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**THE DEVELOPMENT OF COAL-BASED TECHNOLOGIES
FOR DEPARTMENT OF DEFENSE FACILITIES**

Semiannual Technical Progress Report
for the Period 09/28/1992 to 03/15/1993

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May 13, 1993

Work Performed Under Cooperative Agreement No. DE-FC22-92PC92162

For
U.S. Department of Energy
Pittsburgh Energy Technology Center
Pittsburgh, Pennsylvania

By
The Consortium for Coal-Water Slurry Fuel Technology
The Pennsylvania State University
University Park, Pennsylvania

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1.0 INTRODUCTION

The U.S. Department of Defense (DOD), through an Interagency Agreement with the U.S. Department of Energy (DOE), has initiated a three-phase program with the Consortium for Coal-Water Slurry Fuel Technology, with the aim of decreasing DOD's reliance on imported oil by increasing its use of coal. The program is being conducted as a cooperative agreement between the Consortium and DOE and the first phase of the program is underway.

To achieve the objectives of the program, a team of researchers has been assembled from Penn State (Energy and Fuels Research Center (EFRC), Mineral Processing Section, Fuel Science Program, Department of Mineral Economics, and Polymer Science Program), ABB Combustion Engineering Systems (CE), AMAX Research and Development Center (AMAX), and Energy and Environmental Research Corporation (EER). These four organizations are the current members of the Consortium.

Phase I activities are focused on developing clean, coal-based combustion technologies for the utilization of both micronized coal-water mixtures (MCWMs) and dry, micronized coal (MC) in fuel oil-designed industrial boilers. Phase II research and development activities will continue to focus on industrial boiler retrofit technologies by addressing emissions control and pre-combustion (*i.e.*, slagging combustion and/or gasification) strategies for the utilization of high ash and high sulfur coals. Phase III activities will examine coal-based fuel combustion systems that cofire wastes. Each phase includes an engineering cost analysis and technology assessment. The activities and status of Phase I are described below.

The objective in Phase I is to deliver fully engineered retrofit options for a fuel oil-designed watertube boiler located on a DOD installation to fire either MCWM or MC. This will be achieved through a program consisting of the following five tasks: 1) Coal Beneficiation and Preparation; 2) Combustion Performance Evaluation; 3) Engineering Design; 4) Engineering and Economic Analysis; and 5) Final Report/Submission of Design Package. Following is an outline of the project tasks that comprise Phase I:

Task 1: Coal Beneficiation/Preparation

- Subtask 1.1 Identify/Procure Coals
- Subtask 1.2 Determine Liberation Potential
- Subtask 1.3 Produce Laboratory-Scale Quantities of Micronized Coal-Water Mixtures (MCWM)
- Subtask 1.4 Develop Dry Coal Cleaning Technique
- Subtask 1.5 Produce MCWMs and Dry, Micronized Coal (MC) From Dry Clean Coal
- Subtask 1.6 Produce MCWM and MC for the Demonstration Boiler
- Subtask 1.7 Project Management and Support

Task 2: Combustion Performance Evaluation

- Subtask 2.1 Boiler Retrofit
- Subtask 2.2 Fuel Evaluation in the Research Boiler

- Subtask 2.3 Performance Evaluation of the MCWM and MC in the Demonstration Boiler
- Subtask 2.4 Evaluate Emissions Reductions Strategies
- Subtask 2.5 Project Management and Support

Task 3: Engineering Design

- Subtask 3.1 MCWM/MC Preparation Facilities
- Subtask 3.2 Fuel Handling
- Subtask 3.3 Burner System
- Subtask 3.4 Ash Removal, Handling, and Disposal
- Subtask 3.5 Air Pollution Control
- Subtask 3.6 Integrate Engineering Design
- Subtask 3.7 Project Management and Support

Task 4: Engineering and Economic Analysis

- Subtask 4.1 Survey Boiler Population/Identify Boilers for Conversion
- Subtask 4.2 Identify Appropriate Cost-Estimating Methodologies
- Subtask 4.3 Estimate Basic Costs of New Technologies
- Subtask 4.4 Process Analysis of MCWM and MC
- Subtask 4.5 Analyze/Identify Transportation Cost of Commercial Sources of MCWM and Cleaned Coal for MC Production
- Subtask 4.6 Determine Community Spillovers
- Subtask 4.7 Regional Market Considerations and Impacts
- Subtask 4.8 Integrate the Analysis
- Subtask 4.9 Project Management and Support

Task 5: Final Report/Submission of Design Package

The activities planned for Phase I are summarized below:

Task 1: The coal beneficiation and preparation effort is being conducted by Penn State's Mineral Processing Section with assistance from AMAX and Penn State's Polymer Science Program. This task involves identifying and procuring six coals that can be cleaned to <1.0 wt.% sulfur and <5.0 wt.% ash which have been, or possess the characteristics to enable them to be, made into MCWMs. The coals will be subjected to detailed coal characterization and used to produce laboratory-scale quantities of MCWM. A fundamental study of MCWM stabilization will be conducted. Additional activities include developing a dry coal cleaning technique and producing MCWMs and MC from the resulting cleaned coal.

Task 2: The EFRC is conducting the combustion performance evaluation with assistance from CE and Penn State's Fuel Science Program. The technical aspects of converting a fuel oil-designed boiler at a DOD facility will be identified in this task. All appropriate components will be evaluated, including the fuel, the fuel storage, handling and delivery equipment, the burner, the boiler, the ash handling and disposal equipment, the emissions control system, and the boiler control system. Combustion performance as indicated by flame stability, completeness of combustion, and related issues such as system derating, changes in system maintenance, the occurrence of slagging, fouling, corrosion and erosion, and air pollutant emissions will be determined. As part of this task, MCWM and MC will be evaluated in EFRC's 15,000 lb steam/h

watertube boiler. CE will provide a proven coal-designed burner for retrofitting Penn State's boiler. In addition, CE will design the burner for the DOD boiler identified for retrofitting.

Task 3: An engineering study will be performed for a complete retrofit of a DOD boiler facility to fire either MCWM or MC. The designs will be performed by EER with input from the other project participants. The designs will include the coal preparation, the fuel handling, the burner, the ash removal, handling, and disposal, and the air pollution control systems. The two designs will be applied to the DOD boiler identified in Task 4. The retrofits will be designed for community/societal acceptability. The deliverables for this task will be a detailed design that can be used for soliciting bids from engineering/construction firms to retrofit the candidate DOD boiler.

Task 4: An engineering cost analysis and technology assessment of MCWM and MC combustion will be performed by Penn State's Department of Mineral Economics and the EFRC with assistance from the industrial participants. The effort will involve surveying the DOD boiler population, identifying boilers for conversion, identifying appropriate cost-estimating methodologies, estimating basic costs for new technologies, developing a process model, analyzing and identifying transportation costs for commercial sources of MCWM and cleaned coal, determining community spillovers, and determining regional market considerations and impacts.

