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DOE/PC/89797--T4

SEP 09 1991

**R&D for the Storage, Transport, and Handling
of Coal-Based Fuels**

DOE/PC/89797--T4

DE92 001639

**Quarterly Progress Report
for
January 2, 1991 - March 31, 1991**

Customer Order No.

DE-AC22-89PC89797

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ABSTRACT

Three different feeders for the Residential Storage System have been successfully demonstrated. The relative flowability, as determined by the Hausner ratio, angle of repose, and Jenike shear cell for three test coals is:

Wyodak > Upper Elkhorn > Illinois No. 6 (cleaned by Bechtel process)

1.0 INTRODUCTION

This is the sixth Quarterly Report summarizing technical progress from January 2, 1991 to March 31, 1991 on the R&D for the Storage, Transport, and Handling of Coal-Based Fuels, Contract DE-AC22-89PC89797, sponsored by the U. S. Department of Energy, Pittsburgh Energy Technology Center. Westinghouse Advanced Energy Systems is the prime contractor for this project with assistance from the Westinghouse Science and Technology Center and the University of Pittsburgh as principal subcontractor.

The product of several advanced physical coal cleaning processes is a dry, ultrafine coal (DUC), in the order of 10 microns mean mass diameter. To utilize this fuel commercially, cost-effective, environmentally safe systems must be provided for the storage, transport, and handling of this finely divided form of fuel. The objective of the project described herein is the development of total logistics systems for DUC, including experimental verification of key features. The systems to be developed will provide for safe, economic, and environmentally protective storage and delivery of DUC for residential, commercial, and industrial uses.

2.0 SUMMARY

Three feeders for the Residential Storage Tank System have been successfully operated. The pinch valve concept has been tested with polyvinylchloride particles having a mean mass diameter of 420 microns. The rotary feeder has been bench tested with coal and is being installed in the system. Testing of the commercial massaging/flexible wall feeder has included flow calibration and power usage at various flow rates.

The contract to fabricate the tanks for the Industrial/Commercial Storage System Test has been awarded to Cannon Technologies, New Kensington, PA. Delivery of the tanks is scheduled for May 1, 1991.

Flow characteristics of the DUC are being measured by several techniques, including:

- Fluidization parameters
- Bed Collapse
- Flow from an Orifice
- Hausner Ratio

Other characteristics being measured are:

- Particle Size Analysis
- Particle Pickup Velocity
- Sonic Absorption
- Angle of Repose

The angle of repose results indicate that the order of flowability of the three coals is Wyodak > Upper Elkhorn > Illinois No. 6 (Bechtel cleaned). These results are consistent with the earlier Hausner ratio measurements. Shear stress measurements made with the Jenike shear cell confirmed the same order of flowability for these coals.

Particle sizes (mean mass diameter) measured for the three coals measured to date are:

Wyodak	21.5
Upper Elkhorn	14.8
Illinois No. 6 (Bechtel)	6.8

The Pneumatic Test Loop has been completed and shakedown runs have been made using 150 micron methymethacrylate particles. Pressure drop data were measured for the horizontal section at several gas velocities. Problems with the screw feeder were determined to have originated from its bench testing by the vendor using flyash.

3.0 TECHNICAL DISCUSSION

Technical progress for each of the tasks which were active during this quarter is discussed in this section.

3.1 Task 1: Project Control (M. H. Cooper)

3.1.1 Objective

Project management, including technical direction and cost control will be accomplished in this task.

3.1.2 Technical Status

Monthly technical and management reports and a quarterly report were submitted to DOE.

The fabricator for the tanks for the Industrial/Commercial Storage System Test was visited to review the production schedule.

3.3 Task 3: Storage Systems

3.3.1 Subtask 3.1: Residential Storage Tank Testing (S. H. Chiang)

3.3.1.1 Objective

The objective of this subtask is the testing of a scale model tank of a DUC storage tank for residential application. Tests will be performed to confirm satisfactory performance of operations and components of this tank, which includes: filling, discharge, bladder operation and level detection.

