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**STORAGE, TRANSPORTATION AND ATOMIZATION
OF CWF FOR RESIDENTIAL APPLICATIONS**

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1. INTRODUCTION AND SUMMARY

There are continuing pressures in the United States to reduce SO₂ emissions in order to control acid rain and its damage to the environment. Advanced beneficiation processes are under development to provide low-ash, low-sulfur coals to allow combustion performance approximately equal to that of oil or gas. A major benefit of this development will be the contribution of these technologies to the abatement of acid rain precursors.

In addition to the industrial and utility applications of beneficiated coal products, there is a large market potential for use of these fuels in small-scale applications, including commercial and residential furnaces. Although much work has been done on the development of components and systems for the formulation and use of CWF for industrial and utility applications, the results of these R&D efforts are not directly applicable to small, residential combustors. It is therefore essential to develop a data base for future use of CWF for this application.

Under a contract with the Department of Energy, Pittsburgh Energy Technology Center (PETC), Tecogen Inc. is developing a CWF-fired advanced combustor for residential applications. In order to bring the technology to the point of commercial readiness expeditiously, it is important to develop components and systems for storage, transportation, and handling of these fuels for end use. This research and development effort is designed to augment the data base on the use of CWF for residential applications.

A highly qualified team has been assembled to perform the program. The primary responsibilities of the team members are as follows:

1. Tecogen Inc.

(A Subsidiary of Thermo Electron Corporation) Waltham, Massachusetts

Tecogen, as the prime contractor, will manage and direct the program. The CWF storage, handling, and integrated combustion tests will be carried out in their advanced combustor facility for residential applications.

2. AMAX R&D, Golden, Colorado

AMAX R&D will assess formulations of CWF and prepare the fuel from beneficiated coal products supplied by DOE and produced by AMAX in

order to conduct tests in the program. AMAX R&D will focus on bulk storage, handling, and transportation prior to distribution for regional residential use.

3. Carnegie-Mellon University, Pittsburgh, Pennsylvania

Carnegie-Mellon University will compare the atomization characteristics of the CWFs prepared in the program. The effects of beneficiation on atomization will be examined, and spray characteristics will be studied by means of high-speed photography and a Malvern Particle Size Analyzer.

The proposed test program will examine the stability and rheology of the CWFs prepared from various beneficiated coal products made from the following coals: Illinois No. 6, Wyodak, and Upper Elkhorn No. 3.

The fuel characterization will include: particle size distribution, ultimate and proximate analyses of coal, ash composition, ash fusion temperature, and solids concentration. For rheological characteristics, data will be obtained at varying shear rates, temperature, and agitation or recirculation in the bulk storage tanks.

The effect of freeze-thaw on the stability and rheology of the CWF will be evaluated. Control of environmental conditions will be examined by means of formulation additives, including the addition of freezing point depressants and biocides.

The bulk storage studies will involve testing CWF stability characteristics with and without agitation or recirculation. The design of the storage tank will be reviewed, and the effectiveness of cone bottom and dish bottom tanks will be tested. The CWF storage and handling tests will be carried out at Tecogen's CWF-fired advanced combustor facility.

Carnegie-Mellon University will evaluate the atomization characteristics of the various atomizers as a function of coal type, formulation, and operating conditions.

Tecogen Inc. and its subcontractors are aware of the work previously carried out and currently under way in the formulation of CWF using beneficiated coal products as well as the data available in the public domain. No attempt will be made to duplicate the work funded previously by DOE or through other research organizations such as EPRI. We are strongly confident that the results of this

program will significantly augment the data base needed for future development of components and systems for storing, transporting, and handling CWF for residential applications.

During the quarter, work was conducted on: Task 1 - Project Planning, Task 2 - Fuel Preparation, and Task 5 - Residential Handling.

2. WORK PERFORMED DURING THE SECOND QUARTER

2.1 TASK 1 - PROJECT PLAN

The work conducted under this task during the quarter was concentrated on establishing coals to be used in the program and cleaning techniques. This was necessary since the Homer City beneficiated coal fuels were essentially unavailable. The coals to be used in this program are Upper Elkhorn No. 3, Illinois No. 6, and Wyodak. The Upper Elkhorn No. 3 coal was chosen as the base coal since Tecogen has extensive working experience with that coal. The Illinois No. 6 coal was chosen due to the large reserves and the high sulfur. The Wyodak coal was chosen as a representative western subbituminous coal.

There will be seven slurries made from the three coals. These are summarized below.

<u>Coal</u>	<u>Cleaning Method</u>
1. Upper Elkhorn No. 3	Flotation
2. Upper Elkhorn No. 3	Heavy Media Separation (HMS)
3. Upper Elkhorn No. 3	HMS/Milled and Filtered
4. Upper Elkhorn No. 3	HMS/Chemical Cleaned
5. Illinois No. 6	HMS
6. Illinois No. 6	Oil Agglomeration
7. Wyodak	HMS

2.2 TASK 2 - FUEL PREPARATION

After agreement on the coals and cleaning techniques, work was focused on procuring the parent coals and setting up the cleaning and slurry production circuits. The following coals were ordered:

- Wyodak subbituminous from the Eagle Butte mine
- Illinois No. 6 from the AMAX Delta Mine, Marion, Illinois
- Upper Elkhorn from the Wentz mine.

