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The ENCOAL Project
Initial Commercial Shipment and Utilization of Both Solid and Liquid Products

Topical Report

March 1995

Work Performed Under Contract No.: DE-FC21-90MC27339

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
ENCOAL Corporation
Gillette, Wyoming

DISCLAIMER

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by

Thomas G. McCord

Abstract

The ENCOAL Corporation has shipped, to two utility customers, over 500 rail cars (six partial trains and two full trains) of solid product (PDF) from its plant located at Triton Coal Company's Buckskin Mine near Gillette Wyoming. Shipments span a range of blends from 15% to essentially unblended PDF. Utility handling of these shipments is comparable to that of run-of-mine Buckskin coal. Results related to spontaneous combustion and generation of fugitive dust are particularly favorable. Combustion tests were performed both in a pulverized-fired boiler and in a cyclone-fired boiler. Commercial utilization of the liquid product (CDL) depends on customer facility capabilities and the source of any blending fuel, as expected. A total of 56 tank cars have been sent to three customers. The 1994 test program met or exceeded ENCOAL's major objectives of transporting and burning both PDF and CDL in existing customer facilities.

Introduction

ENCOAL and Triton Coal Company are wholly owned subsidiaries of SMC Mining Company, which is a subsidiary of Zeigler Coal Holding Company. ENCOAL and the U.S. Department of Energy are co-funding the Mild Coal Gasification Project under Round 3 of the Clean Coal Technology Program. ENCOAL uses the Liquids from Coal (LFC) mild gasification technology, initially developed by SGI International with continuing co-development by SGI International and ENCOAL. The Process generates two products, a solid upgraded coal product (designated as Process Derived Fuel, PDF) and a heavy liquid fuel (designated as Coal Derived Liquid, CDL).

In September 1994, ENCOAL commenced shipment of PDF to utility customers via the Burlington Northern railroad. Shipments made to the first customer, the Western Farmers Electric Cooperative, started at the 15% blend level and ranged up to 30%. The upper level of these blends satisfied the heat content target desired by this customer. Shipments to the second customer, Muscatine Power and Water, started at 40% and ranged up to a 100% product. The rail cars in this last 100% shipment are capped with a small amount of Buckskin coal. Capping is a temporary measure for these first shipments, as discussed below. Because the material becomes blended upon unloading, it will be designated as the 91% blend.

With these first shipments, ENCOAL's goals were to demonstrate its ability to coordinate with the Buckskin Mine in loading and shipping consistent blends, to ship PDF with dust generation comparable to, or less than, run-of-mine Buckskin coal and to ship PDF blends that are stable with respect to self heating, compared to run-of-mine Powder River Basin (PRB) coal. Furthermore, ENCOAL intended to demonstrate that PDF could be transported and delivered to customers using regular commercial equipment. With respect to utilization, the goal for these shipments was for customers to burn trial amounts (1/2 train minimum) of PDF blends with minimal adjustment of equipment. Successful attainment of the these goals by ENCOAL would allow utilities to plan performance test programs in 1995 with confidence in the viability of full scale use of PDF. As described below, these goals have all been met.

Coincident with PDF shipments was a broadening of the customer base for the liquid CDL product. ENCOAL Corporation ships CDL to Dakota Gasification. However, Dakota Gasification's facility is unique and there is a need to demonstrate broader market applications for CDL as an industrial low sulfur boiler fuel. Two customers have recently received shipments of CDL, one a blender and the other a large industrial facility. ENCOAL Corporation laboratory data have shown that results will be dependent, chemically, on the source of any blend fuel. As discussed below, initial results from these two customers confirm the data. Initial testing of CDL has shown that extraction of higher value products is both technically and economically feasible. Further work is planned in 1995.

PDF: Status of Product Development

Operation of the plant and the parameters required to produce and ship stable material with minimal dust are described in detail in a paper presented just before the first commercial shipment in September of 1994.[1] Descriptions of the Project at various stages have also been published[2,3] as well as laboratory results used to project product properties[3,4].

In 1994, ENCOAL's focus shifted from optimizing plant operation to maintaining continuous production for customer shipments. During this period, more extensive data have been generated with respect to sulfur distribution in the products. The data show a reduction of over 20% on a #SO_2/MMBtu basis. For example, for a run-of-mine feed coal sulfur content of 0.96 #SO_2/MMBtu, the corresponding PDF value will typically be 0.74 #SO_2/MMBtu.

With respect to spontaneous combustion, the ability to control self heating of PDF continues to progress with the expectation that material eventually will be shipped without special handling at the ENCOAL Plant.[1] For the tests reported here, two methods of stabilization were successfully demonstrated.