Task 5: The results from each of the tasks will be summarized in a final report. In addition, the design packages for the boiler retrofits will be submitted. These will include the engineering design and economic analysis.

The accomplishments and status of Tasks 1, 2, 3, 4, and 5 are presented in Sections 2.0, 3.0, 4.0, 5.0, and 6.0, respectively. Section 7.0 discusses miscellaneous activities that were conducted. Activities planned for the next semiannual period are listed in Section 8.0. References, acknowledgments, and selected nomenclature are contained in Sections 9.0, 10.0, and 11.0, respectively. The project schedule is given in Figure 1-1, with a description of the milestones contained in Table 1-1.

2.0 TASK 1: COAL BENEFICIATION/PREPARATION

The primary objectives of this activity are, initially, to select appropriate coals which can meet the specific requirements of the project and to prescribe the necessary cleaning steps. Longer-term objectives are to develop improved cleaning procedures which can be used to increase the yield of usable coal and to expand the reserve base of potential candidates for retrofitted boilers.

2.1 Subtask 1.1 Identify/Procure Coals

The Mineral Processing Section, with assistance from AMAX, selected a preliminary set of six candidate coals. The test coals are listed in Table 2-1. The principal selection criteria used were as follows:

Availability. The test coals were selected from seams containing significant reserves (> 300 million tons) and currently operating mines - See Table 2-1. Proximity to potential technology-demonstration boilers was also taken into account. Thus, coals I-1 and II-3 are within 350 and 100 miles, respectively, of Crane, IN; II-2, II-3, III-1 and III-2 are located within 200 miles of New Cumberland, PA and within 350 miles of Dover, DE. (See Section 5.1 for a discussion of the boiler selection.)

Quality. Test coals have been selected which fall into three broad categories based on relative ease of preparation to meet project specifications, *i.e.*, less than 5.0 wt. % ash and 1.0 wt. % sulfur; more than 30.0 wt. % volatile matter. The objective is to demonstrate the extent of the potential reserve base of coals which could be used in DOD facilities. The three categories are:

- Type I - coals which can meet the specifications at high yield with little or no cleaning.
- Type II - coals which can be cleaned by conventional means and can meet the specifications at fairly high yield.
- Type III - coals which can be cleaned to meet the specifications but only at low yield using conventional cleaning technology.

The classification of each of the test coals is indicated in Table 2-1. More detail on cleaning requirements is given in Table 2-2. It is expected that the Type I coal will be used in Subtask 1.6 to produce fuel for the performance evaluation in the demonstration boiler (Subtask 2.3).

Laboratory-scale quantities of CWM will be produced in Subtask 1.3 from Type II and III coals for testing in the research boiler (Subtask 2.2). These will also be used in the development of advanced coal cleaning procedures to be conducted as part of Subtasks 1.3 and 1.4.

CWM Characteristics. The test coals were selected from coal seams for which there is existing information and actual experience on CWM formulation and preparation. This information is summarized in Table 2-3. More complete data will be generated on the actual samples and will be used to provide the basis for the grinding studies to be conducted under Subtask 1.3.

Samples of these test coals are currently being procured for further evaluation.

2.2 Subtask 1.2 Determine Liberation Potential

No work was scheduled or performed on Subtask 1.2 during this reporting period.

2.3 Subtask 1.3 Produce Laboratory-Scale Quantities of Micronized Coal-Water Mixtures

To achieve the desired target of <5.0 wt. % ash and <1.0 wt. % sulfur in the clean coal product, a strategy of combining several stages of operation will be used. The importance of advanced cleaning becomes clear if one looks at the quality of coal delivered to electric utilities. In 1987, the last year for which comprehensive data are available, the average ash and sulfur contents of coal receipts at electric utilities of 50-Megawatt or larger was 10.5% and 1.9%, respectively, for

bituminous coals. These data show that a considerable improvement in coal cleaning technology is needed, if the goals of this project are to be met.

The production of premium coal for use in the preparation of CWM requires the removal of a large fraction of the mineral matter, including pyritic sulfur, from the raw coal. To obtain adequate liberation of the clean coal from the mineral matter, grinding to top sizes of 0.15 mm (100 mesh) and finer will usually be required. However, to take advantage of the liberation, a cleaning technology must be used, which is not only capable of processing such fine material, but can do so economically. For this reason, physical beneficiation processes such as flotation, selective agglomeration, and gravity concentration are the only viable options for near-term application. At the present time, flotation is the only one of these processes that is being used commercially to treat -100 mesh coal.

Evaluate Fine Gravity Separations

Although flotation is quite effective in recovering fine coal and rejecting mineral matter impurities, it is not applicable to all coals (*e.g.*, oxidized coal); it requires chemical reagents; and, it is not always effective in rejecting pyritic sulfur. Similar problems are found for separations involving selective agglomeration, though not necessarily for the same coals. A gravity-based, fine-coal cleaning technique would provide an effective alternative for processing those coals not amenable to flotation or selective agglomeration. Gravity concentration processes are especially attractive since they are not affected by the surface properties of the coal and are particularly effective in rejecting pyritic sulfur because of its very high density.

Gravity concentration processes include water-only devices such as jigs, tables, spirals, and hydrocyclones, and dense-medium devices such as baths and cyclones. In gravity concentration, particles of mixed sizes and densities are separated from each other due to the differential settling of the particles in water under the influence of gravity or a centrifugal force. The same separating principles apply to dense-medium processes although in this case, a suspension of fine solids (typically magnetite) and water is used. Dense-medium processes are capable of making separations over a wide range of relative densities and can be controlled with considerable precision, making them the preferred approach for cleaning coals containing large amounts of near-gravity material. Furthermore, these are the only processes which are capable of making separations at very low (~ 1.30) relative densities, an important capability when attempting to meet the low-ash, low-sulfur requirement for preparing the coal to be used in CWM.

For an ideal separation, all of the coal that is lighter than the relative density of the medium would report to the clean-coal stream, while the remaining material would report to the refuse stream. Such a separation can be represented by a vertical line or a step function passing through the relative density of the medium as shown in Figure 2-1. This figure, referred to as a distribution or partition curve, shows the fraction of feed material of a given relative density that

reports to the clean coal for a particular size fraction. When performing float/sink separations (*e.g.*, a washability study) in the laboratory using heavy liquids, nearly ideal separations are obtained. Hence, the curves generated from this study are referred to as the theoretical curves since they represent the best separation (*i.e.*, highest yield at a given ash) that can be obtained at a certain relative density. For commercial operations, ideal separations are never obtained due to process inefficiencies (*e.g.*, mixing), however, when cleaning coarser size fractions of coal by dense-medium processes, separations approaching ideal can be obtained, and the amount of misplaced material is minimal (Figure 2-1).

