DOE/PC/90167--T9

"MULLED COAL - A BENEFICIATED COAL FORM
FOR USE AS A FUEL OR FUEL INTERMEDIATE"

DOE/PC/90167--T9

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I. EXECUTIVE SUMMARY

Energy International Corporation has been awarded a contract by DOE-PETC (DE-AC22-90PC90167) to evaluate a new concept for utilization of the fine coal wet cake produced by many of the physical beneficiation processes now under development. The project started with the selection of coal feedstocks on May 15, 1990. This report covers activities from April 1, 1991 through June 30, 1991.

II. INTRODUCTION

Under the auspices of the Department of Energy and private industry, considerable progress has been made in:

- o preparation of coal-water fuels
- o combustion of low-ash coal-based fuel forms
- o processes to provide deeply-cleaned coal

These technology advances are compatible with the national objective to increase the environmentally responsive use of readily available and abundant coal resources, and to reduce oil and gas fuel consumption.

As these technical developments move toward commercial application, the needs for coordinated efforts and integrated requirements has become increasingly apparent. Systems are vitally needed to integrate energy delivery systems from the raw resource through processing to application and end use. Problems have been encountered in the preparation of conventional coal-water fuels that mutually satisfy the requirements for storage stability, handling, preparation, atomization, combustion, and economics. Experience has been slow in evolving generic technologies or products and coal-specific requirements and specifications continue to dominate the development. Thus, prospects for commercialization remain highly specific to the coal, the processor, and the end use.

Developments in advanced beneficiation of coal to meet stringent requirements for low ash and low sulfur can be anticipated to further complicate the problem areas. This is attributable to the beneficiated coal being procured in very fine particles with high surface areas, modified surface characteristics, reduced particle size distribution range, and high inherent moisture. Experience in the storage, handling, and transport of highly beneficiated coal has been limited. This is understandable, as quantities of such product are only now becoming available in meaningful quantities.

Since the inception of the project we have:

- Developed formulations for stabilizing wet filter cake into a granular free flowing material (Mulled Coal).
- Applied the formulation to wet cake from a variety of coal sources ranging from anthracite to subbituminous coal.

- Evaluated effects of moisture loss on mull properties.
- Developed design concepts for equipment for preparing the Mulled Coal and converting it into Coal Water Fuel.

This report covers activities from April 1, 1991 to June 30, 1991. During this period we have:

- Evaluated and identified a number of materials that can serve as mulling agents.
- Enhanced our understanding of the mulling process and required concentration of the various mulling agents.
- Selected and procured equipment needed for systems for continuous processing.
- Procured the feedstocks needed for Phase II of the program.

During the next quarter we will:

- Obtain storage and handling system design data for the granular coal.
- Begin the 100 day aging study on various mull formulations to determine the effects of time and exposure on mull properties.
- Demonstrate the continuous production of mulled coal from wet filter cake.

Much of the existing work and experience with advanced coal-based fuels such as CWF has been built on the premise that the fuel should and will be capable of being compatible with use in the existing storage, handling, and transport equipment as a "one-to-one" replacement for conventional oil fuels. Expensive additives, additional processing, equipment, and system modifications will be needed to provide effective and versatile fuel delivery systems. This will be even more significant for fine particle high beneficiated coal fuels.

The conventional approach for formulation of CWF would be to develop a single formulation that meets the requirements of the total fuel system. At best, the resultant material will have properties that represent a compromise.

Energy International is developing a technology that will create a staged formulation with the first coal form (Mulled Coal) that can be stored, transported, and pumped. Just prior to combustion, the Mulled Coal (MC) will be modified to provide the properties needed for proper atomization. This concept is an alternative to the expensive and energy intensive thermal drying processing of fine coal wet cakes. The material is suitable for both

direct feed use in conventional and fluid bed combustors as well as on-site conversion to combustible slurries. By maintaining the coal form relatively close to the feed wet cake, only minor processing with low additive levels and low energy blending is needed at the point of production. Its conversion to slurry or other use-feed form is made near the time of use and thus the requirements for stability, climatic control, storage, transport, and handling requirements are much less severe.

III. PROJECT DESCRIPTION

The Mulled Coal project is divided into a series of tasks designed to produce formulations and system designs suitable to convert fine coal "wet cakes" into a material that can be stored, handled, and transported to a site where it can be utilized as a fuel in existing and developing combustion devices.

