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

Contract No. DE-AC22-90PC90167

Technical Progress Report No. 3
For the Period October 1, 1990 through December 31, 1990

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I. EXECUTIVE SUMMARY

Energy International 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.

During the past quarter (October 1 to December 30, 1990), Energy International has extended the evaluation of the granular mull to include fuel slurry formulations. Initial steps were taken to identify critical transport, storage and handling characteristics.

Activities during the next quarter will concentrate on completing Phase I work in preparation for PETC review and evaluation.

II. INTRODUCTION

The mulled coal project started with the selection of coal feedstocks on May 15, 1990. This report covers activities from October 1, 1990 through December 30, 1990 including selection and procurement of a western subbituminous coal sample for evaluation.

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

a. preparation of coal-water fuels,
b. combustion of low-ash coal based fuel forms,
c. 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 have 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 produced in very fine particles with a high surface area, 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 produce are only now becoming available in meaningful quantities.
Much of the existing work and experience with advanced coal-based fuels such as EWF 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 specifications that represent a compromise.

Energy International has been awarded a contract by DOE-PETC to evaluate a new concept for utilization of the fine coal wet cake produced by many of the physical beneficiation processes now under development.

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) would 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 U.S. Department of Energy (U.S. DOE) Pittsburgh Energy Technology Center (PETC) and Energy International Corporation have executed a contract to address the storage, transport and handling of beneficiated coals in the form of a modified wet cake ("mulled coal") to yield a coal water fuel having acceptable properties for atomization and combustion on industrial, commercial and/or residential scales.

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 previous to formulation of the Mulled Coal.

3. Conversion from Mulled Coal to the final fuel form should require minimal equipment and relative 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 ACQUISITION

1.1.1 Feedstock Selection

Phase I feedstock selection has been completed.

1.1.2 Procurement - I

Purchased 100 lbs. cleaned wet filter cake of Spring Creek subbituminous coal.
1.1.3 Procurement - II

No Phase II procurement activities were performed during this project period.

1.2 FEASIBILITY STUDY

1.2.1 Administration

Project administration for Task #2 included further evaluation of various reagents and formulations for the "granular" form of mull and consultant supervision.

The following reports and/or deliverables were prepared and submitted during the quarterly period.

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1.2.2 Reagent Studies

Additives were varied in concentration for evaluation of mull stability.

1.2.3 MC Formulations

The granular mull formulations were prepared with varying additives, moisture content and grinding size for evaluation in the lab scale tests of Task #3.

1.2.4 CWF Formulations

As discussed in the last Quarterly Report it was discovered that simple addition of a surfactant, especially those with higher HLB (hydrophobic lithophobe balance) numbers, were effective in turning the granular mulled coal into a free flowing slurry without additional water. To expand our knowledge and experience with the granular product, experiments were carried out to determine the effect of moisture content, particle size and surfactant concentration on the viscosity of the slurries. Figure 1 (a repeat from last quarter's Technical Progress Report) showed the effect of moisture content and particle size on the viscosities of slurries prepared from stabilized (mulled) filter cakes of different particles sizes and moisture contents. As anticipated, moisture content had the greatest effect. Particle size, at least over the range studied, had only a small effect. The
FIGURE 1

Effect of Particle Size and Moisture Content on Slurry Viscosities

Mean Volume Diameter (um)

NPA-1 treated filter cake followed by 1% surfactant

% Moisture in Filter Cake

Viscosity at 100 sec. -1 cps
FIGURE 2

Effect of Surfactant Concentration on Slurry Viscosities

- O — O 30% moisture stabilized wet filter cake
- • — • 35% moisture stabilized wet filter cake
- △ — △ 40% moisture stabilized wet filter cake

Micronized Coal (Mv=14 microns)
FIGURE 3

Effect of Surfactant Concentration on Slurry Viscosities

Slurry Particle Size
Mean Volume Diameter, (um)
O—O 91 um
(30% Moisture Wet Filter Cake)
effect of surfactant concentration is shown in Figures 2 and 3. Figure 2 shows the effect of filter cake moisture content and surfactant concentration. Once again it can be seen that a moisture content has the greater effect on viscosity than surfactant concentration. The slight increase in viscosity observed at 2% surfactant concentration at all three moisture levels has been observed by others in slurry studies and has been attributed to stearic hindrance between particles due to multiple layers of surfactant on the particle surfaces. The results of these experiments show the feasibility of viscosity control by a variety of preparation methods and techniques.

