minus 28 mesh feed coal, consequently a briquetting step was incorporated into the process. The use of condensers and briquetting made the process prohibitively expensive.

WRI also worked with AMAX R and D Center and Riley Stoker to develop a mild-gasification process to produce electrode-binder pitch, cresylic acid feedstock, diesel fuel, anode-grade carbon, carbon black, and activated carbon. The process appears to be economically attractive (Hogsett and Jha 1991) based upon a cost estimated from the preliminary design of a 1000 tons per day (TPD) plant (Ralph M. Parsons Co. 1991).

During the development of the mild-gasification process we learned much about the production and processing of heavy coal liquid (pitch) and how to control the properties of the char produced by mild gasification (Merriam et al. 1990). We are using what we learned, some limitations we found, and some mistakes we made, to make the CompCoal process as economically attractive as possible.

BACKGROUND

A large number of processes have been used to dry coal and many new processes are being developed. The older, more established processes include fluidized bed, entrained bed, rotary drum, indirect heating, and various conveyor-contacting devices. In addition, hot water dewatering, steam filtration, decarboxylation dewatering, multiple fluidized beds, vapor recompression, solar drying, high pressure steam treatment, and nonevaporative thermal dewatering processes are in various stages of development. Some of these processes will be discussed briefly below.

The University of North Dakota Energy Research Center has explored various drying techniques to upgrade low rank coals (Willson et al. 1987). Included in the study were hot-gas drying using both a rotary kiln (Roto-Louvre) dryer and a Parry turbulent entrainment dryer, as well as hot-water and steam drying under pressure. Two bituminous coals (Illinois No. 6 and Pittsburgh No. 8) and Wyoming subbituminous coal were investigated. When directly dried in hot gases, the dried coal readsorbs moisture after cooling and returns to essentially the original equilibrium moisture percentage. In contrast, both steam and hot-water drying produced dried coal in which moisture readsorption was minimal. They concluded that this occurs mainly through rejection of carbon dioxide via the decarboxylation reactions which occur during drying. The temperature used in the steam and hot-water drying (518 - 625°F/270 - 330°C) was high enough to produce a tar which remains in the dried coal due to high pressure. The tar that remained in the coal also contributed to reducing the moisture readsorption.

Fluidized-bed dryers, developed since World War II, permit excellent gas-coal contact, but require very good control of both coal and gas flow distribution to avoid fires or explosions. The McNally Flowdryer, the Dorr-Oliver FluoSolids Dryer, the Link-Belt Fluid-FlowDryer, and the Heyl and Patterson fluidized-bed dryers are well known (Leonard and Mitchell 1968). The water content of the dry coal is often held at 5 to 10 wt %, or 0.5 to 1.0% surface water, to make the drying operation less hazardous and to avoid excessive formation of dust. After the majority of the surface water has been removed, the water content of the coal can be correlated with bed temperature. However, after the surface moisture has been removed, the temperature of the coal increases, bringing the bed closer to its auto-ignition temperature, thus bed temperature is monitored to determine the moisture content of the coal and to avoid hazardous conditions.

Flash dryers use entrained fluidized beds to dry particles in a hot gas stream with a residence time of one second or less. The low residence times permit flash dryers to have a high capacity while maintaining a relatively low inventory of coal in the dryers, thus making flash dryers somewhat less hazardous than slow, fluidized-bed dryers. However, the high gas velocity used in the drying tube requires a more difficult gas-coal separation to remove particulates from the effluent gas.

In spite of the large number and variety of commercially-proven drying processes, more processes are being developed. We think these new processes are being developed because people recognize that successful application of the processes is very dependent upon the character of the coal, the use for the product, and the economics of the application.

The current processes being developed (Davy McKee Corporation 1984) represent a variety of technologies. Hot water dewatering and decarboxylation employ similar principles. Both use thermal dewatering, require a high pressure treating reactor, alter the structure of the micropores in the coal to prevent readsorption of water, and require additional drying of the coal after dewatering.

The vapor recompression processes reduce process energy requirements by compressing water vapor to a higher pressure and using the steam to put heat back into the drying operation. Thus, much of the heat of vaporization of the water removed from the coal is made available at an elevated temperature for use in drying coal. Vapor recompression has been tested in pilot plants but is not known to have been used for drying coal on a commercial scale. The process seems to offer high thermal efficiency but will require high capital costs and high maintenance costs.