First, when PDF is used to enhance the heat content of run-of-mine Buckskin coal, simply blending with the run-of-mine Buckskin coal results in a product that is stable with respect to spontaneous combustion. This method has been demonstrated to be acceptable for blends containing up to at least 40% PDF in these tests. Second, at high levels of PDF, stability is attained by blending, in equal proportions, PDF that is transferred directly from the ENCOAL Plant product silo with PDF that has been exposed to the atmosphere in a pile and then reclaimed into the coal handling system. During stabilization, the temperature of the PDF may initially increase, but then decrease as stabilization progresses.

In this paper, PDF that has been exposed to ambient conditions in the pile will be designated "ambient-stabilized PDF". Material that is transferred directly from the ENCOAL Plant PDF product silo to storage silos will be designated "run-of-plant PDF". In this sense, the blends that have been shipped can be considered as "blend-stabilized PDF".

Excessive fugitive dust is controlled by the use of an SMC Mining Company patented additive, designated MK. The outlet of the PDF product silo contains equipment designed specifically to apply the additive for maximum effectiveness. However, in processing the ambient-stabilized PDF some additional dust is generated. More MK additive is applied to the ambient-stabilized PDF when it is reclaimed into the Buckskin coal handling system. This latter MK application system is not as sophisticated and effective as the system in the PDF product silo. Thus, there is a difference in dust depending on whether ambient-stabilized PDF is contained in the blend shipped. In either case, dust is comparable to that of run-of-mine Buckskin coal.

A comparison of PDF particle size distribution with that of run-of-mine PRB coal is shown in Figure 1. This plot shows the amount of sample that has passed through the next larger sieve used in the analysis and that is retained on the sieve with the indicated hole opening size. For example, 75% of the PDF in this sample passed through a sieve with 1/2 inch openings but was retained on a sieve with 3/16 inch openings. The plot shows that the particle size distribution of the PDF sample is narrower than that of the run-of-mine sample. That is, PDF contains fewer large particles and fewer small particles compared with run-of-mine PRB coal. Thus, while

PDF has a larger fines content, it also generates less fugitive dust. Figure 2 highlights the smaller particle size range. The size of the small sieve openings is included in this figure. The feed coal to the ENCOAL Plant is 2"x⅜". Size reduction occurs as a result of the coal moving through the several stages of the process.

To provide added assurance that loss of the smaller sized particles during transport would not be any different than that of Buckskin coal, the rail cars of 100% PDF were topped with a small amount of run-of-mine Buckskin coal. ENCOAL plans to add an MK system to its loadout facility to apply a "seal" to the top of rail cars, thereby eliminating the need for the run-of-mine Buckskin cap. The amount of MK applied to seal the top of the rail cars will be small and will not impact the product significantly.

The heat content of the PDF in these shipments was somewhat less than is anticipated in the future. The reason is that the ambient-stabilized PDF contained more water than run-of-plant PDF. In the case of the shipments described in this report several heavy rain storms drenched the PDF as it was being stabilized. This water was not equilibrated with the PDF. It was free water incurred in a thin pile exposed for a short time for stabilization. A conical pile was built using the PDF remaining in the stabilization pile, after completing shipments in December. The moisture content of the pile has steadily decreased as the water drains. When operation of the ENCOAL Plant is enhanced such that the ambient stabilization step is not required, water content will decrease. ENCOAL will be able to decrease the moisture content of the run-of-plant PDF as well. The moisture content of commercial PDF will then be slightly less than its equilibrium moisture value, which is in the range of 8% to 10%. Projected specifications for PDF subsequent to achieving in-plant stabilization are shown in Table 1.

First Set of PDF Shipments: Low Blend Levels to a Pulverized Unit

The first commercial quantities of PDF were loaded on September 17, 1994. Shipments originated on the Burlington Northern Railroad and were delivered to the Hugo Plant of the Western Farmers Electric Cooperative (WFEC), a 400 MW pulverized coal fired unit. This plant operates on Powder River Basin coal from the Buckskin Mine. Western Farmers was interested in determining the impact on operations of increasing the average heat content of their feed coal and thus needed blends containing relatively small amounts of PDF. The target value for the blend in the final shipment was 9,000 Btu/lb. This interest coincided with ENCOAL's approach of introducing PDF into the marketplace on an incremental basis.

Initial trains were loaded with half the cars in the train containing PDF blends and the other half of the cars in the train containing run-of-mine Buckskin coal. This scenario allowed for comparison of dust generation and handling of the blends with the run-of-mine coal during unloading, under identical weather conditions. If any unanticipated need were to develop, during the test, for special handling of the blends, such effort would be limited to about 5,000 tons. The first four trains were shipped with half the cars containing PDF blends and the other half containing run-of-mine Buckskin coal. Blend levels were successively increased with shipments at 15%, 20%, 25% and 30% PDF. The final shipment was a full train of a 25% PDF blend. The final blend quantities and blend quality data are shown in Table 2. Western Farmers had the option to discontinue shipments during this period, at their discretion. For these initial shipments, delivery was completed and the PDF blends burned without any need to modify plant operations. The goals listed above were met successfully. Results are presented in further detail below.