As the size fraction of coal being processed decreases, the separation efficiency also decreases, as indicated by a flattening of the partition curves (Figure 2-2). This separation inefficiency is typical of gravity concentration processes and is a function of the physics of the separation process (Klima and Luckie, 1989). At the present time, commercial preparation plants are cleaning coal down to 0.6 mm (28 mesh) and in some cases, 100 mesh, using dense-medium cyclones. The processing of finer coal has not been done, primarily because of the decrease in cyclone performance with decreasing particle size.

Cyclone Separations

In an effort to extend the size range of coal treated by dense-medium separation, a micronized-magnetite cycloning process was developed at the U.S. Department of Energy's Pittsburgh Energy Technology Center (Klima et al., 1991). This process entails the use of an ultrafine (micronized) magnetite and water mixture as the separating medium in a cyclone for cleaning fine coal. It differs from commercial dense-medium cyclone operations in that the magnetite is much finer in size consist. For example, the finest magnetite grade from one commercial supplier is nearly 100% <45 μm , with about 15% <5 μm , while micronized magnetite is approximately 100% <10 μm , with over 60% <5 μm . The fineness of the micronized magnetite not only allows finer coal particles to be processed, but it also allows a higher number of "g's" to be employed during the separation. The result is a process that is capable of achieving separations of particles down to 38 μm (400 mesh), which is not possible with current dense-medium cyclone technology.

Since deep cleaning for the preparation of CWM will typically require the coal to be ground to top sizes of 100 mesh or finer to achieve liberation, a large fraction of the coal would be less than 400 mesh. Previous research has shown that the performance of micronized-magnetite cycloning decreases to such an extent that processing much below 400 mesh may not be possible (Klima and Killmeyer, 1991). To improve the separation efficiency in the finer size fractions, it is necessary to increase the effective "g"-force acting on the particles. One method of increasing the magnitude of the "g"-force in a cyclone is to increase the volumetric flow rate. The number of "g's" at some diameter, d , within the cyclone, can be estimated by (Zanker, 1977):

$$N_g = \frac{27.4 D_i^2 Q_i^2 (D_c)^{2n+1}}{A_i^2 D_c^3 g} \quad (2-1)$$

where D_i = cyclone inlet diameter, D_c = cyclone diameter, Q_i = cyclone volumetric flow rate, A_i = inlet area, g = gravitational acceleration, and n = constant usually between 0.5 and 0.8. It can be seen from Equation 2-1 that increasing the cyclone flow rate, Q_i , for a fixed cyclone geometry, will increase the "g"-force, which should improve the overall separation. This was the case for the micronized-magnetite cycloning separations (Klima and Killmeyer, 1991). However, in other cases, it was found that an increase in the number of "g's" had only a minimal effect on cyclone performance (King and Juckes, 1984) or actually caused a deterioration in performance (Chedgy et al., 1986).

Two explanations could be offered for these apparent discrepancies. In the first case, an increase in the "g"-force will increase the size classification of the magnetite within the cyclone. This results in potentially large relative density differentials between the clean coal and the refuse streams, which in turn can impact cyclone performance. This problem can be overcome by the use of ultrafine magnetite. The work by DOE had shown that the differential between the relative densities of the overflow and underflow streams was less than 0.1 when using micronized magnetite, compared to values typically >0.3 when conventional magnetite was used.

The other explanation is related to the variable interactions that occur whenever Q_i is increased. When the flow rate is increased, the retention time decreases since

$$t = \frac{V_c}{Q_i} \quad (2-2)$$

where V_c is the internal volume of the cyclone. In addition, the level of mixing would be expected to increase with an increase in the flow rate. In fact, an equation for estimating a mixing coefficient in a cyclone is given by (Schubert and Neesse, 1973)

$$D_m = 3 \times 10^{-3} Q_i \frac{D_i}{A_i} \quad (2-3)$$

where A_i = inlet area. Also, a change in the flow rate will also affect the pulp split, which has been shown to change the relative density of separation (Moorhead, 1991). Therefore, in a cyclone, the number of "g's" cannot be increased independently by increasing the flow rate without causing a corresponding decrease in the mean retention time, an increase in mixing, and a change in the pulp split, all of which can offset the expected improvement in separation efficiency (Klima and Luckie,

1990). Furthermore, utilizing smaller diameter cyclones to generate sufficient "g's" is usually not practical for commercial applications due to the reduced capacity of the smaller diameter units. Consequently, an alternative separator is needed to extend the size range of particles that can be processed efficiently by centrifugal separation.

Centrifuge Separations

As an alternative to a cyclone, it should be possible to use a continuous centrifuge as a dense-medium separator, also employing an ultrafine-magnetite/water mixture as the dense-medium suspension. This device offers at least one major advantage over the cyclone for fine-coal cleaning: the ability to control independently the mean retention time and the number of "g's". As with the cyclone, the mean retention time can be increased (or decreased) simply by decreasing (or increasing) the flow rate through the device. However, unlike a cyclone, higher "g's" can be obtained at a constant flow rate by increasing the rotational speed of the centrifuge bowl. The number of "g's" for a centrifuge can be calculated by

$$N_g = 5.5 \times 10^{-3} \frac{D_b N^2}{g} \quad (2-4)$$

where D_b = the bowl diameter and N = rotational speed. Since Equation 2-4 does not depend on Q_i , the separating force can be increased, as required for the efficient separation of fine coal from refuse particles, without decreasing the separation (retention) time. In addition, the amount of turbulence that occurs in a centrifuge should be lower since high inlet pressures are not needed as is the case in the cyclone. Also, by changing the scroll speed, it may be possible to vary the pulp split independently, and hence, regulate the relative density of separation.

At this time, high-g solid-bowl centrifuges are used primarily as dewatering devices in a variety of industrial applications including coal, minerals, and waste-water treatment. They have also been used to perform ultrafine size separations, *e.g.*, in the kaolin industry. These devices are capable of operating at several thousand rpm to generate over 3,000 g's.

Test Plan

The coal to be used for this test work will be from the Upper Freeport or the Pittsburgh seam (*i.e.*, Type III coal) at feed sizes of -100 mesh. The magnetite will be obtained from one of the commercial suppliers and will be classified either dry (by a Donaldson Acucut classifier) or wet (by a classifying cyclone) to produce material of the appropriate size range (*i.e.*, -10 μ m).