The Fleissner Process dries coal by heating the coal with steam under pressure. Some of the water is driven from the coal in the liquid state, thus reducing energy requirements of the process. At temperatures somewhat above normal evaporative drying temperatures, the coal structure is changed and carbon dioxide and water are driven from the coal. The coal is made hydrophobic by the treatment. Further drying of the coal is required after treatment. While the process was developed in 1927, the principle of altering the coal structure remains attractive. Also, expelling carbon dioxide from the coal has many of the same benefits as expelling water. The Fleissner Process requires high pressure to achieve the necessary temperature because the process uses steam. The principle of altering the coal structure to drive out water and carbon dioxide and seal off the micropores can be used at atmospheric pressure.

A drying process was developed for Powder River Basin (PRB) coal during the early 1980s. Initial work was done by Anaconda Minerals Company, and later with Arco they tested a 4 ton/hr pilot plant at Tucson, Arizona. The process has been licensed to Kaiser Engineers. The process is a fluidized-bed drying process using conventional equipment with a proprietary product treatment step (Skinner et al. 1984). The developers conducted laboratory research to determine methods to avoid low-temperature oxidation of the product. These methods included the use of cooling, controlled preoxidation, treatment with carbon dioxide, and spray application of oil or a chemical solution of the product.

If the drying process is a stand-alone operation, it is critical to treat dried coal to minimize or prevent moisture readsorption and self heating. In addition, dried coal is more friable than raw coal and hence generates more dust. To minimize these problems, it is common to spray oil on the coal as it leaves the dryer. The use of 1.5 to 2 gal of No. 6 oil per ton of coal has been shown to be effective in minimizing the problems discussed above (Bauer 1980). However, the addition of oil to dried coal increases operating costs.

Numerous mechanical treatments are also available for stabilizing coal products by reducing the surface contact with air. These include briquetting, pelletizing, and extruding with or without an added binder. An excellent list of references for use of binders in pelletizing is given in U.S. Patent 4,615,712 (Wen 1986) which describes the production of humic acid from oxidation of coals or leonardite and the use of the humic acid as a binder.

As we can see, a great deal of work has been done to develop coal-drying processes, and a large number of commercially-proven processes are available. However, coal from the Powder River Basin (Luckie and Draeger 1976) has not been successfully dried on a commercial scale even though a plant using a commercially-proven process was built in 1988. Most of the drying has been done using eastern U.S. bituminous coals and coals in foreign countries.

In this brief survey of published information related to coal drying, it soon becomes apparent that many of the so-called "drying" processes use conditions more severe than those required simply for removal of surface water. For development of the CompCoal process we are concerned with the removal of water, partial decarboxylation, and partial devolatilization of coal with the goal being the production of a stabilized char. The stabilization of the char is needed to prevent self heating, dust formation, and readsorption of moisture (Schmeling et al. 1977 and Jeglic 1986).

It is relatively easy to develop a process to drive the moisture from PRB coal. In previous work conducted at Western Research Institute, a number of combinations of gas flow rate and temperature were used to dry minus 8 mesh PRB coal to zero or low moisture content using a fluidized bed (Figure 1). However, this dried coal must still be stabilized to maintain the characteristics of a good-quality fuel. Although the dried coal we produced was dust-free, we did not scale the process to larger particles which are known to be weaker and more susceptible to dust formation.

We think a process to produce a good premium-quality fuel should go beyond simply removing water from the coal. Much of the oxygen in PRB coal can be removed by driving carbon dioxide, and some carbon monoxide, from the coal. This partial decarboxylation not only increases the heating value of the coal, but the removal of oxygen from the coal helps to stabilize the coal and to reduce the susceptibility to self heating (Tomuro et al. 1985). We controlled the partial decarboxylation (Figure 2) during our mild-gasification work to avoid accumulation of coal liquids in the dryer. Work at the Institute of Gas Technology (1976) reports that if the reaction temperature is less than 662°F (350°C), most reactions are intramolecular changes in the coal structure. These reactions include decarboxylation, demethoxylation, and partial dehydroxylation. Thus, they state that the reaction products are mainly water and CO₂. However, we have found that significant quantities of condensable coal liquids are evolved from PRB coal at temperatures as low as 600°F (315°C).