The base coal, the upper Elkhorn No. 3, will be made into slurry using four different cleaning techniques. Process flow block diagrams are shown in Figures 2.1, 2.2, and 2.3. The heavy media cleaning circuit process units are shown in Figure 2.1. Coal is received and crushed to pass through a 5/8-inch

Production of Coal Slurry Fuel at AMAX R&D Center
(Either no Cleaning or HMS Cleaning)

Figure 2.1

Production of Coal Slurry Fuel at AMAX R&D Center
(Chemical Cleaning)

Figure 2.2

Production of Coal Slurry Fuel at AMAX R&D Center
(Froth Flotation Cleaning)

Figure 2.3

screen prior to being fed to the heavy media separation (HMS) stage. In the HMS stage, water and a magnetite slurry are added. The HMS unit is a stirred conical vessel with the feed entering tangentially in a cyclonic manner. Two streams leave the HMS unit – the product and the waste. The waste and product are separated from the magnetite slurry, which is recycled. The waste material is discarded along with the fines (minus 14 mesh) material. The product (cleaned coal) is fed to the initial grinding stage. Water and dispersant are added to facilitate the grinding. The product is ground to minus 0.3 mm. The ground product is micronized in a Draiswerke stirred ball mill. Additional dispersant may be added in the Draiswerke mill to lower the viscosity and facilitate micronization. The micronized product is mixed into a slurry of the desired formulation by the addition of stabilizers, water, and dispersant. The resulting slurry is tested for stability and viscosity before shipment.

The chemical cleaning circuit process units are shown in Figure 2.2. The circuit is also used to make the HMS water washed (leached) product as well. The first four process steps produce a ground HMS product as previously discussed. The ground HMS product is pressure filtered and fed to a caustic autoclave where a 10-percent sodium hydroxide solution is added. This process step operates at 450°F. Much of the ash is dissolved in this step and washed out of the product stream in a rinsed pressure filtration step. The filtered product is fed to a second autoclave operating at 175°F. A 10-percent solution of hydrochloric acid is added to dissolve the ash materials not removed by the caustic step. The product is pressure filtered and rinsed. Finally, the product stream is fed to a hot-water high-pressure wash at 450°F and filtered. The filtered product is reslurried and micronized in the Draiswerke stirred ball mill. The slurry is adjusted to the desired formulation. For the water leached product, the material will be fed straight from the initial grinding stage to the hot-water high-pressure wash stage through a pressure filtration step.

A flotation product will also be made and processed into a slurry. The flotation circuit process stages are shown in Figure 2.3. As for the HMS products, mine production coal will be received and crushed to minus 5/8 inch in size prior to going through the initial grinding stage in the 4-foot by 4-foot ball mill. This material then flows through the froth flotation system. The clean product is pressure filtered and resuspended. Final grinding is then done in the Draiswerke stirred ball mill to obtain the micronized product. Dispersant may be added to the Draiswerke mill to lower the viscosity and facilitate micronization. The micronized product is adjusted to final slurry specification by the addition of stabilizer, water, and dispersant.

During the quarter, two coals were processed into slurries. These were the Illinois No. 6 coal from the Delta mine and the Wyodak subbituminous coal from the Eagle Butte mine. Both these slurries were made from a cleaned coal processed by HMS.

Approximately 400 gallons of slurry were prepared from HMS cleaned Illinois No. 6 coal from the Delta Mine in Saline County, Illinois. Of this amount, 100 gallons were used at Tecogen for residential handling and storage tests, 50 gallons were used at Carnegie-Mellon for atomization tests, and the balance was used at AMAX for bulk storage tests. The properties of the fuel are listed in Table 2.1. The fuel contains 0.985-percent A-23 dispersant (based on the dry coal content) with no stabilizer.

A number of laboratory-scale slurry preparation tests were made on the Wyodak subbituminous coal. These are summarized in Table 2.2. The laboratory-scale data indicate that a slurry of acceptable rheology can be made with a solids content of 42 percent at most and may contain as much as 40 to 80 pounds of dispersant per ton of dry coal. The higher heating value of this fuel will be on the order of 5,100 Btu/lb. Several slurry preparation tests were also made from samples of Wyodak coal that had been dried in a recycled gas stream (the dried coal from the first stage of the WRI inclined mild gasification process) and from dried coal fines from the AMAX drying plant at Gillette, Wyoming. Slurry loadings of 48-percent coal were obtained from the inclined bed product and 45 percent from the AMAX commercial dryer plant fines. These tests indicate that pretreatment drying of the Wyodak subbituminous coal is likely to produce a more highly loaded slurry (higher heating value).