3.3.1.2 Technical Status

Additional tests on the pinch valve for the feeder control mechanism were carried out. The tests were done in two parts. The first part measured the mass flow rate of the solids through the pinch valve under the influence of gravity alone. No conveying gas was employed. The second test case included the presence of conveying gas. In each of these tests varying pressures were applied to the pinch valve outer surface. PVC particles with an average mass diameter of 420 microns were employed. Figure 3.3-1 shows the results of these tests indicating good reproducibility.

In projecting the use of this valve in a residential situation it would be more suitable to have it fail in a shut-off position. Red-Ball Incorporated is the manufacture of the valve and they are being contacted to see if an arrangement with the close failure position is made or could be made.

The rotary feeder's construction was finished with the new design incorporated. Figures 3.3-2 and 3.3-3 show the details of the feeder. The rotary feeder was calibrated with coal in a bench top experiment and is now ready for insertion into the line. Once in the line the valve will be tested at various rotational speeds up to 30 rpm, different pocket spacing, and different gas pressures and flowrates.

The tank is now ready to be tested with DUC using the pinch valve and gas arrangement.

3.3.2 Subtask 3.2: Industrial/Commercial Storage System (B. M. Woodle, M. H. Canton, M. H. Cooper)

Figure 3.3-1. Pinch Valve Calibration

Figure 3.3-2. Rotary Valve Assembly

Figure 3.3-3. Rotary Feeder Rotor

3.3.2.1 Objective

The objective of this subtask is the design and testing of a reduced scale model of an industrial storage system for dry, ultra-fine coal. Tests will be performed to demonstrate satisfactory filling and discharge of this system.

3.3.2.2 Technical Status

The test cell to be used for this system has been cleared of previous equipment and the control room has been renovated. Pre-formed piping and valves for the gas control system have been ordered. The design of the control panels has been initiated.

The contract for the fabrication of the two storage tanks has been awarded to Cannon Technologies, Inc., New Kensington, PA. Delivery of these tanks is scheduled for May 1, 1991.

3.5 Task 5: Handling

3.5.1 Objective

The objective of this task is the verification of the satisfactory operation of the components and systems to be used for handling DUC at the system interfaces.

3.5.1.1 Subtask 5.1: Characterization of the DUC

3.5.1.1.1 Objective

A variety of different tests are to be performed to characterize DUC.

3.5.1.1.2 Technical Status

Fluidization

Flow characteristics of the DUC will be measured by three separate techniques - fluidization, bed collapse, and flow from an orifice. The ratio of tap to aerated bulk density will also be determined to assess the cohesiveness and flowability of the DUC.

Bed collapsing tests for the Upper Elkhorn coal, the Wyodak coal, and the Illinois No. 6 coal (processed through heptane/asphalt agglomeration) were completed and the data are being analyzed. Both the Wyodak and the Illinois No. 6 coals tended to adhere on the transparent wall of the fluidized bed and obscure the bed surface during experiments. Thus the visual information of bed surface from the video might not be available. The pressure drop measurement will be employed to characterize the bed collapsing tests.

The angle of repose of all three coals were also determined by passing the coal through a vibrating screen and a funnel, the same apparatus used earlier for bulk density determination. Instead of catching the powder in a container for bulk density determination, the powder was allowed to pile on a flat surface. The angle of repose was measured at four places, 90 degrees apart, using an inclinometer. Two separate determinations were conducted for each coal. The results are tabulated below.

<u>Coal</u>	<u>Angle of Repose</u>	
	<u>1st Determination</u>	<u>2nd Determination</u>
Illinois No. 6	40° (37° to 43°)	38° (34° to 41°)
Upper Elkhorn	39° (34° to 44°)	42° (39° to 45°)
Illinois No. 6	31° (29° to 34°)	33° (29° to 36°)

The Wyodak coal has the lowest angle of repose and thus is comparably more free flowing. This is consistent with the result obtained from the Hausner's ratio determination. Under compaction, the angle of repose will be higher from that reported here. This will be especially true for the Illinois No. 6 coal processed through haptane/asphalt agglomeration because the residue binder will tend to agglomerate the powder again.