When the temperature is raised above that needed for drying and partial decarboxylation, pyrolysis begins. With the onset of pyrolysis, coal tars become mobil within and on coal particles, and gas is produced in increasing amounts. The flow of gas and vaporization of some of the low-boiling liquids, drive liquids and vapors from the particles. The onset of pyrolysis (600 - 800°F/315 - 427°C) coincides with the release of hydrocarbon gases and the formation of sulfur-containing gases derived from the decomposition of pyrites and sulfides in the coal.

The control of the pyrolysis reactions strongly influences the characteristics of the products and the relative quantities of gas, liquid, and char produced. During our mild-gasification work we learned how to control the process to produce maximum amounts of pitch and minimum quantities of light liquids. The pitch, which is a brittle solid at room temperature, has the properties needed to stabilize char converting it to a premium-quality fuel. The light liquids, because of their relatively high vapor pressure, are not suited for use as a stabilizing agent.

The char which we produced by the mild gasification of PRB coal (Table 1) has many of the desirable properties of a premium solid fuel (Daw et al. 1990). However, for that project we did not attempt to stabilize the char, since one of the objectives of that project was to produce a highly reactive char which was suitable for converting to pure carbon. We propose to make a CompCoal product with a heating value of about 12,500 Btu/lb and a composition between that of the dried coal and the char shown in Table 1. This compliance fuel will also produce less than 1.2 lb of SO₂ per million Btu. In addition, the product will be stabilized to reduce dust formation, readsorption of moisture, and the potential for spontaneous ignition.

DESCRIPTION OF THE COMPCOAL PROCESS

In the CompCoal process coal is dried, partially decarboxylated, mildly pyrolyzed, and stabilized. The CompCoal product is dust-free and resists readsorption of moisture (Table 2). In the process (Figure 3) volatiles are driven from the coal in the pyrolyzer. The high-boiling components (pitch) in the volatiles are adsorbed on the surface of the pyrolyzed char, thus coating the particles and sealing off the pores within the particles. The low-boiling components pass through the char bed. These low-boiling components can be burned as plant fuel, as we describe herein, or can be collected and used in some other manner. We plan to coat the char with about 6 to 8 wt % pitch, which is equivalent to about 15 gal of stabilizing agent per ton of coal.

The results of mild-gasification test 15, conducted at a maximum temperature of 950°F (510°C), showed that pyrolysis at that temperature produces more than enough stabilizing agent (700°F/370°C boiling liquid) and more than enough fuel (gas plus 700°F/370°C boiling liquid) to serve the process (Merriam et al. 1990).

The combination of options shown in Figure 3 results in a low-cost process because:

- No liquid products or emissions are produced
- No heat transfer surfaces are used
- Blowers are located in the process in clean gas streams
- The fluidized-bed reactors are high-throughput, low-cost devices
- Gases and vapors are burned as fuel; no solids are burned

A process flow diagram (Figure 4) and stream flows and conditions (Table 3) are used to size equipment for a 1000 TPD CompCoal plant (Table 4).

PRELIMINARY TESTING

We have considerable experience with both the dryer and pyrolyzer sections of the CompCoal process (Figure 4) based upon operations using bench-scale (Merriam and Cha 1989) and 100 lb/hr (Merriam et al. 1990) test equipment. Our objective for the tests described here was to test the concept of depositing pitch on char and to evaluate the effect of the coating upon the quality of the coated and stabilized char (the cooler section in Figure 4).

Two different scales of reactor systems were tested to evaluate the appropriate configuration for the stabilizer (cooler) section. These included a small, batch-operated, laboratory-scale reactor which can process about 100 g of coal in the pyrolyzer section and up to about 100 g of coal or char in the stabilizer section. The other system was a modified, bench-scale, inclined fluidized-bed (IFB) reactor. This latter system can pyrolyze about 10 lb of coal per hour in the inclined fluidized-bed pyrolysis section and treat about 1 lb of coal or char contained in the batch, fluidized-bed stabilization section.

During the laboratory-scale tests several variables were investigated. These included the use of an upflow packed-bed or a fluidized-bed pyrolyzer section coupled to an upflow packed-bed, a downflow packed-bed, or a spouting fluidized-bed stabilizer section. In addition, the final operating temperature of the stabilizer, the coating time for the feed in the stabilizer, the mesh size of the coal in the stabilizer, and the presence of coal or char in the stabilizer were evaluated with respect to the properties of the product. A total of 19 tests were conducted in the laboratory-scale reactor. The pertinent results from some of these tests will be discussed here. For the bench-scale tests the variables investigated were the pyrolyzer feed rate and the presence of coal or char in the stabilization section.