Second Set of PDF Shipments: High Blend Levels to a Cyclone Unit

After successful demonstration of handling and utilization of the lower PDF blend levels, a set of shipments was made to a second customer, Muscatine Power and Water. These shipments started in November, 1994, just two months after the first shipment of PDF from the ENCOAL Plant. Tests were run in an 80 MW cyclone fired unit in conjunction with testing run-of-mine Buckskin coal.

For this unit higher blend levels of PDF were of interest. As in the first set of shipments, partial trains were shipped to demonstrate acceptable handling and combustion characteristics. The first train consisted of a 40% PDF blend in about half the cars, the rest of the cars containing run-of-mine Buckskin coal. The second train was similar to the first except the blend contained 70% PDF. The third train in this set was a full train of unblended PDF, capped with run-of-mine Buckskin coal. This was the first train containing a 100% PDF product to leave the ENCOAL Plant. The final blend quantities and blend quality data are shown in Table 3. Muscatine had the option to discontinue shipments during this period, at their discretion. The utilization goal for these shipments was demonstration of applicability of PDF to cyclone units.

PDF Blending at the ENCOAL Plant

The blending procedures that were established are as follows. The run-of-plant PDF is stabilized by pre-blending 50/50 with either ambient-stabilized PDF or run-of-mine coal. Either of these blend stabilized products can be further blended with run-of-mine coal to achieve the heat content desired by the customer.

Results: PDF Handling Characteristics

<u>Coal Handling System - Hugo</u>
At this site, coal is unloaded in a rotary dumper and transferred to a silo for short term storage. Material in the silo is either transferred to long term storage or conveyed directly to the boiler bunkers. For the five shipments in this test program, the PDF blends in the silo were conveyed to the boiler bunkers and burned as needed.

<u>Coal Handling System - Muscatine</u>
In contrast to Hugo, Muscatine has a bottom dump unloading system. Cars are unloaded at ground level. Coal from the hopper under the unloader is conveyed to a radial stacker. For these shipments, the coal was then pushed out with rubber tired dozers for storage or to an underground feeder for transfer to the boiler bunkers.

<u>Self Heating Results - Hugo</u>
The PDF blends were handled through the plant system without difficulty. The top of one train was checked and found to be warm, estimated to be on the order of 100°F. As indicated above, some increase in temperature might be experienced as the PDF continues to stabilize. Several cars were delayed by several days en route to Hugo. These cars were at ambient temperature upon arrival, including one that was delayed for about 20 days.

<u>Self Heating Results - Muscatine</u>
Because this is a bottom dump system, the temperature of the blends could be checked readily. The material was warm to the touch (under 100 °F). The rail cars were at ambient temperature as was the pile under the radial stacker and the pile pushed aside for storage. Because the test unit was scheduled for shutdown at the end of the year, not all of the material in the final (91% blend) train was consumed. Thus, over 9,000 tons of the 91% blend were stored for use early in 1995. At the time this report was written, this material had been stored for eight weeks, uncompacted, without any evidence of self heating.

Bulk Density

At the lower blend levels shipped to Western Farmers, rail cars were easily loaded to normal coal weights. The Muscatine 91% PDF blend shipment provided an opportunity to compare with run-of-mine Buckskin coal. Buckskin shipments to Muscatine use the newer, and more precise, batch-loadout system at the mine. The effective capacity for this train set, using this system, is 108 tons/railcar. Because storage silos are used for the PDF blends and because of their location at the mine, it is more efficient to use the flood-loadout system for PDF. Using this system, about 10% of the railcars were loaded above 103 tons. When an MK system is installed such that the run-of-mine cap is not required, the amount of PDF loaded into a car will increase. The average tons/car value was somewhat lower because a flood-loading system inherently has a lower precision compared to a batch-loading system. Further tests are scheduled to determine an "effective shipping density" of PDF versus run-of-mine Buckskin coal in standard railroad equipment. This parameter is of interest because PDF flows well, as described below, and fills more of the volume of a railcar compared to run-of-mine coal.

Dust Generation - Documentation

At both Hugo and Muscatine, two trains were video taped during unloading to document dust generation. They were the first and second deliveries to Western Farmers and the first and last deliveries to Muscatine.