Shear Measurement

Shear stress of the DUC will be measured with a Jenike shear cell to evaluate the flow characteristics of the DUC. The shear stress, together with other parameters measured in this Task 5, will allow ranking of different powders in terms of handling difficulty.

The wall friction angles between the Upper Elkhorn coal (with and without flow aid) and the Wyodak coal, and four metal samples of ANSI C1020 hot-rolled steel were determined and reported here. The addition of 0.5% Aerosil 200 as flow aid to the Upper Elkhorn coal did not show any effectiveness at all as seen in Figure 3.5-1. The four metal samples gave wall friction angles ranging from 27.9° to 31.4° with no flow aid and from 28.4° to 30.5° with flow aid. In the case of Wyodak coal, the wall friction angles are from 25.2° to 27° as shown in Figure 3.5-2. Again the Wyodak coal exhibits a better flowability compared to that of the Upper Elkhorn coal, a conclusion consistent with results of other characterization techniques employed in this study. The data on wall friction angle between different powders and hopper wall materials provide essential information for hopper design.

Wall yield loci were also completed for the Illinois No. 6 coal with and without flow aid. The flow aid used in this case was 0.5% by weight of Aluminum Oxide C. Data will be analyzed and presented next month.

DETERMINATION OF WALL FRICTION ANGLE (UPPER ELKHORN COAL)

Figure 3.5-1. Determination of Wall Friction Angle
- Upper Elkhorn Coal With and Without Flow Aid

DETERMINATION OF WALL FRICTION ANGLE (WYODAK COAL)

Figure 3.5-2. Determination of Wall Friction Angle - Wyodak Coal

Particle Size Analysis

In the past the particle size analysis had been performed by use of the Microtrak analysis. Since additional testing of the pickup velocity on the Bechtel coal needed to be performed, more pellets were required in the powder form. Placing the pellets in the ball mill directly from the storage drum produced a paste of the solids because of the binder on the particles. The pellets were heated at 75°C for 24 hours and then placed in the ball mill for 24 hours. The pellets so handled were able to be reduced to a manageable powder. The particle size a D_{50} of 7 microns. The particle size distribution is seen in Figure 3.5-3 on the log-probability paper showing a straight line representation indicating a log-normal distribution is valid.

It is noteworthy that the largest particles in this sample are about 30 micron in size. One observation on this analysis is the question as to whether we have caused additional size reduction with the procedure of reduction from pellets to powders.

Since the pellets were so prepared, the other two coals were also re-analyzed to compare the particle size distribution with log-normal plots. Figure 3.5-4 and 3.5-5 are the size distributions for the Upper Elkhorn and Wyodak coals respectively. Both of these plots show the log-normal distributions do apply. The Upper Elkhorn coal gives a D_{50} of approximately 14 microns with particles up to 70 microns being present. A microphotograph of the coals is presented in Figures 3.5-6a - 3.5-6c where one can see larger particles present in the Upper Elkhorn sample. The Wyodak coal show a D_{50} of approximately 21 microns with particles up to 100 micron being present.

Figure 3.5-3. Particle Size Distribution, Illinois No. 6,
Coal Cleaned by Bechtel

Figure 3.5-4. Particle Size Distribution,
Upper Elkhorn Coal

Figure 3.5-5. Particle Size Distribution, Wyodak Coal

$D_{50}=6.8$ micron

Figure 3.5-6a. Photomicrograph of Illinois No. 6 Coal Cleaned by Bechtel Process

$$D_{p50}=21.52\mu m$$

Figure 3.5-6b. Photomicrograph of Wyodak Coal

$D_{50}=14.75\mu m$

Figure 3.5-6c. Photomicrograph of Upper Elkhorn Coal

A ranking of the size distributions differ from what we had determined before at the beginning of the project. Presently we obtained the following size ranking

Wyodak > Upper Elkhorn > Bechtel

whereas before the Upper Elkhorn and Bechtel were interchanged in size rank. The Upper Elkhorn was reported as having a D_{50} of 5 microns. Upon review of these data and repeating several analyses in the last month, the first sample was probably taken from the top of the containing drum thus did not provide a true representation of the whole sample. The coal was sampled from various locations in the drum and the results presented are a true representation of the actual size.