A summary of the test conditions used in the two reactor systems are given in Tables 5 and 6. For all of the tests the coal used was from AMAX's Eagle Butte mine in the Powder River Basin of Wyoming. The two chars that were tested were produced during mild-gasification tests, MG115 and MG123, using Eagle Butte coal (Merriam et al. 1990).

The operation of either of the two reactor systems was similar. First the stabilization section was loaded with either coal or char. Next the flow of the gas stream through the system (nitrogen or carbon dioxide) was started, and the pyrolysis section was preheated to about 1000°F (538°C). The gas flow rate for the laboratory-scale tests was 0.3 scfm of nitrogen while that for the bench-scale tests was 6.8 scfm of carbon dioxide. Coal was pyrolyzed in the preheated pyrolysis section, and the vapors were transported to the stabilization section where the higher boiling components of the vapor condensed on the coal or char sample to be stabilized. The lower boiling components of the vapor passed through the stabilization section. A diagram of the inclined fluidized-bed reactor system is shown in Figure 5. As mentioned earlier the important properties that need to be addressed during these tests are the dustiness, the equilibrium moisture percentage, and the spontaneous ignition potential of the stabilized product.

Dustiness

A modified version of ASTM D 441 (ASTM 1991) was used to evaluate the dust-forming tendency of the coated products and raw coal. Because the samples produced were quite small we used a tumbler built to 1/10 of the scale of that described in ASTM D 441. In the procedure the sample is screened to plus 10 mesh. The plus 10 mesh material is then tumbled for 1 hr at 40 rpm. After tumbling, the minus 50 mesh material is removed from the sample by screening. The weight percent of minus 50 mesh particles is the dust index (Table 7). The results indicate that the coated coal and coated char from the two reactor systems have a lower dust index than the raw PRB coal.

The oil content of the materials shown in Table 7 is approximated by that portion of the sample which is soluble in tetrahydrofuran (THF). Unfortunately, the determination of THF solubles does not distinguish between the external coating applied and that amount of THF solubles that was inherently present in the coal or char. However, we know the feed char contains only 0.2 wt % THF solubles so the THF solubles for the two char samples shown in Table 7 are a close approximation to the quantity of coating deposited upon the char. However, the coal samples were subjected to temperatures and gas flows that would simultaneously remove any low-boiling components inherently present while depositing a high-boiling coating upon the coal. Thus, some of the THF solubles shown for the coal samples were already present rather than applied as an external coating.

Readsorption of Moisture

We use the equilibrium moisture percentage of the materials as an approximate indication of the limit to which coal, char, or the CompCoal product can readsorb moisture from the atmosphere. The equilibrium moisture percentage as measured by ASTM D 1412 is actually intended to measure the moisture content of coal seams and probably gives a high value for the potential readsorption because of the severity of the test conditions. In the test, equilibrium moisture percentage is determined by soaking the coal in deionized water for 2 hr, removing the excess water by filtration, and then storing the coal in a humidity chamber for 48 hr. The humidity in the chamber is controlled to have a vapor pressure for water of 30 mm Hg at 86°F (30°C) (greater than 97% relative humidity). The test specification calls for crushing the coal to minus 28 mesh. However, we did not crush the materials because we did not want to alter the surface characteristics of the coated coal and char.

While the equilibrium moisture does not exactly measure the absolute tendency of the materials to readsorb moisture, we think it is an acceptable indicator for comparison of the relative limits to which two or more materials may readsorb moisture under controlled conditions of exposure.

The readsorption of moisture is a concern with a low-moisture CompCoal product because of the many undesirable effects of moisture and because the heat of adsorption of water is thought to contribute to self heating of dried coal. Boysen et al. (1990) showed that the equilibrium moisture percentages of dried PRB and Usibelli coals correlate with drying temperatures up to about 750°F (400°C) and an equilibrium moisture percentage of about 12 wt %. We used data from other work (Merriam et al. 1991) and data from this investigation to extend the curve up to about 1075°F (580°C) (Figure 6). The results show that increasing processing temperatures above about 700°F (370°C) does not continue to produce significant reductions in the equilibrium moisture percentage of the product. Thus, we cannot expect to obtain a material having a very low equilibrium moisture percentage simply by processing at temperatures exceeding about 1000°F (538°C).

