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DEVELOPMENT

By
W.G. Willson, W. (Bill) Irwin,
and Todd A. Potas
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W.G.Willson, EMRC, and Mineral Industry Research Lab,
University of Alaska Fairbanks,
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Todd A. Potas, Energy and Mineral Research Center,
University of North Dakota

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Introduction

Alaska's 5.5 trillion tons of estimated coal resesources comprise about half the United States' coal resources.(1) The largest of Alaska's coal basins, estimated to be over 4 trillion tons, is the Northern Alaska Basin. It consists of a tremendous subbituminuous coal deposit which in areas overlies a rich bituminuous deposit.(1) The Cook Inlet-Susitna Basin, which is composed mainly of low-rank coals may contain over a trillion tons.(1) The remainder of the coal basins are small by Alaskan standards but still contain billions of tons of reserves. As an example, the Nenana Basin which boasts Alaska's only operating mine, the ultra modern Usibelli Coal Mine, has "only" about 10 billion tons of proven reserves.(1) The locations of the major coal regions in Alaska are shown in Figure 1.

The outstanding feature of almost all Alaskan coals, regardless of rank, is the extremely low sulfur content.(2) The majority of the Alaskan coals are already compliance coals. Many of the low-rank coals (LRCs) have sulfur levels below 0.2 %; for example, the latest three year average for the Usibelli subbituminuous coal was 0.17 %. In addition, many of the LRCs have moderate ash levels and reactivities typically an order of magnitude higher than their bituminuous counterparts. They are prime candidates for use in advanced applications such as, gasifiers, fluid-bed combustors and even in diesels and turbines. Many of the low-rank coal are recoverable by strip mining and are also near tidewater making them amenable to low-cost ocean transport.(1)

Major reasons for the limited use of Alaskan coals include low population density, distance from high energy use areas, abundant more convenient energy forms (gas and oil) and mining and transportation costs. In addition, the low-sulfur, highly reactive LRCs are plagued with the high moisture inherent in their ranking. This has restricted the world wide usage of most LRCs to mine mouth power generation. However, a new applications of an "old" technology, steam drying, could expand international use of LRCs and provide a valuable Alaskan export to nations of the Pacific Rim.

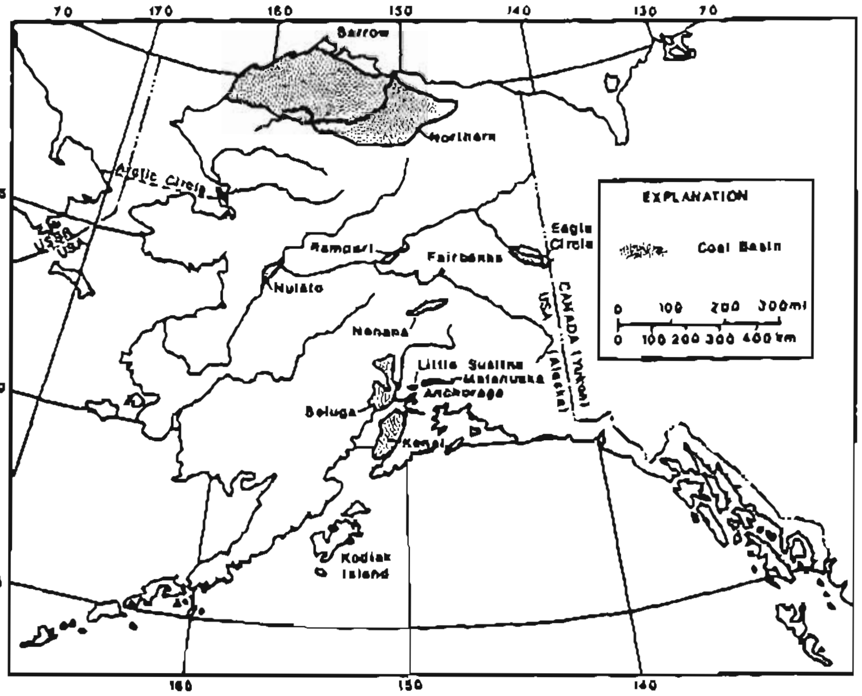

FIGURE 1 - COAL REGIONS OF ALASKA.

BACKGROUND

Drying processes are generally categorized by operating temperature, drying environment and type of feed (either sized or ground coal). Within these broad categories, processes differ according to the type of drying equipment and methods of quenching and stabilizing the dried product.

Conventional Evaporative Drying

Numerous low temperature drying technologies are available. Most processes use hot flue gases to evaporate coal moisture. The final product moisture content is dependent on feed size and residence time at temperature. With an entrained reactor, like a Parry drier, moisture levels can be reduced to a few percent (3). For larger-sized feeds, such as those used in rotary kiln driers, a nominal moisture level of 15% is typical (3).