The work is divided into two phases:

Phase I will provide the technology base and establish the technical feasibility of the concept of stabilizing the fine coal "wet cake" in a form that can be readily stored and moved to the location where it can either be combusted "as is" or converted into a desired fuel form at the combustion site. The information developed during Phase I should provide a basis for design and implementation of a demonstration program (Phase II).

Phase II will demonstrate the ability to utilize the Mulled Coal to improve the ability to store and move fine coal products as a stable "wet cake". Tasks in this phase will first test components of the various systems required for storage, handling and combustion of the fine coals and subsequently demonstrate operations of an integrated system for storing, handling, and combustion of the highly beneficiated fine coal products.

Phase I - Once the feed coals are selected, basic technical information for formulations of Mulled Coal will be developed through bench studies. Some base assumptions for the process concept are:

1. Chemical formulations will have to consider end use as well as the chemistry involved with the beneficiation processes.
2. If any changes in particle sizes are required for the combustor, they should be made before formulation of the Mulled Coal.
3. Conversion from Mulled Coal to the final fuel form should require minimal equipment and relatively moderate conditions such as dilution, addition of small quantities of reagents, mild agitation, little heating. Grinding, high temperatures, corrosive or hazardous materials, etc. should be minimized.

Phase II - Phase II will comprise the design, acquisition, and testing of the system components required to simulate the storage, transportation and combustion of the "mulled coal" formulation(s). The "mulled coal" will be prepared in sufficient quantities to perform a full system test of the preferred formulations.

IV. PROJECT STATUS

1.0 Phase I - Technology Development

1.1 Feedstock Procurement

Several tons of precleaned coal were purchased by Energy International from Westmoreland Coal Company's Wentz Preparation Plant and were delivered to CQ Inc. at Homer City. Most of this coal was fed into the CQDC plant heavy-media cyclone circuit and cleaned to an ash content of 1.5-2.0%. Two tons were collected for the Mulled Coal project and shipped to EI in drums. Approximately 22 tons of the precleaned coal were set aside to be used for the continuous coal mulling production unit. CQ will produce four tons of wet cake product to be converted into mulled coal using the mulling equipment provided by EI. The wet cake product is to have a mean particle diameter of 20-25 microns, an ash content <2%, and a filter cake of approximately 60 wt % solids.

1.2 Feasibility Study

Task #2 feasibility studies have been completed.

1.3 Lab Scale Tests

Sample Preparation

In an effort to expand our knowledge of the reagents which could be used to produce the granular mull, a series of tests were carried out on a variety of products. Both the surface tension (against air) and the interfacial tension (against water) were measured to identify any correlation of the surface tension of the additive with its ability to form a mull. Then the additive was tested to determine the lowest amount necessary to form the granular mull starting at 1% concentration increasing in 1% increments until a satisfactory mull was produced. Until more quantitative tests are developed, the term "satisfactory mull" is a completely subjective judgment based on our previous formulation experience. The final test was to determine if the resulting mull could be easily converted to a sprayable slurry by addition of 1% surfactant. A list of the reagents screened and the results of the tests are given in Table I. It can be seen that a wide variety of products can be used to prepare the granular form of the mull and that some can be used at concentrations as low as 1% and produce satisfactory mulls. Also, it was found that not all mulls were capable of being turned into slurries with the selected reagent package. More investigation is needed to understand the nature of the mull formation.

Transport Studies

A small experiment was carried out to determine if the granular mulled coal could be transported from one place to another by pneumatic means. A picture of the apparatus assembled is shown in Figure 1. The screw conveyor, contained in the box, fed the plastic tube. Air from the hair dryer (no heat) pushed the granular product along the tube and out the nozzle

TABLE I
Granular Mull Reagent Screening

Reagent	Surface Tension (dynes/cm.)	Interfacial Tension (dynes/cm.)	Mull Formation	Reagent Conc. Wt. %	Slurry Formation
NPA-1	33.0	42.0	yes	3	yes
NPA-2	35.4	27.0	yes	3	yes
NPA-3	25.4	44.9	yes	2	yes
NPA-4	25.9	34.1	yes	1	yes
NPA-5	33.8	42.3	yes	3	no
NPA-6	36.9	8.2	no	>3	no
NPA-7	29.0	15.0	yes	1	yes
NPA-8	26.2	46.1	yes	1	yes
NPA-9	25.4	12.5	no	>3	no
NPA-10	32.1	10.0	no	>3	no
NPA-11	29.8	27.9	no	>3	no
NPA-12	34.5	6.3	yes	1	yes
NPA-13	32.5	40.7	yes	3	yes
NPA-14	33.0	21.4	yes*	3	yes
NPA-15	33.8	9.1	yes*	3	yes