Approximately 400 gallons of slurry was made from HMS cleaned Wyodak subbituminous coal. The production run slurry contained 40.6 percent solids compared to the laboratory-scale test of 42 percent. A complete listing of the slurry properties is presented in Table 2.3. As can be seen from the data on fuel viscosity, the Wyodak slurry is pseudoplastic in the shear rate range between 100 s^{-1} to 1000 s^{-1} , whereas the Illinois No. 6 slurry is dilatant over that same range.

2.3 TASK 5 - RESIDENTIAL HANDLING

Work during the quarter on this task was aimed at generating a preliminary design for the slurry handling test facility and identifying long lead time items required for the slurry handling test facility. The longest lead times were required by the pressure transducer vendors for supplying the transducers. Eight to twelve weeks were required for these items. The pressure transducers as well as other piping and instrumentation and miscellaneous equipment were ordered.

TABLE 2.1

PROPERTIES OF ILLINOIS NO. 6
COAL SLURRY FUEL

Batch A: HMS Cleaned Illinois No. 6 Bituminous Coal
Delta Mine, Marion, Illinois

	<u>Batch A</u>
Fuel Analysis, %	
Moisture	45.55
Coal	54.00
Additives	0.45
Dry Coal Composition, %	
Ash	5.89
Volatile Matter	37.92
Fixed Carbon	56.19
Total Sulfur	2.47
Pyrite Sulfur	0.74
Fuel Viscosity, Centipoise	
at 100 sec ⁻¹	200
at 500 sec ⁻¹	275
at 1,000 sec ⁻¹	285
Particle Size Distribution, % Passing	
150 Micrometers	100.00
106 Micrometers	99.95
75 Micrometers	99.79
53 Micrometers	99.48
45 Micrometers	98.72
38 Micrometers	98.19
30 Micrometers	95.72
20 Micrometers	86.91
15 Micrometers	71.42
10 Micrometers	52.98
8 Micrometers	44.76
6 Micrometers	36.80
4 Micrometers	38.32
3 Micrometers	22.42
2 Micrometers	14.86
1 Micrometer	5.06
Mass Mean Diameter, Micrometers	11.4

TABLE 2.2
SLURRY PREPARATION TEST RESULTS
ON WYODAK COAL SAMPLE

Property	Raw Coal			WRI Dryer Product		AMAX Drying Plant Fines		
	As Received		Filtered					
Coal, %	42.0	40.3	41.3	47.5	46.9	45.3	45.3	45.1
A-23, %	6.0	4.0	6.0	6.0	4.0	6.0	4.0	6.0
Viscosity, cP								
at 100 s ⁻¹	550	400	500	525	480	450	525	500
at 1,000 s ⁻¹	400	230	470	470	350	410	420	380
Coarse, % ^a	60	60	60	60	60	60	60	60
Fines, % ^b	40	40	40	40	40	40	40	40
MMD, μm	11.5	11.5	11.8	15.9	15.9	10.9	10.9	10.9

^aMinus 75 μm , 20 μm mass mean diameter.

^bMinus 15 μm , 5 μm mass mean diameter.

TABLE 2.3
PROPERTIES OF WYODAK COAL SLURRY FUEL

Batch B: HMS Cleaned Upper Wyodak Subbituminous Coal
Eagle Butte Mine, Gillette, Wyoming

	<u>Batch B</u>
Fuel Analysis, %	
Moisture	57.78
Coal	40.60
Additives	1.62
Dry Coal Composition, %	
Ash	5.75
Volatile Matter	44.86
Fixed Carbon	49.39
Total Sulfur	1.01
Pyrite Sulfur	<0.01
Fuel Viscosity, Centipoise	
at 100 sec ⁻¹	410
at 500 sec ⁻¹	290
at 1,000 sec ⁻¹	255
Particle Size Distribution, % Passing	
150 Micrometers	99.10
106 Micrometers	97.75
75 Micrometers	95.43
53 Micrometers	94.16
45 Micrometers	93.22
38 Micrometers	92.08
30 Micrometers	87.74
20 Micrometers	74.37
15 Micrometers	65.96
10 Micrometers	51.78
8 Micrometers	46.57
6 Micrometers	38.53
4 Micrometers	29.66
3 Micrometers	23.67
2 Micrometers	16.38
1 Micrometer	5.19
Mass Mean Diameter, Micrometers	17.0

3. SUMMARY STATUS ASSESSMENT AND FORECAST

Significant progress was made during this quarter. An agreement was reached on the supply of the slurry fuels and on the raw coal as well as the cleaning techniques to be used for each coal. This agreement was required since the fuels from the Homer City Facility were originally to be used and were no longer available for this program. Once the coals and cleaning techniques were established the program work accelerated.

In the next quarter, slurries from the base coal (upper Elkhorn No. 3) will be made and delivered. Bulk stabilization work will be initiated as well as residential handling and storage tests.

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