For the preliminary centrifuge testing, a "batch" separator, which has been fabricated as part of a related study, will be used. The test unit has a diameter of 152.4 mm and is 152.4 mm long (Figure 2-3). The feed slurry enters at the top of the unit, near the center of the separator. As the slurry moves through the separator, the higher-density and/or coarser solids migrate

towards the bowl wall and are withdrawn by a suction line located near the wall at the bottom of the centrifuge. The lower density and/or finer solids, which settle at a slower rate, are also removed by suction but at a location closer to the center of the bowl. It is expected that density gradients will form along the radius of the bowl, even when micronized magnetite is used. However, by varying the location of the suction points, it should be possible to withdraw lower or higher relative density fractions and hence, change the pulp split, without changing the relative density of the medium. The separator has been mounted to an existing laboratory floor-model centrifuge to provide a means of controlling the rotational speed.

The purpose of the "batch" separator testing will be to examine the movement of solids and liquid in a centrifugal field. The primary test variables for this part of the study include rotational speed (*i.e.*, N_g), volumetric flow rate, and percent solids. Testing is currently being conducted to determine the effect of these variables on the size classification of fine particles. This information will be useful in determining the segregation of the dense-medium solids under various operating conditions. Samples will be taken at each of the conditions to determine the solid and water splits from which the relative density differentials can be calculated. Each of the samples will be analyzed with a Microtrac to determine the product size distributions. The size distributions from one of the centrifuge tests is given in Table 2-4. Although these data are only preliminary, there is indication that size classification can be performed on relatively fine material.

Concurrent with this testing, a continuous high-g, solid-bowl centrifuge will be procured. The testing in the "batch" centrifuge will be used to provide insight into the operating conditions for the high-g unit. The first phase of this task will involve testing a dense-medium slurry to determine the classification effects of the ultrafine magnetite. The key variables include the volumetric feed rate, centrifuge speed, and solids concentration. In addition, the scroll speed will be varied to change the pulp split. As with the "batch" unit, samples will be taken to determine the pulp splits. Subsequent tests will use a dense-medium and coal mixture to determine the separation efficiency when cleaning the -100 mesh coal. Because of the large number of test conditions that are possible, a float/sink separation at a single relative density or an ash and/or sulfur analysis will be performed on the clean coal and refuse products as a screening procedure, thereby minimizing the time expended on heavy-liquid fractionation. The results from this phase will be used to determine the range of operating conditions for the more detailed centrifuge performance testing. Several tests will be run over this range and the partition curves generated for several size fractions.

Computer simulations will also be performed to investigate the effects of design and operating conditions, including media classification, on centrifuge performance. These studies will involve the use of an unsteady-state pulp-partition model to generate partition curves for dense-medium separations (Cho and Klima, 1993). This approach may be useful in directing the

centrifuge testing, thereby minimizing the number of experimental runs needed to determine the optimum operating range.

Evaluate Surface-Based Cleaning Processes

In recent years, several surface-based advanced coal cleaning technologies have been developed, or are in various stages of development. These include:

- Advanced froth flotation
- Spherical or selective agglomeration
- Column flotation

These methods will be used, individually or in combination, to accommodate a wide variety of coals from different sources.

There are several ways to increase the recovery and grade of coal. These include the use of small bubbles, aggregation of coal particles to increase size, and modification of surfaces to impart greater hydrophobicity. All these effects are likely to increase the rate of flotation. At present, the work is being directed towards achieving the following:

- enhanced separation efficiency of fine particles;
- determining the effect of oil droplet size in froth flotation; and
- determining the effect of bubble size in column flotation.

To evaluate the flotation results, studies of flotation kinetics are being carried out and the approach being taken is discussed in the following paragraphs.

Flotation Kinetics Models

The kinetics of flotation are necessary for the design of a flotation circuit. Even though the rate of flotation of coal has been studied extensively there is not general agreement on the models which should be used. Various investigators have been unable to select an appropriate model to describe the laboratory data for kinetics of coal flotation. Since such data are essential for scale-up, studies have been initiated to address this issue. Normal practice is to use a kinetic model to fit the coal yield data. Two types of models have been considered in the past:

- **Phenomenological Models:** These models consider the process of flotation as analogous to a chemical reaction or other rate processes.
- **Microscopic Models:** In these models the sub-processes occurring in the flotation cell, such as bubble-particle collisions, attachment, and detachment, are considered.

While microscopic models provide a detailed insight into the processes that are occurring in the flotation cell, phenomenological models are simpler and adequate for scale-up and design. They are also suitable for evaluating the effect of various operating variables in laboratory experiments. Dowling et al. (1985) evaluated several models, and found that all the models tested gave a reasonably good fit to the experimental data. Though some models were better than others, the hierarchy of best models was expected to be a function of the material being floated. Since a suitable model is essential for the evaluation of flotation kinetic data and to use the results for

design and scale-up, a continuing effort is needed in the areas of model evaluation and development. Therefore, several models were considered for this project and a few were selected for further evaluation. The criteria used were as follows:

- Minimum number of parameters to obtain a reasonable goodness of fit.
- Physical meaning of the model parameters. This aspect was deemed important for interpreting the effect of various operating variables on flotation performance.

On the basis of the literature survey, the following three models were selected for initial evaluation:

Model I: Classical First-Order Model

Model II: First-Order Model with Rectangular Distribution of Floatabilities

Model III: First-Order Model with Sinusoidal Distribution of Floatabilities

Model I: Classical First Order Model. This is the basic model in which the flotation process is considered analogous to a first-order chemical reaction. The model is well known and used by many investigators to describe the kinetics of flotation in a laboratory cell. The mathematical form of this model can be written as:

$$R = R_{\infty} [1 - \exp(-k_1 t)] \quad (2-5)$$

where R is the recovery at time t , R_{∞} is the recovery after a long time (ultimate recovery) and k_1 is the first-order rate constant.

Model II: First-Order Model with Rectangular Distribution of Floatabilities. This model was suggested by Huber-Panu et al. (1976) and Klimpel (1980) by considering a rectangular distribution of the rate constant in the first-order model. The mathematical form of this model may be written as:

$$R = R_{\infty} [1 - (k_{II} t)^{-1} \{1 - \exp(-k_{II} t)\}] \quad (2-6)$$

where k_{II} is the first order rate constant. This model was also derived by Meyer and Klimpel (1984) by considering the effect of the mechanical rate of froth removal from the cell.

Model III: First-Order Model with Sinusoidal Distribution of Floatabilities. This first-order model was suggested by Fuerstenau in which a sine function is considered to describe the distribution of floatabilities. The mathematical form of this model may be written as:

$$R = R_{\infty} \left[1 - \frac{1 - \left(2k_{III} \frac{t}{\pi}\right) \exp(-k_{III} t)}{1 + \left(2k_{III} \frac{t}{\pi}\right)^2} \right] \quad (2-7)$$

where k_{III} is the first order rate constant.