* poor mulls, not free flowing

Figure 1
Screw and Pneumatic Conveying Apparatus
for Mulled Coal

into the collecting tray. The nozzle was a vacuum cleaner crevice tool. The screw feeder conveyed the product easily and the air conveyed it through the nozzle without difficulty. Neither the product feed rate nor the air flow rate were measured. The experiment was carried out to demonstrate the feasibility of pneumatic and screw conveyance of the granular mulled coal. The mulled coal used was prepared from a 35% moisture filter cake using an Upper Elkhorn #3 coal containing 1.3% ash (UE3-304-DCC-H) and having a 13.4 micron mean volume diameter using 3% NPA-1 as the mulling agent.

Storage Studies

Some bench-scale experiments were begun to determine the effects of storage and room temperature aging of the granular mulls prepared from micronized coal (UE3-210-WRM-A Mv=13 um) and three levels (1, 3, and 5%) of the mulling additive NPA-1.

Mulls were prepared using a 35% moisture filter cake and 1, 3, and 5% additive. Sufficient wet filter cake and each of the mulls were placed in 100 ml graduated cylinders to fill them to the 100 ml mark. The cylinders were weighed before and after filling to obtain the net weight of the wet cake and mulls. The filled cylinders were allowed to stand at ambient temperature and in an oven at 140 degrees F and weighed periodically over a 32 to 38 day period. An additional experiment was run using a 40% moisture wet filter cake at 140 degrees F. The results of the experiments are given in Tables II, III, and IV. It can be seen that the additive retarded the escape of moisture. There was little or no change in the volume for any of the samples even though the weight loss (especially for the wet cake and the mull containing 1% additive) was significant. The results are also shown graphically in Figures 2, 3, and 4. There is a significant difference or "break" between the 1% and 3% reagent addition for the 35% moisture containing mull both at ambient and elevated temperatures. There was little, if any, additional water retention by going to a 5% mulling additive concentration indicating saturation was reached around 3% additive. This may be a method for determining the minimum amount of additive necessary for good mull formation. It can be seen in Figure 4 that at a 40% moisture content the optimum additive concentration may not have been reached since there was significant moisture retention with each increase in additive concentration.

Handling Studies

In order to demonstrate that the slurry prepared from the mulled coal could be sprayed a small spray apparatus was assembled. A schematic of the apparatus is shown in Figure 5. Two experiments were conducted. In the first, a 40% moisture granular mulled coal was mixed with 1% (based on dry weight of coal) surfactant. After the mixture was converted to the liquid slurry (using the KA muller) it was poured into the spray feed tank and the pump started. Qualitatively the slurry which was at a 58.7% coal content sprayed very well. In the second experiment a 35% wet filter cake was similarly treated. This resulted in a 63.9% coal solids slurry. Initially a very fine spray was produced, but eventually the pump and the slurry recycle almost stopped. The slurry appeared too viscous and dilatant for our spray apparatus. Run data for the two experiments are given in Table V.

TABLE II

Effect of Ambient Temperature Aging on Nulls

Elapsed Time, days	Filter Cake		1% NPA-1		3% NPA-1		5% NPA-1	
	% Weight Loss	Bulk Density gms/ml	% Weight Loss	Bulk Density gms/ml	% Weight Loss	Bulk Density gms/ml	% Weight Loss	Bulk Density gms/ml
0	0	0.5517	0	0.5966	0	0.6245	0	0.6374
3	2.88	0.5358	3.06	0.5783	2.35	0.6098	2.58	0.6209
10	9.69	0.4982	9.53	0.5397	5.14	0.5924	5.72	0.6009
17	17.14	0.4571	15.06	0.5067	7.28	0.5790	7.93	0.5868
26	23.70	0.4210	18.30	0.4874	9.00	0.5681	9.90	0.5744
38	29.00	0.3917	21.80	0.4665	11.38	0.5534	12.66	0.5567