The coating of raw coal and char using either the laboratory-scale or bench-scale reactor systems produced materials that contained, in general, increased levels of THF solubles. In addition, these materials had lower equilibrium moisture percentages than the coal or char feeds. The results of these tests are shown graphically in Figure 7. The results also show that coated char has a lower limit for readsorption of moisture than does coated coal. Thus, it appears that during the production of the char its capacity to adsorb moisture is limited, probably because of pore collapse, and coating the char further reduces that limit. The five data points slightly above the line for coated coal represent that data obtained for samples produced using the laboratory-scale reactor. Remember that these products were produced in a downflow, packed-bed stabilizer while the other coal products were produced using a fluidized-bed stabilizer. For these five tests the stabilizer temperature reached a temperature above 296°F/147°C (see Table 5); a temperature comparable to that in the stabilizer section for the bench-scale tests. Notice in Table 5 that the stabilizer temperature for the other laboratory-scale tests on coal are less than 255°F (124°C), and the equilibrium moisture percentages for the products are higher (26.2 to 31.2 wt %) even though the percentage of THF solubles is comparable to that of the other coal products. This seems to indicate that the stabilizer temperature has some impact on the properties of the coal product. The impact of the stabilizer temperature on the char products does not seem to be as important. The stabilizer temperature for CC016 was 186°F (86°C) while that for CC019 was 339°F (171°C), and the data for these two products fall nicely on the line produced by the results for the char products from the bench-scale tests.

Self Heating

Self heating or spontaneous ignition is a problem often encountered with dried coal. We also observed self heating of the chars produced by mild gasification of PRB coal (Merriam et al. 1990). Even when self heating is controlled by moving the coal piles, the low level of oxidation results in a lower heating value of the coal.

Tomuro et al. (1985), working with western U.S. subbituminous coal, showed that the oxidation rate is directly proportional to the volatile oxygen content of the char (coal) and that removal of oxygen by devolatilization lowered the oxidation rate. They also showed that coating the surface of the carbonized coal further decreased the oxidation rate.

Listed in Table 8 are the results of determining the self-heating potential of raw PRB coal, the feed chars, and the coated char products. A description of the test apparatus and how the tests were conducted is contained in the report by Merriam et al. (1991). Table 8 contains the results for both the feed char for CC019 and its product and the feed char for IFB 69 and its two products. The feed chars to the stabilizer are quite reactive, spontaneously igniting in about 9 to 10 hr in our test apparatus. However, the ignition time for the coated chars is longer, requiring from 15 to 36 hr. In addition, there seems to be a positive correlation for percentage of THF solubles and the time to spontaneous ignition. The raw PRB coal takes the longest time to spontaneously ignite (about 72 hr). The reader is cautioned that the test used here to evaluate the self-heating potential of the various samples is employed by us to monitor the change in this property with respect to the experimental conditions of the process. The results reported do not correlate directly with conditions at a mine site but rather indicate the presence of a trend, in this case, a decreasing potential for self heating with an increasing percentage of a tar coating as produced by the CompCoal process.

PRELIMINARY ECONOMIC EVALUATION

The cost of capital equipment items (Table 9) are proportioned from published costs of similar equipment (Ralph M. Parsons Co. 1991) designed for a 1000 TPD mild-gasification plant using PRB coal. We assumed that the plant would be located at a PRB mine and would use existing crushing and screening equipment. The plant will operate for 330 days each year and will produce 573 TPD of the CompCoal product. The plant uses 16.6×10^9 Btu/day in coal feed while producing 14.3×10^9 Btu/day of the CompCoal product for a conversion efficiency of 86%.

We have charged PRB coal to the operating costs (Table 10) at a rate of \$4.25 per ton. We have used 10 year straight-line depreciation to provide rapid recovery of the capital investment and to simplify the calculations. Electrical power is estimated by proportioning gas flow rates to horsepower taken from the Parsons design (Ralph M. Parsons Co. 1991). We have assumed 50% debt financing for the project.

Income from the CompCoal plant is based upon two sources. First, the concentrated product can result in shipping the same quantity of energy at reduced tonnage, thereby reducing freight costs. Second, the CompCoal product is a premium fuel which commands a premium price in the market place.

The reduction in freight costs is estimated from shipment of 189,300 tons/yr (TPY) of the CompCoal product, containing 4.732×10^{12} Btu, at \$20/ton for a freight cost of \$3,786,000. Shipment of 285,090 tons of 8300 Btu/lb PRB coal containing the same amount of energy costs \$5,701,807 for freight. Thus, \$1,915,807 is saved by reduced freight costs.