Dust Generation - Hugo

The rotary dump facility at Hugo operates such that dust is well contained. The trains containing the 15% and 30% blends were video taped during unloading to document dust generation. While the patterns of dust flow appeared different in comparing the blended half of the trains versus the run-of-mine half of the trains, the amount of dust generation appeared similar to this observer. The coal unloading operator and a shift foreman both commented that dust appeared to be less for the PDF blends compared with the run-of-mine coal. Locations in the building that tend to collect coal dust were relatively free from dust after unloading the blend portions of the trains. From a quantitative point of view, no change in motor amps was observed in the dust collectors in the rotary dump facility between the two different halves of the trains.

Dust Generation - Muscatine

As indicated above, the coal handling system at Muscatine is unlike that at Hugo and provided a tough test for dusting. As at Hugo, two of the trains (40% blend and 91% blend) were video taped to document results. The first shipment to Muscatine contained 40% PDF in about half the train. This PDF was run-of-plant material and was expected to show relatively little dust. Expectations were met as the PDF blend and run-of-mine portions of the train were comparable in dust generation. There was a strong wind blowing during the unloading of this train providing a good test for the effectiveness of the MK additive in controlling dust.

The second partial train (70% blend) was thought, by plant personnel, to be somewhat more dusty than the first train, but within the range of dust normally observed with run-of-mine Buckskin coal. This may have been because half the PDF blend contained ambient-stabilized PDF.

The third train, a full train containing about 91% PDF, showed very little dust, as documented on the video and as observed by the author and plant personnel.

Operationally, an increased rate of fines collection in the baghouse hoppers occurred as the amount of PDF in the blend increased. These hoppers are part of the dust control system and are located at transfer points in the coal handling system. This increase is likely to be the result of relatively high air velocities at the point of dust collection. No adjustments had been made to the dust control air velocities for this test. Experience at the ENCOAL Plant has shown that the velocity of the suction air at transfer points can be adjusted to collect fugitive dust but not to collect a significant amount of fines. While the increase in dust loading did not inhibit handling during the test burn at Muscatine, long term use would entail appropriate adjustment.

Coal Flow

No difficulties were noted for conveying or transferring the blends at the Hugo Plant or at Muscatine. Dozer operators at Muscatine noted that the PDF was harder to push, probably because of the higher percentage of smaller particles. They also noted that there was a tendency for the material not to stay in front of the blade. ENCOAL has also noted the tendency for PDF to flow readily. These observations indicate that the greater number of smaller size particles in PDF does not produce any difficulties in handling. In fact, it was noted at Muscatine, that there was less tendency for material to hang up during unloading of the bunkers with the PDF blends. The greater flowability of PDF was noted in that PDF cleared into the unloader bunker more quickly than run-of-mine Buckskin. No problems with conveying were noted with the greater flow characteristics.

PDF Handling - Conclusions

These two sets of shipments demonstrate that PDF, either blended or unblended, can be shipped to, stored at and handled at utility sites for test burn purposes. Long term use may require some equipment adjustment.

Results - PDF Combustion Characteristics

<u>Combustion Testing Goals</u>
As indicated above, the goal for these initial sets of shipments was to demonstrate the viability of PDF as a commercial fuel with the intent to execute performance testing starting in 1995. As is the case for coal unloading and handling equipment at the two test sites, the combustion equipment is completely different.

At Western Farmer's Hugo Plant, there is one unit, a 400 MW wall-fired pulverized coal steam generator. The unit is designed for PRB coal. Introduction of PDF into the unit at low levels should not impact operation significantly as the ash composition is the same as the base feed coal.

In contrast, at Muscatine there are three units, the one of interest being an 80 MW cyclone-fired steam generator. The cyclone unit was designed for Illinois high sulfur coal. In this unit, Muscatine encounters the same challenges as other cyclone furnace operators in meeting the Clean Air Act Amendment sulfur and nitrogen oxide requirements. Thus, the PDF tests were run in conjunction with run-of-mine Buckskin coal to determine the viability of PRB products as a potential solution for Phase II needs. Because the precipitator for this unit was designed for high sulfur coal, its performance with the lower sulfur Western coals needs to be addressed.

For the Western Farmers shipments, the combustion goals were to demonstrate no adverse effects of low level blends in pulverized units and to look qualitatively at performance related parameters. For the Muscatine shipments, the combustion goals were to demonstrate the ability to burn unblended PDF in a cyclone unit and to determine the effect on operation of a cold side precipitator with relatively small plate area. Some initial data on NO_x generation, especially in a cyclone unit were also of interest.

<u>Combustion Results - Hugo Plant</u>
The PDF blends burned without incident at the Hugo Plant. Because a half train is used in a fairly short time in a 400 MW unit, that is, in less than 24 hours, there was not an attempt at quantitative evaluation. During operation with the full train of 25% PDF, the plant was experiencing

interruptions unrelated to the fuel. Thus, load was varying and no attempt was made at quantitative evaluation.