Flotation Kinetics Results

Studies conducted as a part of this project show that the statistics of fitting Model I improved considerably when the flotation products were screened and analyzed individually, as can be seen from the results given in Figure 2-4 and Table 2-5. For the purpose of illustration, Model I was used to fit the flotation kinetic data. Evaluation of other models is in progress. This method is a compromise between the traditional method of analyzing the flotation products collected at pre-selected time intervals and a more elaborate method in which size-specific gravity fractionation on flotation products is done followed by analysis of individual fractions. The traditional method is well known and was used recently by researchers at the University of California, Berkeley, as part of a project sponsored by the DOE. The second approach was developed and used by Penn State's Mineral Processing Section (R. Hogg and S. Chander) as part of a project also funded by the DOE. The first approach is not very satisfactory because the model discrimination is often poor whereas the second provides more details but requires laborious experiments and data analysis. It should be noted that the size fractionation approach was used by Lay and Bell (1962), Rastogi and Aplan (1985), and later by others. Even though the method has been known for many years, its statistical advantages have not been discussed and it has not been used extensively in coal flotation research.

In the approach used in the present investigation, various flotation products were screened and the screen fractions were dried and weighed. The results were used to calculate the yields from which the rates of flotation of the individual size fractions were determined. The ash and sulfur analyses are also being conducted and will be reported later. The results are given in Figure 2-4 for a hvA bituminous coal from the Upper Freeport seam. The symbols represent the measured data and the lines were obtained by fitting the model. Figure 2-4a is for the unscreened material and Figure 2-4b is for various screen fractions. A careful examination of the experimental data and fitted results in Figure 2-4a shows a certain amount of 'systematic' error. The goodness of fit can be determined by examining the statistical data for fitting the model which are given in Table 2-5. With Model I, the results were better when the model was fitted to individual size fractions as can be seen from the value of r^2 and MRS (mean residual squares). There was one exception, however, in that the -400 mesh fraction which gave larger errors. The reasons for this are being investigated.

Even though the effects of particle size and collector concentration on the rate of flotation and ultimate recovery appear to be reasonable, these results are considered to be preliminary until the validity of this approach has been tested using other models and tests with additional coal samples.

Enhanced Separation Efficiency of Fine Particles

To meet the target ash and sulfur contents of the clean coal, micronization of coal followed by cleaning at fine sizes will be necessary. Fine grinding of coal is often necessary to achieve the liberation of coal from sulfur-bearing and ash-forming minerals. The extent of grinding required will vary, of course, with coal rank and seam. Since the separation efficiency of traditional methods of separation decreases with decrease in particle size, studies will be conducted to improve recovery and grade of coal by surface based separation processes. Dodecane was selected as a model collector as it closely resembles #2 fuel oil, which is commonly used in coal flotation. This substance was used as a model collector in recent studies on coal flotation, sponsored by the DOE. Since the data on emulsification of dodecane are meager, especially in the presence of surfactants and coal, the study has been started by investigating the kinetics of emulsification of oil. The results are discussed in the paragraphs that follow.

Effect of Oil Droplet Size in Froth Flotation

Although the beneficial effects of pre-emulsifying the fuel oil collector, commonly used in froth flotation of coal, are well known, sufficient quantitative data are not available to relate drop size to performance. The role of oil is likely to become even more important for the cleaning of coal at fine sizes. In a recent investigation Chander et al. (1993) observed a correlation between the emulsifying power of the surfactant and the flotation of a low rank coal. The behavior of a high rank coal will be investigated in this study. Since emulsion drop size is an important variable, measurements were made as a function of surfactant concentration. The experimental set-up is shown in Figure 2-5 and the drop size is given as a function of time in Figure 2-6. Since oil droplets act as collectors for coal particle, their number and size will have a direct influence on the flotation performance. Flotation studies will be conducted in the presence of various types and concentrations of surfactants and oil and the emulsification results will be of assistance in interpreting the results of the cleaning processes in which oil is used.

Column Flotation

A flotation column is a bubble column device in which separation between disperse phases is achieved using differences in their affinity for air bubbles. The concept of column flotation was first developed and patented in the mid 1910s by Flinn and Towne (Gahl, 1916). However this early design was not commercially successful as it was plagued by solid settlement on the gas distributor. The success of the Boutin and Wheeler design of a flotation column that was patented in the early 1960s (Anon, 1965) is attributed in part to its ability to overcome the solid settlement problem on the gas distributor.

At present, flotation columns are employed in a number of applications in the mineral processing industry (Dobby and Finch, 1986). Indeed flotation columns have been found to be effective in fine coal cleaning (*e.g.*, Bensley et al., 1985; Luttrell et al., 1988; Parekh et al., 1990).

In spite of the considerable research efforts and industrial applications of column flotation in the last seventy seven years, the design and scale-up of flotation columns remains an empirical art. For example, all present designs are based on the use of analogy with chemical kinetics. According to this approach, the rate of recovery of hydrophobic particles in the collection zone may be represented as a first order rate process. Thus, only the Damkohler number, k'_p , and the mixing parameters of the process vessel or age distribution of the particles, are required for design and scale-up. Accordingly, the recovery is given by:

$$(1-X) = \frac{4q \exp\left(\frac{Pe_p}{2}\right)}{\left\{ (1+q)^2 \exp\left(\frac{Pe_p q}{2}\right) - (1-q)^2 \exp\left(\frac{-Pe_p q}{2}\right) \right\}} \quad (2-8)$$

where X is the recovery factor and q is defined as

$$q = \left(\frac{1+4k'_p \tau_p}{Pe_p} \right)^{0.5} \quad (2-9)$$

In Equation 2-8, Pe_p is the particle Peclet number, a measure of the particle mixing intensity in the sedimentation dispersion model. Some issues about this approach were recently raised by Ityokumbul (1992 a,b) which may lead to new perspectives in the design of flotation columns. Firstly, the use of Equation 2-8 in flotation column design and scale-up is predicated on the validity of the sedimentation-dispersion model in providing an accurate description of the solid particle behavior in the column. Unfortunately, solid tracer analysis using the sedimentation-dispersion model has consistently shown that the particle mixing intensity increases with size and in most instances, may even be larger than the corresponding value for the liquid (Mills and O'Connor 1990; Mills et al. 1992; Xu and Finch, 1992). Since the larger particles have a higher inertia, it is highly unlikely that they will be more mixed than the smaller ones under the same flow conditions. For the same reason, the dispersion coefficient of the solid particles cannot be larger than that of liquid molecules under the same flow condition. As indicated above, the results from the sedimentation-dispersion model are at variance with physical reality. The reasons for this observation (*i.e.*, increased mixing with particle size) have been provided by Ityokumbul (1992a) and will not be repeated here. Suffice it to say that it clearly demonstrates that the sedimentation dispersion model does not provide an accurate description of the particle behavior in flotation columns. Ityokumbul (1992c) has recently shown that the behavior of solid particles in a flotation column may be described using the sedimentation-convection model.