The CompCoal product, because of its low sulfur content and high heating value, is clearly a premium fuel, but WRI does not have the market contacts to determine what the selling price will be. We have treated the selling price of the CompCoal product as a variable to determine the price at which the return on investment becomes attractive (Table 11). Our evaluation shows that an attractive return on investment can be earned if the CompCoal product sells for \$20/ton or higher.

SUMMARY OF THE INITIAL EVALUATION

WRI is presently conducting bench-scale tests to produce a simulated CompCoal product and to evaluate the stability and handling characteristics of the product. We have shown that pitch or coal tars produced by pyrolysis of PRB coal can be deposited upon coal or char as a coating. The coating reduces the dustiness, the capacity to readsorb moisture, and the self-heating potential of the char. Based upon the promising results of this initial evaluation of the CompCoal process, we feel that the process may become economically attractive and technically feasible.

We have used data from other work to evaluate the possibility of stabilizing dried coal or char by processing the coal at higher temperatures. This evaluation has shown that increasing the temperature from about 700 to 1100°F (370 to 593°C) results in only a slight reduction in the moisture readsorption capacity of the product.

Results of our tests show that coated char has less capacity to readsorb moisture than raw PRB coal which is coated in the same manner.

Obviously, more work is needed to develop the CompCoal process. The screening we have conducted to date has not resulted in the discovery of any insurmountable obstacles to the development of the process. We plan to conduct longer tests, produce larger samples of coated product, and conduct more extensive evaluation of the process and the quality of the product.

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DISCLAIMER

Mention of specific brand names or models of equipment is for information only and does not imply endorsement of any particular brand.

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Table 1. Properties of PRB Coal and Char, wt % as received

	Coal	Dried Coal	Char
Moisture	30.7	0	0
Ash	4.9	6.4	8.7
Volatiles	33.7	42.6	17.4
Fixed Carbon	30.7	52.0	74.0
Sulfur	0.35	0.5	0.6
HHV, Btu/lb	8300	11,975	13,200
lb SO ₂ /MM Btu	0.84	0.84	0.84

Table 2. Target Specifications for the CompCoal Product

HHV 12,500 Btu/lb
 0.6-0.9 lb SO₂/MM Btu
 1/2 in. by 20 mesh
 No Dust
 Low Moisture Readsorption
 Low Self Heating
 Good Combustion Characteristics

Table 3. Stream Flows and Conditions

Stream	Material	Flow MPPH	Temp °F	Press psia	Enthalpy MM Btu/Hr
1	Raw Coal	83.3	60	12.5	0
2	Dry Coal	51.1	250	14.5	3.398
3	Char	44.2	900	14.5	12.995
4	CompCoal Product	47.8	200	13.5	2.342
5	Dryer Effluent	189.2	250	14.5	10.784
6	Fines	5.3	250	14.0	0.352
7	Dryer Effluent	183.9	250	14.0	10.482
8	Dust	0.6	230	13.5	0.040
9	Air	62.6	60	17.5	0
10	Fuel Gas	90.0	220	17.5	4.464
11	Flue Gas	152.7	1500	16.5	59.370
12	Pyrolyzer Fluidizing Gas	63.2	1500	16.0	24.572
13	Flue Gas	84.6	1500	16.0	32.892
14	Cooler Fluidizing Gas	70.1	900	14.5	15.899
15	Dryer Effluent	188.6	230	13.5	8.657
16	Dryer Recycled	78.2	230	17.5	3.589
17	Dryer Effluent	110.4	230	17.5	5.067
18	Vent Gas	110.0	220	16.0	4.752
19	Water	22.3	60	43.5	0
20	Dryer Recycled Gas	162.8	900	16.5	36.923

Table 4. Equipment Needed for 1000 TPD CompCoal Plant

Coal Feed System

Assume crusher, screens, belts already in place
Add feed conveyor, surge bin, feed screws, rotary valves
Feed Conveyor - 41.7 TPH, 24 in. wide, 120 ft long, 25 hp
Surge Bin - 25 ton capacity
Feed Screws (3) - carbon steel (CS), 6 in., 20 ft long, 2 hp
Rotary Valves (3) - CS, 8 x 10 in., 2 hp