As would be expected from the higher heat content of the blends, feeder speeds decreased when the blends were introduced. A greater number of pyrite fires than is normal were occurring prior to, during and following the period when the PDF blends were being used. It was not possible to determine whether there was an effect of PDF on the frequency of these events.

Pressure drop across the pulverizers increased between 0 and 10% when the PDF blends were introduced. This increase was not proportional to the amount PDF in the blend and did not limit capacity of any of the pulverizers.

Pulverized fuel samples were taken from the pulverizers. Analysis of these samples showed a decrease in the amount of material passing 200 mesh at a given coal feed rate (lb/hour). However, feed rate through the pulverizers decreased, at a given boiler load, because of the greater heat content of the PDF blends. Because of this compensating effect, the particle size distribution of the pulverized material remained within WFEC's pulverizer operating criteria. These results are consistent with the higher heat content and slightly lower Hardgrove Grindability Index (HGI) of PDF compared to run-of-mine PRB coal.

During operation on the full 25% blend train, conversion from run-of-mine Buckskin to the blend occurred at full load. Results from the plant's performance monitoring system calculated a possible 10°F to 20°F decrease in furnace exit gas temperature (FEGT) following the transition, indicating some increase in furnace heat absorption. An increase in furnace absorption is desirable in this unit. While the results are tenuous, they provide additional incentive for longer term performance testing. For performance tests, furnace exit gas temperatures should be measured using recently developed optical technology.

Testing was too short to draw conclusions on ash deposition. Precipitator samples were not taken, for the same reason.

Based on the experience at Hugo, potential customers can plan performance tests with greater confidence that PDF is a viable fuel which can be used with little or no equipment modification.

Combustion Results - Muscatine

As indicated above, testing of PDF blends was carried out in conjunction with a test of run-of-mine Buckskin coal, the first time PRB coal had been burned in this unit. The unit reached rated capacity on run-of-mine Buckskin coal. Unit load was limited by precipitator performance for the PDF blends. The reason for limitation by the precipitator for the PDF blends was most likely because of the effect of the lower sulfur content of the PDF blends on flyash resistivity, compared to the sulfur content of the run-of-mine test material. The measured stack SO_2 during the successful Buckskin test was in the range of 1.6 #SO_2/MMBtu, while it was less than 0.8 #SO_2/MMBtu for the PDF blends. Thus, it is possible that the unit would have reached rated capacity if the sulfur content of the PDF had been closer to 1.6 #SO_2/MMBtu. ENCOAL and Muscatine are planning another test with a shipment of 100% PDF where the sulfur content will be 1.5 #SO_2/MMBtu or higher.

Slag behavior was similar to the Buckskin run-of-mine test. That is, for the PDF blends, slag flow in the cyclone, on the furnace floor and through the taps was similar to slag flow in the run-of-mine test. There was an increase in carbon content in the bottom ash as the PDF content of the fuel burned increased. This observation implies that the amount of fuel particles not being captured in the slag layer in the cyclone is somewhat larger for PDF compared with run-of-mine PRB coal. Further work will be carried out in order to minimize or eliminate this increase. Operation of the unit near rated capacity for an extended period of time on PDF was not possible because of the precipitator limitation noted above. Thus, the opportunity to evaluate ash deposition while burning PDF was not available.

About 2,400 tons of the 91% full train was used before the test was ended for a planned year end shutdown. This shutdown was for dispatch purposes unrelated to the PDF test burn. Because of the relatively narrow load range imposed on the unit by precipitator constraints with the lower sulfur in this shipment and because the prime use of this unit is in cycling duty, Muscatine opted to restart Unit #8 on its base fuel after the shutdown. As indicated above, another test is planned using PDF with sulfur content high enough to allow the unit to operate without the load being limited by the precipitator. Included in future tests of PDF should be a low load test. It may be, with the higher flame temperatures, that lower loads can be maintained for PDF compared to run-of-mine PRB coal. Capability to reduce the low load limit would be an advantage for units in cycling service.

One other feature of PDF needs to be addressed in future tests. That is, NO_x generation. The possibility of NO_x reduction was predicted in laboratory combustion testing[3]. In the tests referenced, it was suggested that the stable flame associated with combustion of PDF might counter higher NO_x generation generally expected with higher flame temperatures.

In the Muscatine test, hourly averages of NO_x emissions for the 40% and 70% blends are in the range of values observed for the run-of-mine Buckskin coal. However, for the 91% blend, NO_x emissions were on the low end of the range, indicating that there may be some reduction relative to run-of-mine PRB coal. Thus, burning PDF should be similar to or better than run-of-mine coal from a NO_x point of view.