These processes are the most economical, due to the low temperatures employed, and are preferred if the dried product can be utilized immediately. However, since the drying temperatures are too low to cause permanent changes in the coal structure, the dried coals reabsorb the lost moisture when re-exposed to humidity or water unless steps are taken to minimize the exposed dried coal surface area (3). The untreated, dried product is also susceptible to spontaneous heating and fines production to a greater extent than the raw coal under similar handling and storage conditions.

Methods for minimizing these problems include: coating the coal with residual tar or oil; drying only larger lump coal; or producing briquettes or pellets from dried pulverized coal. All of these require additional processing steps, which increase the cost of the final product, and must be evaluated on a coal- and site-specific basis. For oil treatment, the key economic factor will be how small an amount of oil is required to stabilize the product. For large-size coal drying, the key will be the amount of fines produced and their use. For briquettes or pellets, the economic criteria will be binder requirements and processing costs.

The largest low-rank coal commercial drying venture in the U.S. is entering its initial operating phase at AMAX Coal Company's drying plant near Gillette, Wyoming. Drying of Belle Ayr Mine subbituminous coal to 10 - 15% moisture is accomplished in a fluid-bed drier. The gravel-sized dried product is stabilized by a coating of residual oil and fines are returned to the process combustor (4). Technical and economic data regarding product stability as a function of process parameters and oil treatment are anxiously being awaited by a number of coal owners with an eye towards export to the Pacific Rim.

High Temperature Drying

If LRCs are dried at temperatures above 240°C, the basic chemical and physical coal characteristics begin to change. Decarboxylation occurs and carbon dioxide is evolved (5). Decarboxylation helps reduce the capacity of coal to bind water by ridding the surface of hydrophilic functionalities (5). Many of the coal's volatile tars and oils, are also liberated during high temperature drying and migrate to the coal surface (5). If the tars are not stripped during drying, they remain on the coal, effectively sealing the micropores and reducing the coal's surface area and ability to hold water.

Product stability, especially regarding fines production and spontaneous combustion, is a major concern for most high temperature drying processes, just as it is with low temperature processes. The same stabilization methods described previously for low temperature drying processes are used to enhance product stability.

Hydrothermal processing (hot-water drying, HWD) is an advanced technology featuring high pressure, non-evaporative drying, which solves stability problems by producing a safe, transportable liquid. In this process, a utility grind of LRC is continuously treated as a dilute slurry at coal specific temperatures beginning as low as 240°C and the corresponding saturated steam pressure for as little time as a minute (3,5,6,7). Water is removed via expansion and expulsion by carbon dioxide. Devolatilized, hydrophobic tars and oils are retained on the coal surface in the pressurized aqueous environment. Uniform tar distribution, obtained only by aqueous processing, seals most of the micropores and prevents water reabsorption. The overall process, which can be described as induced coalification, removes the inherent moisture and reuses the moisture as the carrier solvent. For some high moisture coals, the process may even become a net producer of water. In some coals, alkali cations associated with the carboxyl groups are released into the aqueous phase and can be removed by washing the product during the final mechanical dewatering step, rendering a product with a much lower propensity for boiler tube fouling due to reduced contents of sodium and other minerals.

The technical feasibility of HWD has been demonstrated in a continuous 2.5 ton/day process development unit (PDU) at the Energy and Mineral Research Center (EMRC), University of North Dakota (8). LRCs from the Western and Gulf Coast regions of the U.S. and Western Canadian coal-producing regions have been converted into concentrated coal/water fuels (CWFs) by HWD. As a general rule, the increase in energy density for CWFs produced hydrothermally versus CWF prepared from untreated coals have been an increase of about 50% for lignites and 30% for subbituminous coals (4). Bench-scale tests have shown even more dramatic increases in energy densities for CWFs prepared from higher moisture feeds, such as Australian brown coals, peat and biomass (9,10).

Alternate end use applications, such as using CWFs in combustion turbines and/or diesel engines, have placed new demands on the fuel's combustion characteristics due to the greatly shortened residence times allowable for combustion. Instead of the usual seconds available in conventional combustors, reaction times in heat engines are measured in milliseconds. Thus, to achieve more complete carbon burnout, bituminous CWF suppliers have had to go to more costly fine grinding to produce "micronized" CWFs (mass mean diameters of around 10 microns or less) (11). The small size and much narrower particle size distributions negate any advantages bituminous coals might have held over LRCs in producing more concentrated CWFs, since concentrations from 50-55 wt% are the rule (12). For advanced applications the higher reactivity of LRC CWFs should prove to be a decided advantage over bituminous CWFs, by requiring less grinding to reach a size for complete carbon burnout or to enable utilization in higher speed engines.