Reactors

Dryer - 3 min coal residence time, 200 ft³, 10 ft TT, 13 ft diameter, CS
Pyrolyzer - same as dryer except add \$25,000 for low-alloy steel
Cooler - same as dryer

Blowers

Air Blower - 63 MPPH, 16,100 acfm, 12.5 psia and 60°F suction, 5 psi AP, 200 hp
Dryer Gas Blower - 190 MPPH, 51,500 acfm 14.5 psia and 200°F suction, 5 psi AP, 2250 hp
Pyrolyzer Blower - 153 MPPH, 41,500 acfm 14.5 psia and 200°F suction, 5 psi AP, 1500 hp

Cyclones

Dryer cyclones (5) - 190 MPPH, 250 F, 14.5 psia, 55,400 acfm, CS

Burner

Heat release 48 million Btu/hr
Fuel - Gas, 2900 PPH, 560 Btu/scf HHV, MW 32
- Vapor, 2600 PPH, 20,500 Btu/lb
Refractory lined, no heat transfer surface, 22 psia, 1500°F

Vent Gas Scrubber

Limestone slurry for SO₂ removal
Gas 110 M PPH, 29,800 acfm
Inlet 230°F and 17.5 psia
Scrub - 140 PPH of SO₂, 1200 ppm inlet

Bag Filters (4)

Flow 184,000 PPH, inlet 14 psia and 250°F
(1-5 psig), 50,000 acfm, CS

Table 5. Conditions Used for the Laboratory-Scale Tests to Stabilize Raw Coal and Char

Test Number	Pyrolyzer		Stabilizer	
	Temp, °F	Time, min ^a	Temp, °F	Configuration
CC005	1038	30	218	downflow, packed bed
CC006	1018	15	313	downflow, packed bed
CC007	1009	5	304	downflow, packed bed
CC008	1000	0	330	downflow, packed bed
CC009	1034	15	255	downflow, packed bed
CC010 duplicate of 9	1028	15	245	downflow, packed bed
CC011	1028	15	137	downflow, packed bed
CC012 duplicate of 11	1029	15	148	downflow, packed bed
CC014	1026	15	296	downflow, packed bed
CC015	1014	15	167	downflow, packed bed
CC016, char	1014	15	186	downflow, packed bed
CC017	1016	15	254	spouting, fluidized bed
CC018	1011	15	334	spouting, fluidized bed
CC019, char	1013	15	339	spouting, fluidized bed

^a Time the pyrolyzer was above 1000°F

Table 6. Conditions Used for the Bench-Scale Tests to Stabilize Raw Coal and Char

Conditions	IFB Test Number			
	69A	69B	70A	70B
Stabilizer Feed	Char	Char	Coal	Coal
Source	MG123	MG123	EB	EB
Fluidizing Gas	CO ₂	CO ₂	CO ₂	CO ₂
Flow Rate, scfm	6.8	6.8	6.8	6.8
Pyrolyzer Feed	Minus 16 mesh PRB coal from the Eagle Butte mine			
Pyrolyzer Feed Rate, lb/hr	10	10	10	10
Feed Time, hr	0.25	0.50	0.25	0.50
Pyrolysis Temperature, °F	1003	1003	1000	1010
Stabilizer Temperature, °F				
In	397	394	376	399
Out	325	335	348	349

Table 7. Dust Index of PRB Coal, Coated Coal, and Coated Char

Material	THF Solubles, wt %	Dust Index, wt % minus 50 mesh
PRB Coal (-1/8", +10 mesh)	7.2	1.4
Coated Coal - CC002 ^a	6.1	0.9
Coated Coal - CC003 ^a	10.6	1.3
Feed Char	0.2	ND
PRB Coal (+16 mesh)	5.8	1.7
Coated Char - Test 69A	6.5	1.0
Coated Char - Test 69B	8.8	0
Coated Coal - Test 70A	5.4	1.0
Coated Coal - Test 70B	6.0	0.9

^a These are products from two preliminary tests of the laboratory-scale reactor. The operating conditions were similar to those for the other tests, except that the stabilizer section for CC002 was configured upflow.