1.2.5 Duty Specifications

Results of the bench scale studies will be utilized to develop equipment specifications for the mechanical systems to transport, store, and atomize the mulled coal fuels. Gordon S. Trivett and Williams Technologies will be consultants for this task.

Internal deliverables: Mechanical systems specifications.

The systems should have the following characteristics:


Handling Systems: Screw type conveyor and/or pneumatic transport capable of handling 0.5-5 tons/minute for filling carriers and transferring to storage units. Smaller scale handlers 10-100 lbs/hour for transfer to the combustion unit. Prototypes: sand pumps, grain conveyors.

Transport: Covered containers to exclude fugitive dust and to control blowing designed to handle material such as wet sand, grain, etc. with a definable angle of repose and tendency to form friable masses on freezing. Prototypes: sand trucks, finely ground materials.

Storage: Covered bins or silos with height and widths to be determined. The bottoms should be slanted and fitted with screw feeders to remove the gravity fed product. Requirements for vibration and heating to be determined. Capacity will vary from 100-1000 tons at the plant and distribution centers to 1-50 tons at the point of usage. Prototype: pulverized coals silos, grain storage.

Coal Water Fuels Preparation Circuit: The specifications will vary depending on the combustion system. However, general specifications will include:

Particle size: provided in feed coal

Solids loading: 65-70% for industrial size
60-65% for residential/commercial
45-50% for heat engines

Viscosity: To be determined but will generally be required to have a power law factor < 1.1 with viscosity < 1000 cp @ 100 sec⁻¹.
Stability: CWF will be prepared at the point and time of usage with no storage. The system will be purged at shutdown. A conceptual block flow of the CWF prep circuit is shown in Figure 4. The projected capacity will be 10-100 lbs/hr of mull. Provision for addition of CWF reagents and makeup water will be required as will in-line monitoring of critical CWF properties.

1.2.6 Plan Revisions

The results to date will be evaluated and necessary changes in the work plan will be made. Major changes will be recommended to PETC.

Internal Deliverables. Plan revisions if any.

The mulled coal formulations resulted in production of two distinctly different types of mulls, the "gel" and the "granular".

The "gel" mull is of the type anticipated in the proposal, i.e., a highly viscous liquid with consistency ranging from that of bread dough to heavy oil. The formulations are similar to those for CWF. Conversion to CWF can be achieved by addition of water in a high shear system. However, the handling characteristics of the mulls varies greatly from coal to coal and is extremely sensitive to water concentration. Storage, handling, and transportation must utilize sealed systems with rigorous control of water concentration and water chemistry.

The "granular" mull is a form not anticipated. The material has much of the consistency of dry sand with a particle size several times larger than the feed coal. The formulation utilizes a reagent readily available at costs 10% that of the gel type. The granular mull can be converted to CWF utilizing conventional CWF reagents in a low shear system. The handling characteristics are not sensitive to moisture levels, feed particle size, or variations in coal processing. Initial studies suggest that loss of moisture during storage has little effect on the handling characteristics.

The granular mull is the preferred form for the following reasons.

1. Consistency of handling characteristics over a range of moisture levels, coal particle sizes, and coals.

2. Lower reagent costs.

3. Potentially simpler storage, handling and transportation systems.

The designation of the granular mull as the preferred form results in the following:

1. Subsequent work will be on granular formulations.

2. Preliminary results suggest that the original problems anticipated during transport will be considerably simplified. This is especially true for generation of hard pack due to the low frequency vibrations and viscosity changes due to temperature cycling.
3. Storage, handling, and transport now becomes more of a solids handling issue with the likelihood of identifying existing systems that can serve as prototypes.