TABLE III

Effect of Aging on Mulls at 140 deg. F
(35% Moisture Content)

Elapsed Time, days	Filter Cake		1% NPA-1		3% NPA-1		5% NPA-1	
	% Weight Loss	Bulk Density gms/ml	% Weight Loss	Bulk Density gms/ml	% Weight Loss	Bulk Density gms/ml	% Weight Loss	Bulk Density gms/ml
0	0	0.5394	0	0.5037	0	0.5449	0	0.5080
1	3.59	0.5200	3.93	0.4839	2.35	0.6297	3.68	0.5856
6	11.01	0.4800	11.81	0.4442	6.77	0.6012	6.89	0.5666
12	18.94	0.4372	18.20	0.4120	10.69	0.5759	9.73	0.5488
19	27.15	0.3929	23.98	0.3829	13.53	0.5576	12.82	0.5296
32	34.4	0.1857	29.60	0.1494	19.10	0.1236	16.60	0.1012

TABLE IV

Effect of Aging on Mulls at 140 deg. F
(40% Moisture Content)

Elapsed Time, days	Filter Cake		1% NPA-1		3% NPA-1		5% NPA-1	
	% Weight Loss	Bulk Density gms/ml	% Weight Loss	Bulk Density gms/ml	% Weight Loss	Bulk Density gms/ml	% Weight Loss	Bulk Density gms/ml
0	0	1.0722	0	0.5255	0	0.6049	0	0.6130
1	5.03	1.0182	1.98	0.5147	1.58	0.5953	1.44	0.6015
6	18.42	0.8747	8.70	0.4794	8.05	0.5562	5.68	0.5756
12	27.42	0.7782	14.83	0.4454	13.85	0.5211	9.17	0.5543
19	31.74	0.7318	24.50	0.3964	19.07	0.4895	11.76	0.5385
32	38.62	0.3888	31.99	0.1680	26.20	0.1585	16.33	0.0997

TABLE V

Run Conditions for Spray Tests

<u>Run No.</u>	<u>Slurry Spray Rate</u> <u>Gallons/ Hour</u>	<u>Slurry Pump</u> <u>psi</u>	<u>Air Rate</u> <u>SCFH</u>	<u>lbs Air/</u> <u>lb Slurry</u>
1	6.72	40	35.0	0.04*
2	2.54	43	31.6	0.11*

* literature recommends values between 0.1 to 0.3

Figure 3

Effect of NPA -1 Concentration on the
Weight Loss of Milled Coal
Containing 35% Moisture at 140 Deg. F

Aging Time at 140 deg. F, days

Figure 4

Figure 5
Slurry Spray Nozzle Test Apparatus

Figure 6
CONTINUOUS PROCESSING SYSTEM FOR
MAKING MULLED COAL AND/OR COAL-WATER-SLURRY

2.0 PHASE II - SYSTEM DEMONSTRATION

2.1 Component Development

Component Design

Two mixing equipment manufacturers have been contacted in regard to making the granular "mulled coal" product and converting it to a coal water slurry. Several gallons of dry, micronized coal (13 microns MV) were taken to Paul O. Abbe Company in Little Falls, New Jersey and to Teledyne Readco in York, PA for testing.

Only one piece of mixing equipment, a one cu. ft. batch ribbon mixer, was available for testing at Paul O. Abbe Company. This mixer was only partially successful in making the coal mull and converting it back to liquid slurry. The wet cake tended to build up on the mixer blades and on the back of the mixer near the top which was above the blades. The following modifications were recommended:

- Teflon wipers should be added to the blade edges and on the ends.
- Muller paddles should be installed.
- A variable speed motor should be installed.
- The mixing chamber should be cylindrical to eliminate the dead space at the top. The cylinder should be hinged so the top half can be removed.
- Top ports should be added for injecting the desired reagents.

Paul O. Abbe Company has sent us price quotations on a mixer with the above modifications, but the expected delivery date was 12 to 14 weeks after the order was placed. This would exceed our scheduled dates for making mulled coal for aging tests and materials flow and handling studies.