Table 8. The Self-Heating Potential of Raw PRB Coal, the Feed Chars, and the Coated Char Products

	THF Solubles, wt %	Ignition Temperature, °F	Time to Ignition, hr
PRB Coal	9.1	388	71.7
Feed Chars			
CC019	0.3	356	8.6
IFB 69	0.2	347	10.3
Coated Chars			
CC019	6.6	367	35.6
IFB 69a	6.5	415	14.8
IFB 69b	8.8	402	20.3

Table 9. Cost of Capital Equipment for a 1000 TPD CompCoal Plant

Number		\$1000	
		Cost	Installed
1	Conveyor - 24 in., 120 ft, 25 hp	195	389
1	Feed Bin - 25 ton capacity	60	113
3	Feed Screws - CS 6 in., 2 hp	233	464
3	Rotary Valves - CS 8 x 10 in., 2 hp	16	31
1	Dryer - CS 13 ft diameter, 10 ft TT	104	239
1	Pyrolyzer low alloy - 13 ft diameter	129	297
1	Cooler - 13 ft diameter, 10 ft TT	104	239
1	Air Blower - 16,100 acfm	155	310
2	Dryer Recycle Blower - 51,500 acfm	941	1,778
2	Pyrolyzer Blower - 41,500 acfm	448	806
5	Dryer Cyclones - CS 55,400 acfm	138	248
5	Cyclones Rotary Valves - CS 6 x 8 in., 1 hp	45	85
4	Bag Filter - CS 20,000 cfm, 25 hp	60	240
1	Burner - 48 MM Btu/hr	405	648
2	Water Pumps - 45 gpm, 2 hp	20	63
1	Water Tank - CS 10 M gal	25	50
1	CompCoal Product Storage - 430 ton	240	454
1	Loading Conveyor - 24 in., 120 ft	195	389
1	Flue Gas Scrubber	368	672
2	Product Storage Silos, 6500 ton each		<u>2,000</u>
	Cost of Equipment		9,515
	Sales Tax - 5%, Construction Management - 5%		
	and Engineering - 10%		1,903
	Contingency - 20%		<u>1,903</u>
	Total Capital Cost		13,321
	Annual Depreciation - 10 yr straight line	1,332	

Table 10. Operating Costs for a 1000 TPD CompCoal Plant (\$1000)

Coal - 330,000 tons @ \$4.25	1,403
Labor - 3 Supervisors, 53 K/yr	159
Labor - 8 Operators, 45 K/yr	360
Maintenance - 3% of capital cost	400
Depreciation - 10 year straight line	1,332
Limestone - 5 TPD @ \$18/ton	30
Water - \$.50/M gal, 45 gpm	15
Propane (startup) - 10,000 gal @ \$.60	6
Sludge Disposal (Desulfurization)	30
Electrical Power - 4000 hp @ \$0.055/KWH	1,104
Interest Expense @ 10% (50% debt, 50% equity)	<u>666</u>
Annual Operating Cost	\$5,505

Table 11. Net Income from a CompCoal Plant at Varying Selling Prices, \$/ton

	\$15.00	\$20.00	\$25.00	\$30.00
Income, \$ million	2.84	3.78	4.73	5.67
Freight Savings	<u>1.90</u>	<u>1.90</u>	<u>1.90</u>	<u>1.90</u>
Total Income	4.74	5.68	6.63	7.57
Operating Cost	<u>5.51</u>	<u>5.51</u>	<u>5.51</u>	<u>5.51</u>
Net Income	(0.77)	0.17	1.12	2.06
FIT (34%)	<u>0.0</u>	<u>0.058</u>	<u>0.381</u>	<u>0.700</u>
Income After Tax	(0.77)	0.112	0.739	1.360
Depreciation	<u>1.332</u>	<u>1.332</u>	<u>1.332</u>	<u>1.332</u>
Cash Flow	0.562	1.444	2.071	2.692
Discounted Cash Flow				
Rate of Return %	10	22	32	41

Basis = 1000 TPD Feed Coal, 330 days per year, 189,300 TPY of CompCoal product, Freight - \$20/ton, Investment - \$6,660,500

Figure 1. Drying Rates of PRB Coal at Various Fluidizing Gas Temperatures and Flow Rates

Figure 2. Removal of Oxides of Carbon from PRB Coal

Figure 3. Process Flow Diagram for the CompCoal Process

Figure 4. Stream Identification Numbers for the CompCoal Process

Figure 5. Flow Diagram of the Inclined Fluidized-Bed Reactor System

Figure 6. Extension of Equilibrium Moisture Curve to 1100°F Processing Temperature

Figure 7. Equilibrium Moisture for Coated Coal and Char at Various Coating Levels

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