Interpretations that we obtained in characterizing the coals still remain in the same ranking as previously reported since the Bechtel coal did not follow in the rankings due to the binder material present in all the tests carried out with this coal. Generally the Bechtel coal behaved as coal having a much larger size particles due to the binder material.

Figure 3.5-7 is a plot of the combined coals distributions. This plot permits comparison of the coal particle sizes.

Collapsing Bed experiments

Anthracite was ground in a ballmill to a size of D_{50} of 10 microns and added to the experiments to measure bed collapse and floodability. Each test carried out had 2 percent anthracite added. Care was taken that adequate mixing of the coals took place before carrying out the test. The tests indicated that there was no significant difference between the results of the Wyodak coal before and after adding anthracite.

Figure 3.5-7. Particle Size Distributions for the Three Coals

Additional anthracite was prepared for testing in the shear cell units from Westinghouse.

Pickup Velocity

An error was discovered in averaging one of the coal pickup velocity measurements. The correction has been made and is seen in Figure 3.5-8. These results indicate a more monotonic decrease in pickup velocity with particle size over the range studied.

Using the alumina, glass and coal data for multi-particle systems over a wide range, a correlation was developed for the pickup velocity for particles between 10 and 1000 microns. This correlation uses the Archimedes number as the parameter of concern. Two terms one involving the size and the other the shape are given below.

$$U_{gpu} = [1.27 Ar^{-1/3} + 0.036AR^{1/3} + 0.45] [0.70 AR^{-0.2} + 1] U_{gpuo}$$

where

$$AR = g (\rho_s - \rho_f) d_p^3 / (v^2 \rho_f) = \text{Archimedes numbers}$$

$$U_{gpuo} = \text{pickup velocity of single particle}$$

$$D = \text{pipe diameter}$$

$$d_p = \text{particle diameter}$$

$$F_D = \text{drag force}$$

$$F_{rp} = \text{particle Froude number based on terminal velocity}$$

$$U_{gpu} = \text{minimum pickup velocity}$$

$$U_{gpuo} = \text{minimum pickup velocity for single particle}$$

$$U_{gs} = \text{saltation velocity}$$

$$W_s = \text{mass flow rate (kg/sz)}$$

All units SI (kg/m/sec).

Figure 3.5-8. Minimum Pickup Velocities Compared with Mean Particle Size

For the single particle pickup velocities an analysis was done on two cases. One case where the particle is smaller than the boundary layer and the other when the particle is larger than the boundary layer of the fluid. The data obtained for single particles were able to be correlated using the following expressions:.

For particles bigger than the boundary layer:

$$U_{g_{puo}} = [1 - (d_p/D)^{1.5}] [4/3f_s g d_p (\rho_o_f)/(C_D \rho_o_f)^{0.5}]$$

where f_s = coefficient of sliding friction (dimensionless)

and for the particles smaller than the boundary layer thickness the implicit equation below is obtained:

$$1.54 \times 10^{-4} [1 - d_p/D]^{1.5} C_D \rho_o_f d_p^4 (U_{g_{puo}}^7)/V^2 D)^{0.5} = \\ f_s [\pi/6 g d_p^3 (\rho_o_p - \rho_o_f) + 1.320 \times 10^{-6} d_p - 6.35 \times 10^{-3} \rho_o_f d_p^3 (U_{g_{puo}}^{21}/ \\ v^5 D^3)^{1/8}]$$

Figure 3.5-9 shows the plot of these pickup velocities.