Hot-water drying (HWD) by induced coalification alters the hydrophilic nature of LRC to a hydrophobic material with equilibrium moisture levels similar to bituminous coals. This process enables the production of CWFs from LRCs with solids contents comparable to those obtained with high-rank coals. The ability to produce CWFs from LRCs takes on added significance as Pacific Rim countries, led by Japan, which already produces electric power from CWFs commercially, move rapidly to a diversified energy mix from stable suppliers (13). No longer will users be restricted to the purchase of CWFs made from expensive high-rank coals. With HWD, cheaper, more reactive LRCs become available from Alaska.

Canadian Pacific Consulting Services, Inc. (CPCS), Calgary, Alta., Canada, the international consulting arm of Canada's largest transport and resource development corporation with proven CWF experience, has joined EMRC to market LRC CWF internationally. The Mineral Industry Research Laboratory, University of Alaska Fairbanks, with many years of experience in sampling and researching the conversion potential of Alaska's diverse coals, is leading the effort to demonstrate the application of the technology to Alaskan LRCs. Additional participators and team members in the Alaskan technology development program include Placer Dome U.S. Inc., holders of extensive coal rights in the Beluga Coal Field west of Anchorage, and Usibelli Coal Mine Inc. located in Healy, operators of the only producing coal mine in Alaska mining 1.5 MM ton/year split about evenly between export and state use.

EXPERIMENTAL

The initial HWD tests with an Alaskan LRC were made with a subituminuous coal from the Usibelli Mine in the Nenana Basin. The as received coal was pulverized to a "standard" utility grind(90%-200 mesh) and charged as a dilute slurry to the EMRC autoclave drying simulator. The coal was dried in water at three temperatures and the corresponding saturated steam pressures, Table 1.

Table 1.

Analyses of Usibelli Coal as a Function of HWD Temperature.

OPERATING PARAMETERS				
Drying Temp.(°C)	As Rec'd	275°C	308°C	339°C
Pressure(psig)	14.7	1065	1625	2600
Eq. Moist.(wt%)	24.1	11.7	8.5	9.2
PROXIMATE ANALYSES(Moisture Free)				
Ash(wt%)	7.6	8.6	8.6	8.1
Vol. Matter(wt%)	43.5	46.9	45.4	43.9
Fixed C.(wt%)	48.9	44.5	46.0	48.0
Fuel Ratio(FC/VM)	1.12	0.95	1.01	1.10
ULTIMATE ANALYSES(Moisture Free)				
Carbon (wt%)	64.8	67.5	69.9	71.1
Hydrogen "	5.0	5.2	5.4	5.1
Nitrogen "	0.9	0.9	1.0	1.0
Sulfur "	0.1	0.2	0.1	0.1
Oxygen "(diff)	21.6	17.6	15.0	14.6
Ash "	7.6	8.6	8.6	8.1
HEATING VALUE(Btu/lb)				
Moist. Free Basis	11,100	11,800	12,300	12,800
M & Ash Free	12,000	12,700	13,400	14,000
MASS & ENERGY BALANCES(MAF Basis)				
Dry Coal Rec.(wt%)	100	93	88	86
Energy Rec. (%)	100	98	98	99
CWF PROPERTIES *				
Solids Loading(wt%)	44	58	60	62
Heat V.CWF(Btu/lb)	4,900	6,900	7,400	8,000

* Maximum bone dry solids determined for CWFs at a viscosity of 800 cP and as shear rate of 100 1/sec.

Usibelli coal is typical of the high quality Alaskan LRCs with less than 0.2% sulfur (Table 1). It is similar in many respects to the more familiar Powder River Basin coals, but with possibly even better combustion characteristics due to a lower fuel ratio (fixed carbon to volatile matter ratio) (9,14). It is important to note that, while the fuel ratio generally increases upon treatment and also generally with increased drying temperature, it is nowhere near the nominal 1.8 suggested as a cut off point for many bituminous coals. The higher the fuel ratio, the lower the volatile content, which is indicative of a material that is difficult to ignite and requires longer residence times for complete carbon burnout. Usibelli coal, however, showed only a slight increase in the fuel ratio, which remained near unity even at drying temperatures of up to 339°C, as shown in Table 1.

Usibelli coal exhibited other traits more characteristic of coals younger than typical subbituminous coals. It appeared to have a high wax/tar content that made the particles agglomerate immediately after hydrothermal treatment. This made it necessary to use rapid mixing when preparing the CWF. Of industrial significance, after mixing to prepare a CWF with a dry solids content over 60%, the particles showed no further tendency to reagglomerate. Another example of younger coal behavior was the increase in the CWF energy density to over 50% of that possible with the raw coal. This large of an increase is more in line with lignitic or brown coals, and again suggests that the Usibelli CWF should have excellent combustion characteristics and may be usable in advanced applications without micronizing.