Secondly, Equation 2-8 predicts that the recovery should be independent of the initial concentration of floatable particles. This is clearly not the case in flotation, especially at high concentrations for which the column carrying capacity is limited. Furthermore, Equation 2-8 suggests that increased mixing may result in lowering of the recovery. For a typical column application (where slugs of air bubbles are absent), intimate contact between the air bubbles and the hydrophobic particles is indeed required for separation to take place. This intimate contact only comes about as a result of mixing of the liquid phase which contains the hydrophobic particles. To fully understand this, imagine trying to affect liquid-liquid extraction (and other interfacial phenomena) without intimate contact between the phases. It is that fundamental. In fact the results of Espinosa-Gomez et al. (1989) clearly indicate that with lead/zinc separation, the recovery/grade performance increases with mixing intensity.

In view of the inadequacies inherent in the present approach to flotation column design, a new approach based on fundamental principles was recently presented in the literature (Ityokumbul, 1992 a,b). The use of this approach to determine key design and scale-up parameters for column flotation has also been demonstrated (Ityokumbul, 1993) and will form the basis for the analysis of the flotation data in the present study.

Theory

The new approach to flotation column design is based on the consideration of the bubble loading rate, since it is this process that results in the separation. While the detailed theoretical formulation may be found elsewhere (Ityokumbul, 1992 a,b), it was shown that the performance equation is given by:

$$z = \frac{(U_R + V_p)}{ak\Gamma_m (-\ln(1-X))} \quad (2-10)$$

where z is height of the recovery zone required for a given recovery, X , a is the bubble interfacial area, k is the particle transfer rate constant, Γ_m is the maximum bubble load, U_R and V_p are the slurry velocity in the recovery zone and particle settling velocity, respectively. In Equation 2-10, the terms $k\Gamma_m$, $(U_R + V_p)/ak\Gamma_m$ and $-\ln(1 - X)$ are equivalent to the interface mass transfer coefficient, height of a transfer unit, HTU, and number of transfer units, NTU, respectively. As with other mass transfer operations in chemical engineering, the HTU is a measurement of the difficulty of separation. A brief discussion of this follows. The maximum NTU cannot be varied at will. It is determined by the maximum recovery which is a function of the degree of liberation of the mineral, reagent dosage, hydrophobicity of the particles, etc. The validity of this approach has been tested using literature data from a variety of applications (coal and mineral flotation in columns of different sizes). In addition, this approach has for the first time succeeded in

demonstrating the detrimental effect of using excessively tall columns in some applications (Ityokumbul, 1992b; 1993).

As previously indicated, the term $(U_R + V_p)/ak\Gamma_m$ is a measurement of the difficulty of the separation. It follows from this that the difficulty of separation increases with increasing slurry velocity in the recovery zone and increasing particle size. Intuitively, this is indeed a valid observation as the effect can be explained on the basis of reduced particle residence time in the recovery zone. The height of the transfer unit is inversely proportional to the quality of the air dispersion in the system (through the interaction of a and to some extent, Γ_m). This is also a reasonable assumption insofar as flotation is an interfacial phenomenon: increasing the quality of air dispersion results in an increase in the bubble surface area available for flotation. The failure of the first column installations at Inspiration Copper Company was attributed to solid settlement on the gas distributor. Since bubble coalescence was reported with solid settlement on the gas distributor, it is obvious that the available bubble surface for particle collection was reduced resulting in an increase in the HTU. It is obvious from the foregoing that knowledge of bubble characteristics (size, gas hold-up) will be required for the interpretation of flotation data. Unfortunately, information on bubble characteristics is hardly ever reported with flotation data. This makes comparison of flotation results in different vessels and/or with different spargers very difficult.

A comparison of estimates of the HTU from a number of applications in columns of different sizes was made recently and is summarized in Table 2-6. The results obtained indicated that coal cleaning generally gave lower HTUs in comparison to minerals made selectively hydrophobic (Ityokumbul, 1992b). This observation is expected since coal is naturally hydrophobic. From the data in Table 2-6, it is estimated that the maximum collection zone height required for coal cleaning should not exceed 2 m. This probably explains why Parekh et al. (1990) did not observe any dependence of recovery on column height in the range 3-8 m.

Experimental Plan

The laboratory flotation column that is under fabrication at Penn State is a 3" (i.d.) column. Owing to its sectionalized nature, its height can be easily varied. The variation in recovery zone height is required for the estimation of particle transfer constants in the new mass transfer approach to column analysis. For example, the data obtained from this variation may be used in the determination of the ultimate recovery and the minimum column height required to achieve it. This information is obtained from a plot of $z/\ln(1-X)$ vs z (see Figure 2-7 for fluorite flotation). According to the new theory for analyzing flotation column data, the minimum recovery zone height is determined from the change in the slope while the terminal recovery is estimated from the slope of the line drawn from the origin to the minimum recovery zone height. For the fluorite case, it can be seen that the minimum recovery zone height is about 1.7 m, while the terminal recovery is

estimated to be 92%. While the staging observed in Figure 2-7 is a direct indication of the increasing difficulty of the separation, it should be noted that the terminal recovery estimated by this new method remains the same. For the case of coal flotation, recovery zone heights beyond this level will not result in increased recoveries as the data of Bensley et al. (1985) clearly demonstrate. A detailed discussion of the use of this technique for the determination of column design parameters may be found elsewhere (Ityokumbul, 1993).

The preceding analysis has shown that the quality of the air dispersion will have a strong effect on the column performance. Thus, the availability of bubble surface does represent a useful design and scale-up parameter. It is for this reason that the bubble size and gas hold-up will be measured in this study. Since it is the air bubbles that are responsible for the particle collection process in flotation, this information will be valuable when comparing the performance of the different gas distributors that will be used in this study. The column bottom is designed to permit interchange of gas spargers. Several different spargers will be tested including the 'vortactor' that is under development at Penn State. The use of the vortactor is particularly desirable since the micronized coal particles in this study will lack the inertia to collide with the air bubbles. To facilitate the particle collection process, the vortactor will be used to promote the contact between the coal particles and air bubbles. These devices have been shown to be effective in increasing mass and heat transfer rates in chemical engineering applications (Berg et al. 1989). The recent results of Amelunxen (1993) clearly support this line of thinking.

In summary, the experimental work will consist of the following phases:

- bubble size/gas hold-up measurements with the different spargers
- recovery/grade data with the different gas spargers
- analysis of the data to determine design parameters (terminal recovery, HTU, etc.)