A Master's degree thesis by Francisco Cabrejos was finalized. This thesis contains the study of the various coals employed in the study and shows how they compare with the overall equation for determining the pickup velocities. Figure 3.5-10 shows the final results of these studies with the equation which best fits the data.

Sonic Absorption

Several sonic absorption experiments were carried out during this past quarter. Tests were carried out on 450 micron glass beads to serve as a comparison with the coal tests. Figure 3.5-11 shows how the two sizes of glass beads and Wyodak coal absorbed the sonic energy injected into the column with the membrane rupture procedure. This difference in the height of the pressure wave going through the bed is a measure of the absorption process. In additional spread of the signal and the peaks are a measure

Figure

Figure 3.5-9. Comparison of the minimum pickup velocity (U_{gpuo}) for a sphere using both the small- and large-particle models, with an enlargement of the low range of particle diameters (d_p).

Figure 3.5-10. Minimum pickup velocity for multiple-particle experiments: coals (non-spherical particles, 1300 kg/m^3) and ESP dust (non-spherical particles, 3000 kg/m^3).

Figure 3.5-11. Comparison of Sonic Absorption of Wyodak Coal Particles with Glass Beads

of the total energy absorbed in the bed. Using Wyodak coal as the first coal, one finds that this coal absorbs significantly more of the sound energy than the glass beads. Carrying multiple tests on the coal indicated that reproducibility could not be achieved. The more the bed was disturbed by the sonic wave the greater the absorption capacity. This appears to indicate that the packing became tighter after each test. This behavior was not seen with the coarse glass bead experiments where good reproducibility was seen between tests.

In carrying out these tests the pressure transducers used were carefully cleaned after each test to make sure that the ports were not clogged with the fine coal.

The coal beds will now be subjected to a consistent static load before carrying out the sonic absorption experiments. It is anticipated that this procedure will produce consistent sonic absorption results.

3.5.2 Subtask 5.2: Additive to Enhance Flowability of DUC

3.5.2.1 Objective

Addition of a small amount of fine silica, alumina, or anthracite powders (about 1%) to cohesive materials has been found to improve their flowability substantially. The DUC will be mixed with the flow aids identified in the literature search to evaluate their effectiveness.

3.5.2.2 Technical Status

See discussion in the last section on the effectiveness of Aerosil 200 on the wall friction angle of Upper Elkhorn coal. No effectiveness was evident so far.

A new flow aid, fine anthracite coal powder, was obtained from the University of Pittsburgh. The flow aid will be mixed with Illinois No. 6

coal, Wyodak Coal, and Upper Elkhorn coal and its effect on the Hausner's ration will be determined. Shear stresses and yield loci of all the mixed coal samples will also be determined in the Jenike shear cell to evaluate the effectiveness of anthracite coal powder as a flow aid.

3.5.4 Subtask 5.4: Pneumatic Testing

3.5.4.1 Objective

The objective of this subtask is to develop and study the behavior of a 2 inch diameter experimental setup for the transport of DUC through various piping arrangements including a splitter.

3.5.4.2 Technical Status

Test runs were conducted on 150 micron methylmethacrylate particles in the closed loop system as a shake down test. The pressure drop per unit length in the horizontal section was determined at various superficial gas velocities. Figure 3.5-12 is a plot of the results. These results are in agreement with the pressure drop behaviors with gas velocities at constant solids flow rates. One will note that to the left of the minimum pressure drop point are the dilute phase regime.

In operating the system certain observations were noted.

1. The check valve of the screw feeders was found to be leaking thus permitting an intermittent back flow of gas resulting in an irregular flow of solids. The flapper was suitable modified to ensure a more leak-proof system.
2. At low screw feeder RPM values assist valve were turned on to start the initial flow of solids. After this initial startup, this gas flow can be stopped.