4. Stability issues are now related more to surface phenomena than to bulk properties. Preliminary results indicate that the bulk properties are relatively constant over a wide range of feedstocks. However, issues such as oxidation and alteration of the coal surfaces are more critical for the higher surface areas of solids relative to the plan for gels.

5. CWF preparation may become more complex due to the pronounced transition from the solid to liquid properties with an anticipated requirement to add both reagents and makeup water to achieve necessary requirements for viscosity and atomization.

Phase I activities are defined such that these changes can be readily implemented with minor impact on the Work Plan. However, these changes will have a greater impact on Phase II of this program where the demonstration systems will be designed, constructed and operated.

1.3 Lab Scale Tests

1.3.1 Administration

Project administration for Task #3 consisted of subcontract preparation, consultant supervision and generating deliverable reports.

1.3.2 Sample Preparation

Samples of the granular mull were prepared with varying additives and moisture content for evaluation.

1.3.3 Transport Studies
1.3.4 Storage Studies
1.3.5 Handling Studies

Experiments were begun to evaluate the transport, storage, and handling properties of the granular mulled coal. Among the first properties studied were:

- Bulk densities as a function of additive concentration, moisture content and particle size.

- Drying characteristics of the agglomerated product as a function of additive concentration, particle size, moisture content and temperature.
FIGURE 4

Conceptual Flow Scheme For Converting Mulled Coal to Liquid Slurry Fuel

- Mulled Coal
- Screw-Feeder
- De-Lumper
- Dispersing Agent
- Ribbon-Muller Blender
- Stabilizing Hold Tank
- Dispersant Stabilizer Water
- Density Meter
- Viscosity Meter
- Air
- Furnace
- Recycle Pump
- In-Line Mixer
- High Pressure Pump
Bulk Densities

The bulk densities of the granular mulled coal products were measured by pouring anywhere from 95 to 100 ml of the granular product through a powder funnel, into a tared 100 ml graduated cylinder, and then reweighing and measuring as accurately as possible the volume of product. Attempts were made to allow the powder to settle with as little compaction as possible. The values reported are the average of five separate determinations. Figure 5 shows the measured bulk densities of the various size fractions of the Upper Elkhorn #3 coal as a function of the fraction topsize. It can be seen that above a size range of 30 x 100 mesh the bulk densities do not change very much.

Figures 6, 7 and 8 show the measured bulk densities of 30% moisture filter cakes having different mean volume diameters (Mv's) as a function of the NPA-1 additive concentration. While no explanation is offered at this time for the various shapes of the resulting curves it has been consistent in all measurements that the maximum bulk densities are obtained at about the 1% additive level regardless of the mean volume diameter. Once compaction tests are carried out, these numbers will be useful in determining the best storage conditions such as bin heights, configurations, etc.

Drying Studies

It was discovered early on in our formulation work that the wet filter cakes would rapidly lose water after treatment with the non-polar additive (NPA-1). The resulting "granular", finely ground coal would retain its free flowing, dustless properties even at these very low additive concentrations. It was, therefore, decided to determine the drying properties of these mulls with the possible thought of developing a process that would be better (i.e., faster, cheaper, etc.) than the current thermal drying process. The work carried out thus far is summarized in Figures 9, 10, 11 and 12. The apparatus used to make the measurements is shown schematically in Figure 13.

Figures 9 through 11 illustrate the drying curves as a function of filter cake particle size at three different drying temperatures. Figure 12 gives the drying curves for a micronized coal at air temperatures ranging from room temperature to 64 degrees C. It can be seen that particle size had little effect upon drying times (i.e., the time to remove 30% moisture) and that, with the exception of room temperature, most of the moisture was removed in three hours at a constant air flow rate (33.9 scfhr.) regardless of temperature. This shows that there could be dramatic drying of the mull during pneumatic transfer of the product and that, in all likelihood, water would have to be added at the burner front to prepare sprayable slurries.