Stabilization of Coal/Water Suspensions

Overview

The purpose of this part of the project is to obtain an understanding of the hydrodynamic properties of coal/water mixtures with the ultimate goal of obtaining stable coal/water suspensions in which the detrimental effects of coal particle aggregation and sedimentation are eliminated or at least minimized. More specifically, a better understanding is required of how CWM viscosity, sedimentation, and particle aggregation are affected by the coal particle size distribution and concentration, the polymer additives (stabilizers), and the level of coal oxidation.

Initially, work was focused on viscosity and sedimentation. Aggregation is a phenomenon that affects both of these properties and will be considered later as a complication to the simple models that are now being constructed.

Viscosity of Coal-Water Suspensions

There is a wealth of literature on the viscosity and sedimentation of particles suspended in fluids, but most of this, and much of the most rigorously developed theory, describes dilute suspensions. For example, the viscosity of a dilute suspension of spheres is described by the Einstein equation;

$$\frac{\eta}{\eta_s} = 1 + 2.5\phi \quad (2-11)$$

where η is the viscosity of the suspension, η_s is the viscosity of the pure liquid and ϕ is the volume fraction of spheres.

In coal suspensions it is necessary to account for:

- a) The particle size distribution,
- b) The effect of hydrodynamic interactions at high concentrations, and
- c) The effect of interparticle interactions (*e.g.* via Van der Waals forces)

Then, in order to account for additives, oxidation, etc., it is necessary to consider

- d) The excluded volume effect of adsorbed polymer, and
- e) The effect of surface charges introduced as a result of oxidation (*e.g.* formation of carboxylic acid groups).

Although this is a complicated situation, a simple empirical model can provide significant insight. For example, the use of the Dougherty/Krieger treatment, which replaces the η_s term in Equation 2-11 by an effective viscosity η^* and also accounts for hydrodynamic interactions via parameters $[\eta]$ and p , produces:

$$\frac{\eta^*}{\eta} = \left(1 - \frac{\phi}{p}\right)^{-[\eta]p} \quad (2-12)$$

It has been found that $p = 0.57$ at low shear rates, $p = 0.68$ at high shear rates, and $[\eta]$ is of the order of 2.67. It can be seen from Equation 2-12 that the effective viscosity becomes infinite at $\phi \sim p \sim 0.68$. This suggests that for monodispersed slurries of spherical particles, p should be fundamentally related to the value of ϕ found for random close packing. g (~ 0.625). This will be addressed subsequently, but Equation 2-12 produces the plot of viscosity vs. concentration shown in Figure 2-8, and this provides a qualitative description of the behavior of coal-water mixtures.

The Effect of Particle Size Distribution

The initial stages of this work have focused on the effect of particle size distribution on the simple or semi-empirical models described above. An analysis of the particle size distribution of three sample sets reveals that they are roughly log normal (see Figure 2-9). [Note that because of the way the data are obtained, particles below a certain size level are listed as cumulative totals, so the distribution can only be fitted to the extended tails of the curves]. The distribution $\langle r \rangle$ is centered at $3\mu\text{m}$, and the dimensionless weight of the distribution σ is fairly constant for different samples.

The effective viscosity depends on the two parameters ϕ and σ and, in general:

$$\eta^* = \eta \cdot f(\phi, \sigma) \quad (2-13)$$

The function $f(\phi, \sigma)$ must have the following two properties

- (a) It must be infinite as $\phi \rightarrow \phi_m(\sigma)$, where ϕ_m is the volume fraction where the packing is a maximum, for a given particle size distribution σ .
- (b) At $\sigma = 0$ it must produce Equation 2-12 replacing p with ϕ_m .

There are a number of functions satisfying these conditions, but the simplest is a modified form of Equation 2-12;

$$\eta^*/\eta_0 = \left(1 - \phi/\phi_m(\sigma)\right)^{-[\eta]\phi_m(\sigma)} \quad (2-14)$$

Because experiments have shown that ϕ_m is a linear function of σ when the latter is small, it can be proposed that:

$$\phi_m(\sigma) = \phi_{m_0} + \alpha\sigma \quad (2-15)$$

In this equation:

$$\phi_{m_0} = \phi_m(\sigma = 0) = 0.63, \alpha \approx 0.1, \sigma \approx 101.5.$$

It therefore follows that

$$\phi_m \approx 0.7 + 0.8 \approx 0.875$$

This is close to the experimentally observed results.

This approach will be explored in more detail in the next few months, but clearly the initial modeling effort has been successful.

Sedimentation of Coal-Water Slurries

Two problems have been focused on, the dynamics of sedimentation, so that a density profile development can be described, and an equilibrium model, which will be closely connected to penetrometer measurements.

The Dynamics of Sedimentation or Settling

Just as simple equations for the viscosity of suspensions can be modified to account for the effect of hydrodynamic interactions, so can an equation describing sedimentation velocity be modified as follows:

$$V_s = \frac{2a^2g (\rho_c/\rho_o - 1)}{9\eta_{\text{eff}}} \quad (2-16)$$

where again an effective viscosity has been employed. A CWM that is left to stand will, after a certain time, appear as in Figure 2-10, with a middle region that has approximately the same concentration as the initial suspended CWM, while a top layer depleted in particles (labeled water) appears and a bottom layer of randomly close packed particles (packed residue) is also formed. Between these layers would be an interface. If the interface is sharp, then there would be the three distinct layers shown in Figure 2-10. If the interface is broad, then in the limit there is a continuously varying concentration profile. Using some simple assumptions the profile shown in Figure 2-11 has been calculated, which suggests that between the slurry layer and the bottom of the container there will be an almost continuously varying concentration profile, but that above the slurry layer there is a sharp transition to a pure water layer. This type of behavior has been observed qualitatively and experiments are being designed that will allow us to obtain a quantitative description.

Equilibrium density profile

Here the expected density profile *after* equilibrium has been reached is calculated. For a profile $\phi(h)$, where $\phi(h)$ is the volume fraction of coal particles at a height h , it follows from the conservation of mass that

$$\phi_0 H = \int_0^H \phi(h) dh \quad (2-17)$$

where ϕ_0 is the starting volume fraction (assumed uniform) and H is the height of the slurry.