These tests indicate that PDF is a viable fuel for cyclone units. While not demonstrated in this test, the ability of the Buckskin mine to supply a slightly increased sulfur feed coal to the ENCOAL Plant, gives PDF a potentially unique position for supplying wet bottom units. That is, PDF has a heat content similar to fuels used in cyclone units, its lignitic ash has been demonstrated to be acceptable for operation in such units and its sulfur content can be tailored to provide acceptable cold side precipitator performance. Performance testing in 1995 should verify this observation.

CDL Tests - Background

The requirements for shipping and utilization of the liquid CDL product are completely different from those of PDF. As long as the PDF product is stable with respect to moisture and self heating, blending is unlikely to result in any reaction with the co-blended material during storage, handling and transportation. Customer utilization of PDF increasingly will focus on combustion. CDL, on the other hand, will interact with material with which it is blended. Keeping it separate from other liquid fuels is not a viable option, in most applications.

Optimum utilization of CDL will evolve over time. Up to the present time, most of the CDL has been sold to Dakota Gasification for blending into one of their liquid streams. Their facilities are designed to handle coal liquids and thus can utilize CDL without modification of operations. The next step is to broaden the market for CDL by shipping to industrial customers looking for low sulfur blend stock. Longer term, CDL will be processed to extract the higher value products and possibly to upgrade the remaining material. Future commercial ventures using the LFC technology will incorporate CDL upgrading in their suite of products.

The current value of CDL to heavy fuel oil customers is its low sulfur and low viscosity. Otherwise, the residual fuel market is well supplied from US refineries. Blending of petroleum heavy fuels is well established, mainly through experience. Adding a coal based heavy fuel to petroleum based residual fuels adds a new dimension to the picture.

Shipping Unblended CDL

CDL has a higher pour point than typical residual fuel oil. On the other hand, at temperatures normally used for handling residual fuel oil (above 100°F), CDL has a lower viscosity than residual fuel oil and flows well. Thus, tank cars, tank trucks, transfer lines and storage tanks handling CDL need to be capable of attaining or maintaining temperature above 100°F, minimum. Of the shipments made to date, difficulties have been encountered twice, once at a facility that did not have heat traced lines and once in tank cars that had been modified such that only the outlet valve was heated. Off loading and handling has been without incident otherwise.

Unprocessed CDL has a distinctive odor, which has been noted at a few unloading sites. There are three ways to handle this. First, as environmental concerns continue to be addressed, equipment will be modified to prevent vapor escape in general. Second, filters have been used at one site successfully. Third, conditioning CDL at the ENCOAL Plant, such as washing, is being considered.

Blending of CDL

In the petrochemical business, compatibility of various refinery and chemical plant heavy liquid streams has been a factor in blending such streams for further utilization. In particular, streams derived from thermally induced reactions tend to be incompatible with streams derived from reactions catalyzed at lower temperatures. Refiners have developed tools to predict when streams will be compatible. In addition, methods, such as the use of additives, have been developed to increase the range of compatibility. ENCOAL is using these techniques where appropriate.

Laboratory tests performed on CDL from pilot plant samples had indicated CDL would be compatible with some refinery streams, but not others. The factor dictating compatibility is aromatic content. Because of aromatic content, streams derived from cat-cracking operations are more likely to be compatible with CDL compared to streams from straight run distillation.

Also, with respect to blending, if there is an acceptable, but not 100% miscibility, blend range, it may well be that compatibility will occur for higher CDL contents. The generic explanation is that peptizing agents keep asphaltenes suspended in aromatic material. As aromatic material is blended with material with lower aromatic content, the peptizing agents are diluted into the co-blended material. At some dilution, sufficient peptizing agents have been dissolved that the asphaltenes precipitate and a solid phase of asphaltenes is formed, especially at temperatures below 100°F. The resulting material is no longer suitable as a fuel because lines will plug with the solid phase. If the unstable material is successfully injected into a furnace, combustion will also deteriorate. The laboratory data fit the above description for some materials.

Field Experience

Two recent shipments to industrial customers are also in agreement. One customer has receiving, storage and combustion equipment capable of handling heavy liquids. CDL was blended with an aromatic bottoms product at this site. The customer had performed an analysis of these blends before taking shipment of CDL. Tests predicted that the blends would be compatible. Actual results confirmed the predictions and combustion of CDL blends up to 35% proceeded successfully. Because the customer wanted to use CDL to cut the other material, higher CDL blends were not used.

A second customer was a blender, intending to use CDL for sulfur reduction. The co-blending material, in this case, was a straight run residual fuel oil with lower aromatic content. In addition, small amounts of CDL were used in these blends. Both of the blender's customers, to which these low CDL blends were shipped, experienced a range of handling and combustion problems due to incompatibility. The blender also experienced combustion difficulties with this blend in his own fired-heater.