Figure 3.5-12. Pressure Drop in Horizontal Section as a Function of Superficial Gas Velocity

3. A bed of solids of at least 6 inches should be maintained at all times in the hopper to the screw feeder in order to eliminate unusual torque changes during the hopper refill.
4. At low gas velocities and high solids loading the particles are seen to salt on the bottom of the pipe. Increasing the gas velocities shows a strand of solids moving slower than the gas. This strand is much thicker and discontinuous for low solids flow. At high gas velocities the flow appear to be homogeneous without any unusual flow patterns or interruptions.

During this quarter the screw of the screw feeder was found to have large hard lumps of solids in the bearing section of the feeder. This material caused the screw to turn with some labor and tripping of the motor. Cleaning of the unit improved the operation. These hard lumps appear to have come from the initial testing that was done on the unit at MSA before arriving at the University. The initial tests were conducted on fly ash and it is conjectured that water entered this bearing section forming the large hard lumps. Rusting in this section indicates that water was present also in the bearing section.

Care must be taken not to allow moisture to enter this part of the unit. Periodic checking of the bearing section should keep the problem well under control.

An electrical grounding and shielding problem arose when the load cell was connected into the system. The signal that is not properly grounded or shielded will cause undue fluctuations in the signals. Proper electrical ground eliminated these problems. Care should be taken that earthing for all low level signal shields is carried out only at one end, i.e., either at the sensor side or at the main measuring instrument side.

Electrical decoupling helps in a number of other circumstances to eliminate signal variations. Decoupling can be accomplished by an isolation transformer or by simply using a long length of wire (about 50 ft.) installed between the mains and the AC-DC unit. This technique was employed to eliminate the signal variations from the pressure transducers.

The shaker unit of the filter located directly above the hopper was found not to operate at times. Low starting torque was observed to be the reason of this malfunction. When the unit will operate at low torque positions manual starting and stopping will be carried out.

The orifice pressure drop was installed to help in the calibration of the air flow rate. This meter will be used to check the blower output.

The system was cleaned and prepared for insertion of Wyodak coal. The nitrogen storage area and supply was prepared for use with the coal.

Shakedown runs continued throughout March with powder leaks being addressed. The filter-receiver needed to be reinforced at the entrance and outlets to eliminate leaks from the sheet metal screws used in the filter-receiver construction. Other significant leakages were seen at the connection points of the filter-receiver with the storage tank and the recycle air joint. These leaks are now under control.

The Endress and Hausner flowmeter was calibrated using the methylmethacrylate particles.

3.5.5 Subtask 5.5: Feeder Development

3.5.5.1 Objective

The objective of this task is to develop a reliable feeder to supply the DUC from a residential storage tank. Two feeders will be tested: the externally massaging/flexible wall feeder and the peristaltic pump. The feeders will be evaluated on performance, capital cost, and operating cost.

3.5.5.2 Technical Status

Tests employing the externally massaging/flexible wall feeder from AccuRate was initiated during this quarter. Calibration of the feeder for the Upper Elkhorn coal was completed, showing a linear relationship between the delivery rate versus feeder auger setting (Figure 3.5-13).

Long-duration feeding tests for Upper Elkhorn coal employing the feeder were completed. The power usage for the feeder at various feeding rates are also measured with an in-line ammeter so that operating cost can be estimated. The results of the feeding tests are summarized in Figure 3.5-14. The standard error of feeding rate increases with increasing feeding rate, ranging from 0.05 kg to 0.35 kg. No plugging was experienced during the entire operation duration of more than 140 hours. The power requirement of AccuRate feeder is shown in Figure 3.5-15. At steady state operation, the power requirement tends to level off at high feeding rates. The startup power requirement is dependent on the feeding rate, however.

(UPPER ELKHORN COAL)

Figure 3.5-13. Calibration Curve for AccuRate Feeder

(UPPER ELKHORN COAL)

Figure 3.5-14. Long-Duration AccuRate Feeder Tests
- Upper Elkhorn Coal

Figure 3.5-15. Power Requirement of AccuRate Feeder

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