Two pieces of mixing equipment were tested during our trip to Teledyne Readco. A 6-quart Sigma Blade Mixer was tested to make batches of mulled coal from the wet cake coal. This mixer made a satisfactory mull, so it was decided to lease one for making the necessary mulled coal samples for the aging studies and flow handling tests. This mixer was received the last week of June and the sample preparation runs have been scheduled. A 2-inch continuous processor made satisfactory mulled coal, and also converted the mulled coal to a satisfactory coal-water-slurry. A 2-inch continuous processor has been leased and will arrive in early July. This processor will be tested and incorporated in the skid-mounted test system to be sent to Grand Forks, North Dakota for the continuous production of coal-water-slurry for the atomization testing.

An Accurate volumetric screw feeder was tested at Teledyne Readco and could feed both the coal wet cake and mulled coal product satisfactorily. A Model No. 602 with an open screw feeder (feed capacity range of 1 to 20 cu. ft./hr.) was leased to be used both at EI for the test equipment studies and at CQ Inc. for making the mulled coal production run.

Mulled Coal Preparation

Two tons of deep-cleaned Upper Elkhorn No. 3 coal were received from CQ Inc. to be used for making mulled coal samples for the solids flow testing of various mull formulations. Sufficient quantities of ground coal having average particle sizes of 10, 20 and 60 microns are currently being ground in the large ball mill for the above studies. The as-received coal (1/4 x 28 mesh) is being ground in our 20 in. x 30 in. batch ball mill as a 50% coal-water-slurry to a designated particle size, and then filtered and dried to below 5% moisture content. The proper amounts of dried coal, water, and NPA (as indicated on the test matrices) will be added to the batch Sigma mixer to produce the mulled coal samples for the aging and flow study programs.

Component Fabrication

A 6-quart Sigma blade mixer has been leased from Teledyne Readco to produce samples of mulled coal for the aging and flow handling studies. Samples will be submitted to Hank Colijn and Associates for the storage and handling studies.

A 2-inch continuous processor has also been leased from Teledyne Readco to be tested and used in the "in-line" system to be assembled and shipped to UNDEERC at Grand Forks, North Dakota for the coal-water-fuel atomization testing. An Accurate volumetric screw feeder has been leased and will be used for feeding both the wet coal cake and mulled coal at EI. This feeder will also be used at CQ Inc. to make the four tons of mulled coal. The continuous processor will be assembled according to Figure 6 and operated by the end of July.

V. PLANNED ACTIVITIES

1. Phase I Final Report will be completed.
2. Four tons of mulled coal will be prepared at Homer City by CQ Inc. to be used for the full system testing of the solid mull and CWF at Grand Forks, North Dakota (UNDEERC).
3. A 100-day aging test program of various coal mull formulations will be initiated.
4. A 2-inch continuous processor will be tested for making mulled coal and CWS continuously. The operating experience will be used to assist CQ Inc. in operating their 5-inch continuous processor for making the large batch of mulled coal for UNDEERC.
5. Initial samples of selected mulled coal formulations will be submitted to the consulting engineers on transportation and materials handling systems to perform flow and storage testing.

6. Additional sprayability tests of the mulls and slurries prepared from selected mull samples will be conducted in our bench top spray apparatus.

VI. SUMMARY

Several tons of precleaned coal have been obtained for producing the various mull products. Two tons of coal were received at EI to be used for the aging tests and storage and flow studies.

A patent application has been filed for the novel concept of producing "mulled" coal from wet cakes.

Additional reagent screening showed the same additives can be used to prepare the granular mulls at concentrations of 3 wt % but only a few made satisfactory mulls at 1 wt %. Not all mulls were capable of being turned into slurries with the selected reagents.

Preliminary tests show that the granular mulled coal can be conveyed both pneumatically and by screw feeders. Also, a sample of mulled coal was converted to slurry (approx. 59% solids) and successfully sprayed in a small laboratory spray nozzle test apparatus.

After visiting two equipment manufacturers, two continuous processors were selected to make mulled coal and coal-water-slurry. A 2-inch processor was leased by EI to be used for the skid-mounted test unit that will be taken to Grand Forks, North Dakota (UNDEERC) for producing coal-water-slurry. A 5-inch processor was leased by CQ Inc. to make the mulled coal product at Homer City. Also, a 6-quart Sigma mixer was leased by EI to produce mulled coal samples for the aging and flow handling studies.

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