Conclusions on CDL Experience

As indicated above, utilization of CDL will continue to evolve. At the present time, blends of CDL can be used when customer handling equipment can be heated and the customer uses a compatible blending stock. ENCOAL will continue to develop a matrix of suitable blends from field experience tied to laboratory testing. ENCOAL is also investigating additives for improving compatibility. Furthermore, an appropriate field site for testing and burning unblended CDL is also being evaluated.

Conclusions: Commercialization of Products from the ENCOAL Plant

Commercialization of both the solid (PDF) and liquid (CDL) products from the ENCOAL Plant took a major step forward in 1994. PDF was shipped in trainload quantities for the first time to utility customers. The results of these shipments demonstrated that utility and industrial users can plan for test burns of PDF with confidence. Potential for extending the use of CDL into the industrial low sulfur residual fuel oil market was also demonstrated.

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TABLE 1. Projected Run-of-Plant PDF Quality	
PROXIMATE ANALYSIS	
Heat Content (Btu/lb)	11,400 - 11,600
Moisture (%)	7 - 8
Ash (%)	6 - 9
Volatile Matter*	
ASTM (%)	21 - 24
TGA (%)	19 - 22
Fixed Carbon (%)	57 - 60
Sulfur (%)	0.51 Maximum
ULTIMATE ANALYSIS	
Moisture (%)	7 - 8
Carbon (%)	68 - 70
Hydrogen (%)	3.1 - 3.4
Nitrogen (%)	1.0 - 1.3
Sulfur (%)	0.51 Maximum
Ash (%)	6 - 9
Oxygen, by difference (%)	10 - 12
OTHER	
Hardgrove Grindability Index	45 - 50
#Sulfur/MMBtu	0.45 Maximum
#SO_2/MMBtu	0.90 Maximum
Ash Mineral Analysis	Same as source coal
Ash Fusion Temperatures	Same as source coal

* See Reference 3 for discussion on measurement of volatile matter.

TABLE 2. WESTERN FARMERS ELECTRIC COOPERATIVE SUMMARY OF AMOUNTS SHIPPED AND HEAT CONTENT							
Date	Blend	Tons Shipped			Heat Content (Btu/Lb)		
Loaded	(% PDF)	PDF	PRB	Blend	PDF	PRB	Blend
09/17/94	14.4	922	5,448	6,370	10,911	8,400	8,760
09/24/94	21.2	1,080	4,020	5,100	N/A	N/A	8,910
10/01/94	25.1	1,508	4,493	6,001	N/A	N/A	8,940
10/10/94	31.9	1,603	3,421	5,024	N/A	N/A	9,310
10/24/94	24.0	2,665	8,426	11,091	N/A	N/A	9,060

N/A = not available

TABLE 3. MUSCATINE POWER AND WATER SUMMARY OF AMOUNTS SHIPPED AND HEAT CONTENT							
Date	Blend	Tons Shipped			Heat Content (Btu/Lb)		
Loaded	(% PDF)	PDF	PRB	Blend	PDF	PRB	Blend
11/23/94	39.0	1,957	3,122	5,079	11,200	8,650	9,630
11/29/94	66.6	3,423	1,713	5,136	10,200	8,440	9,670
12/13/94	90.7	10,576	1,082	11,658	10,130	8,660	10,000