In addition to Usibelli's outstanding response to hot-water drying, the coal has shown excellent response to physical and chemical cleaning. With a starting raw ash content of 7-9 wt% on a moisture-free basis, it will be necessary to lower the ash content to utilize the coal in heat engine systems.

Standard Certigrav float/sink separations were performed on various sizes of Usibelli coal at EMRC. Table 2 shows the cumulative physical cleaning results for the Usibelli subbituminous coal at 1/4" by 10 mesh, 80% minus 200 mesh (standard combustion grind) and 100% minus 325 mesh (micronized grind). The yield and ash reduction values for the 1/4" by 10 mesh sample were optimum at 1.40 specific gravities with an 84% yield and 34% ash reduction. Yields were slightly higher for the finer-sized coal, with the ash reductions remaining similar to the 1/4" by 10 mesh results for the various specific gravities.

Bench-scale chemical cleaning tests on the Usibelli coal were performed using 4.0 wt% aqueous nitric acid solution. The 1/4" by 10 mesh physically cleaned sample was ground to 80% minus 200 mesh before chemical cleaning. The coals were reacted for 1 hour at 80°C in the acid solution before filtering. The acid cleaning was performed on an 80% minus 200 mesh raw coal sample for comparison. The acid cleaning results for the various Usibelli coal samples are shown in Table 3.

The acid cleaning alone did not result in significantly improved cleaning over the physical cleaning, as shown by the yields and ash reductions for the raw coal samples. However, when the acid cleaning was performed on the physically cleaned samples, there were large reductions. The most outstanding result was for the 1/4" by 10 mesh, physically cleaned sample. An ultra-clean coal product of 0.70 wt% ash on a dry basis was produced with a total yield of over 80%. Cleaning was successful for the other physically cleaned samples as well, but not to as great an extent.

TABLE 2

CUMULATIVE RESULTS FOR FLOAT/SINK ANALYSIS OF USIBELLI SUBBITUMINOUS COAL.

Sample	Product	Cumulative Yield (%)	Ash (%)	Ash Reduction (%)
1/4" x 10 mesh	1.30-Float	10.81	4.45	48.26
	1.40-Float	84.35	5.65	34.30
	1.50-Float	93.98	6.33	26.40
	1.60-Float	96.64	7.03	18.26
	Total	100.00	8.60	---
80% <200 mesh	1.30-Float	0	0	0
	1.40-Float	54.01	5.34	44.78
	1.50-Float	88.78	6.44	33.40
	1.60-Float	93.70	7.17	25.85
	Total	100.00	9.67	---
100% <325 mesh	1.30-Float	0	0	0
	1.40-Float	48.05	4.80	40.00
	1.50-Float	94.36	5.82	27.25
	1.60-Float	96.93	6.13	23.38
	Total	100.00	8.00	---

TABLE 3

ACID CLEANING RESULTS FOR THE TREATMENT OF RAW AND PHYSICALLY CLEANED SAMPLES OF USIBELLI SUBBITUMINOUS COAL.

Sample	Product	Cumulative Yield (%)	Ash (%)	Feed Ash Reduction (%)
1/4" x 10 mesh	Raw	95.66	4.06	51.67
	1.40-Float	80.05	0.70	91.72
80% <200 mesh	Raw	96.11	6.84	36.25
	1.40-Float	50.07	1.40	86.95
	1.50-Float	84.34	1.50	86.02
100% <325 mesh	Raw	95.73	4.58	48.25
	1.40-Float	45.21	1.78	79.89
	1.50-Float	88.11	2.51	71.64

CONCLUSIONS

The Alaskan subbituminous coal from the Nenana Basin, Usibelli Mine, is an excellent candidate for hydrothermal upgrading to produce concentrated coal/water fuels.

In tests using Usibelli, the hot-water drying process:

- Increased dry solids contents from 44% to 62% without additives.
- Increased energy density from 4,900 to 8,000 Btu/lb.
- Gave product energy recoveries of over 95%.
- Helped maintain a low CWF fixed carbon to volatile ratio.
- Produced slight increases in fuel ratio and significant increases in energy density with increased drying temperature.
- Product coal showed potential for improved combustion characteristics

The Usibelli coal was very amenable to physical and chemical cleaning techniques. This combined with excellent combustion characteristics, make the coal an outstanding candidate for heat engine CWF preparation.

RECOMMENDATIONS

- Assess CWF and cleanability of Alaskan LRCs located closer to tidewater.
- Determine combustion behavior of Alaskan low-rank CWFs.
- Prepare ton-quantities of Alaskan CWF in a demonstration plant located at an appropriate mine site.
- Perform a demonstration test with an Alaskan CWF at a modest generating station, like the 4 MW oil-fired Coast Guard Station on Kodiak Island.
- Prepare clean Alaskan CWFs for combustion testing in pressurized combustion systems and diesel engines.

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