The forced air dried samples are currently undergoing the U.S. Steel oxidation tests. Preliminary results indicate that some surface oxidation of the samples is occurring. Complete results will be given in the next Quarterly Report.
FIGURE 6

Effect of Additive Concentration on the Bulk Densities of 30% Moisture Filter Cakes

Mv = 80 um

Bulk Density, lbs/ft^3
FIGURE 7

Effect of Additive Concentration on the Bulk Densities of 30% Moisture Filter Cakes

$M_v = 20 \text{ mu}$

Bulk Density, lbs/cuft

% NPA-1 Addition

file:bkdend5
FIGURE 8

Effect of Additive Concentration on the Bulk Density of a 30% Moisture Moisture Filter Cake

$M_v = 10-12 \, \text{um}$

Bulk Density, lbs/cuft.

% NPA-1 Addition
FIGURE 9

Drying of 30% Moisture
Stabilized Wet Filter Cake

Air Flow Rate = 33.9 scfh
Air Temperature = 48 deg. C

% Weight Loss

Mean Particle Diameter
- O 20 um
- ▲ 44 um
- △ 88 um

Heating Time, hrs

file: drysum1
FIGURE 10
Drying of 30% Moisture Stabilized Wet Filter Cake

Air Flow Rate = 33.9 scfh
Air Temperature = 58 deg. C

Mean Particle Diameter
- 20 um
- 44 um
- 88 um

% Weight Loss

Heating Time, hrs

file: drysum2
FIGURE 11
Drying of 30% Moisture Stabilized Wet Filter Cake

Air Flow Rate = 33.9 scfh
Air Temperature = 64 deg. C

Mean Particle Diameter

file:drysum3

Heating Time, hrs

% Weight Loss
FIGURE 12

Drying of 30% Moisture Stabilized Wet Filter Cake

Air Flow Rate = 33.9 scfh
Micronized Coal (14–20 um Mv)

% Weight Loss

Heating Time, hrs

Room temp.
48 deg. C
58 deg. C
64 deg. C

file: drysum

-20-
FIGURE 13

MULLED COAL AIR DRYING APPARATUS
1.3.6 CWF Testing

The granular form of mull will be produced, transported and stored in a "dry" form unlike the originally proposed gel paste. As a result, the fuel slurry will be prepared at the point of use immediately preceding combustion. The coal water fuel (CWF) form will be tested in greater detail in Task #3 additives.

2.0 PHASE II - SYSTEM DEMONSTRATION

2.1 Component Development

No task activities during this report period.

2.2 Full System Test

No task activities during this report period.

V. PLANNED ACTIVITIES

1. Compressibility measurements of the granular mull.

2. Sprayability tests of the slurries prepared from the granular mull will be conducted in our bench top spray apparatus.

3. The ability of the granular mull to be pneumatically transported and conveyed by screw conveyors will be evaluated.

4. Other potential additives will be screened as a substitute or backup for the NPA-I granular mulling additive.

5. A summary of Phase I activities will be prepared for the Pittsburgh Energy Technology Center and presented at a review meeting to determine if a Phase II activity is warranted.

6. Upon PETC's approval, a revised Phase II activities plan will be submitted.

7. Phase I Final Report will be prepared.

VI. SUMMARY

The preferred mull formulation is the granular product which maintains a consistency of handling characteristics over a range of coals, moisture levels and coal particle sizes. The granular form of mull appears stable enough to be transported and stored with a minimal additive package. As a result, the actual fuel slurry does not have to be prepared until immediately prior to combustion. This scenario provides increased quality control over the fuel mixture with lower preparation costs.

Additional studies will be conducted on the granular mull to establish parameters for Phase II simulation testing. A summary of Phase I activities will be prepared for a review meeting at the PETC facilities in mid-February.
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