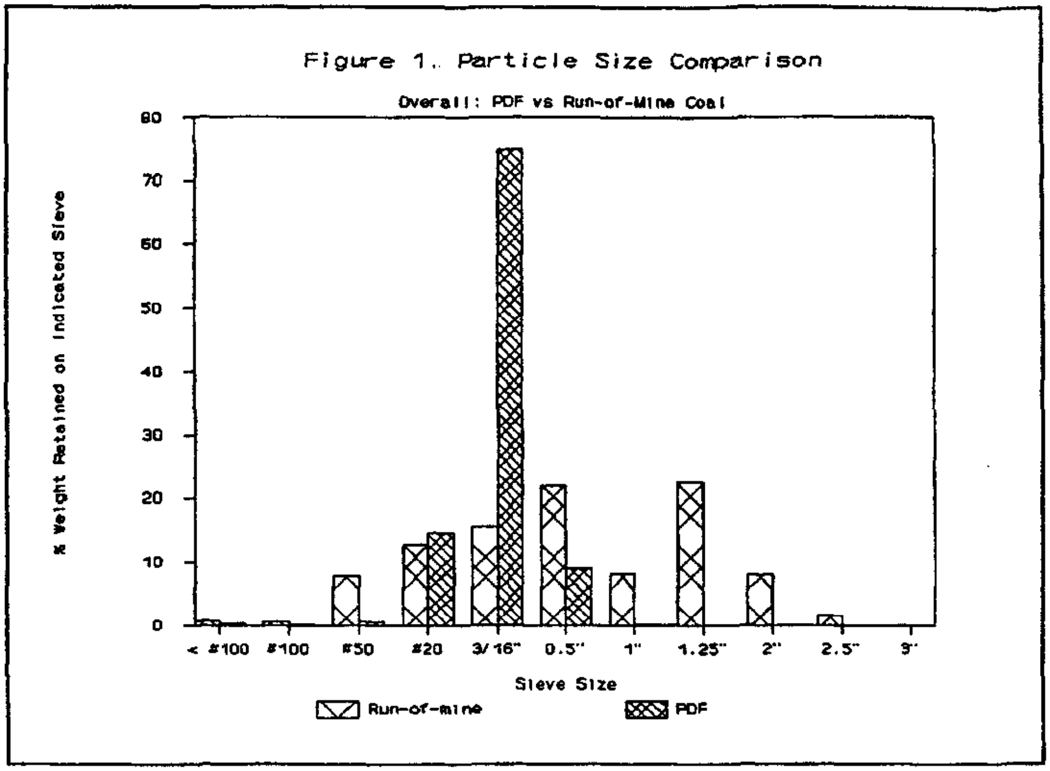
Figure 1. Particle Size Comparison
Overall: PDF vs Run-of-Mine Coal
% Weight Retained on Indicated Sieve
80
70
60
50
40
30
20
10
0
< #100
#100
#50
#20
3/16"
0.5"
1"
1.25"
2"
2.5"
3"
Sieve Size
Run-of-mine
PDF

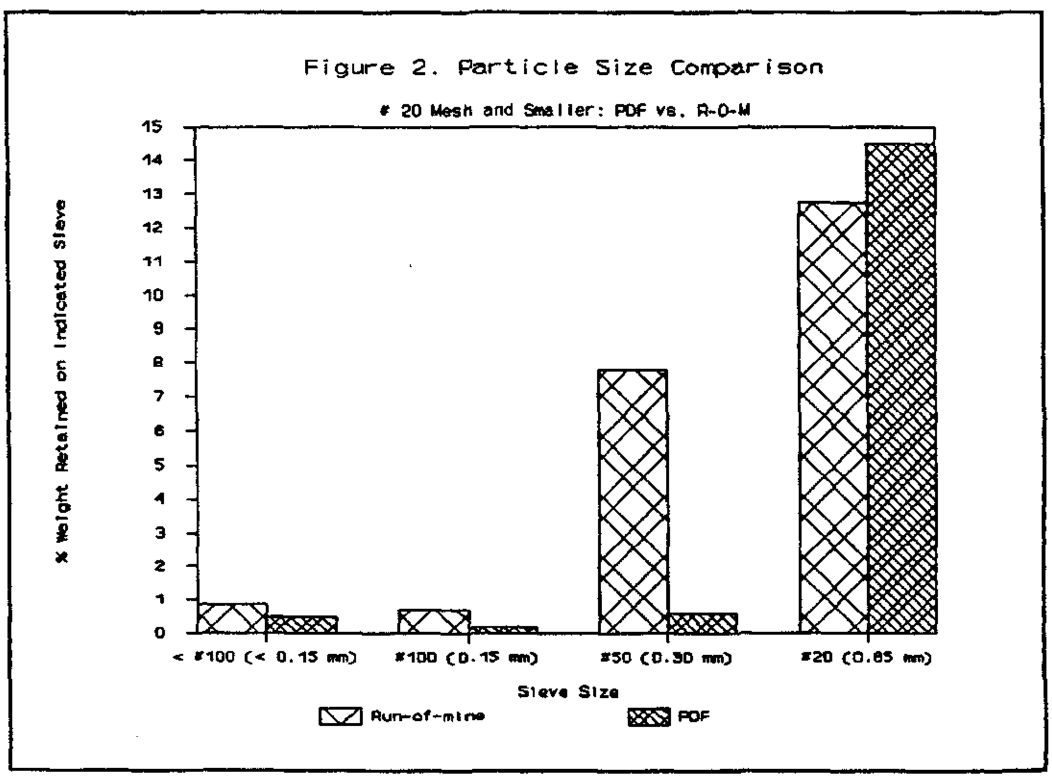
Figure 2. Particle Size Comparison
20 Mesh and Smaller: PDF vs. R-O-M
% Weight Retained on Indicated Sieve
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
< #100 (< 0.15 mm)
#100 (0.15 mm)
#50 (0.30 mm)
#20 (0.85 mm)
Sieve Size
Run-of-mine
PDF