Now, if there is a difference in coal particle concentration between two layers of the CWM, then the variation of osmotic pressure, which will tend to move particles from the more concentrated to the less concentrated zone, must balance the settling force due to gravity. If $\pi(\phi)$ is the CWM osmotic pressure then:

$$d\pi / dh = -c\phi \quad (2-18)$$

$$\text{where } c = g / (\rho_c - \rho_w) \quad (2-19)$$

and g is the gravitational constant and ρ_c and ρ_w are the densities of coal and water, respectively. Hence;

$$-ch = \int_{\phi(0)}^{\phi(h)} \frac{d\pi}{d\phi} \frac{d\phi}{\phi}. \quad (2-20)$$

The initial value, $\phi(0)$, is determined by Equation 2-17. Integrating Equation 2-18, yields

$$\pi(0) - \pi(H) = c\phi_{\text{init}}H \quad (2-21)$$

For dilute solutions $\pi(\phi) = \phi kT/V_0$, where k is the Boltzmann's constant, and V_0 is the particle volume. It is useful to write

$$\pi = (\phi kT / V_0) \Gamma(\phi) \quad (2-22)$$

where $\Gamma(\phi)$ is a dimensionless compressibility factor. If a characteristic length is defined as:

$$L_0 = kT / V_0 c \quad (2-23)$$

then Equations 2-20 and 2-21 yield

$$h / L_0 = - \int_{\phi(0)}^{\phi(h)} (d(\Gamma\phi) / d\phi) (d\phi / \phi) \quad (2-24)$$

and

$$\phi_0 \Gamma(\phi_0) = (H / L_0) \phi_{\text{init}} \quad (2-25)$$

where $\phi(0) = \phi_0$. It must be considered that L_0 is very small. For a typical CWM it is about $\sim 10^{-10}\text{m}$. Therefore $\Gamma(\phi_0)$ must be large ($\sim 10^9$).

Equations 2-24 and 2-25 are the conceptual solutions to the problem, but to apply them it is necessary to know the $\Gamma(\phi)$ function. Models include:

- non-stabilized slurries
- electrically stabilized slurries
- polymer stabilized slurries

At this time only the problem for a non-stabilized CWM has been solved. In this case the following equations can be written for the compressibility factor:

$$\Gamma(\phi) = \begin{cases} \frac{1 = \phi + \phi^2 - \phi^3}{(1-\phi)^3}, & \phi < 0.5 \\ \frac{1.85}{\phi_{\text{close}} - \phi}, & \phi > 0.5 \end{cases} \quad (2-26)$$

The first line corresponds to the Perkys-Yevik approximation, the second one is due to the divergence of $\Gamma(\phi)$ as ϕ is near the close-packing regime ϕ_{close} .

As $\Gamma(\phi_0)$ is large, ϕ_0 must be very close to ϕ_{close} . So $|d\Gamma / d\phi| = 1 / (\phi_{\text{close}} - \phi)^2 \gg \Gamma/\phi$.

Therefore Equation 2-24 gives the following approximate profile

$$\phi(x) = \begin{cases} \phi_{\text{close}}, & h < h_0 \\ 0, & h > h_0 \end{cases} \quad (2-27)$$

If the exponential 'tail' is neglected then:

$$h_0 / L_0 = \Gamma(\phi_0) = H \phi_{\text{init}} / L_0 \phi_{\text{close}} \quad (2-28)$$

and

$$h_0 = H (\phi_{\text{init}} / \phi_{\text{close}}).$$

The profile is shown in Figure 2-12 and the results show that without stabilizer the CWM has completely settled.

This, of course, is to be expected, but the result is not trivial. Any model must produce this result in order to be valid. The model can now be expanded to consider the effect of stabilizers, etc., with some degree of confidence.

2.4 Subtask 1.4 Develop a Dry Coal Cleaning Technique:

TriboElectrostatic Separation

An alternative to wet cleaning is to utilize a dry beneficiation process such as TriboElectrostatic Separation (TES) (Link et al., 1990). This process involves the tribocharging and subsequent electrostatic separation of fine and ultrafine coal particles. The particles are first aerosolized in an air or gas stream and then charged by contacting them with some material such as copper. A common technique is to pass the aerosol stream through an in-line static mixer. The charged (positive) coal particles and charged (negative) mineral matter particles can then be separated electrostatically by passing them over oppositely charged plates. Previous studies have shown that the separations can be made when the plates are operated at a voltage differential of approximately 40 kV at a very low current (<5mA).

Test Plan

For this study, an electrostatic separator, similar to that tested by DOE, has been fabricated and will be used for the initial phase of the testing (Figure 2-13). Variables to be investigated include the coal feed rate, solids concentration, particle size, and plate separation. The results from this testing will establish the baseline operating conditions of the unit. The work by DOE showed that clean coal products with ash and pyritic sulfur contents of <2.0 and <0.3 wt.%, respectively, at yields of more than 40% were obtained when cleaning -400 mesh Pittsburgh and Upper Freeport coals (Link et al., 1990). The goal for this project is to increase the overall yield for each coal, while still producing a clean coal containing less than 5.0 wt. % ash and 1.0 wt. % sulfur.

In addition, equipment for constructing a dry grinding circuit, consisting of an air compressor, jet mill, and classifier is currently being procured. This circuit will provide a means for producing a wide range of particle size distributions for testing and eventually, for integration with the TES unit. A list of the commercial equipment that has been received is given in Appendix A.

2.5 Subtask 1.5 Produce MCWMs and Micronized Coal from Dry, Clean Coal

No work was scheduled or performed in Subtask 1.5 this reporting period.

2.6 Subtask 1.6 Produce MCWM and Dry, Micronized Coal for the Demonstration Boiler

Fuel Preparation Facility

Work on this subtask focused on completing the fuel preparation facility (MCWM and dry, micronized coal) associated with the demonstration boiler (15,000 lb steam/h boiler). The facility is approximately 70% complete. Figure 2-14 is a plan view of the demonstration boiler site. The boiler is located adjacent to Penn State's East Campus Steam Plant (ECSP) in the boilerhouse labeled 'new addition'. Details of the ECSP, demonstration boiler and ancillary components, and a chronology of Penn State's previous efforts in coal-water slurry fuel research can be found elsewhere (Miller et al., 1993a; Miller and Scaroni, 1990 a,b). In addition, the baghouse, the 15,000 gallon MCWM storage tank, the MCWM transfer station, the diagnostics laboratory trailer, and the future emissions control systems site are shown in Figure 2-14.

A schematic diagram of the equipment train in the fuel preparation facility is shown in Figure 2-15. There are two circuits in the facility, one for producing dry, micronized coal and one for producing MCWM.

Dry, Micronized Coal Preparation Circuit

The dry, micronized coal preparation circuit is nearly complete. The 50-ton coal hopper, reddler elevator, 5-ton surge bin, screw feeder, and TCS mill (pulverizer) have been installed. The booster fan which will be used to pneumatically convey the coal from the mill to the burner is being procured.

MCWM Preparation Circuit

Work is currently underway setting up the MCWM preparation circuit. The 50-ton coal hopper, reddler elevator 5-ton surge bin, and screw feeder are common to the dry, micronized coal and MCWM circuits. The ball mill has been delivered, cleaned (a used mill was procured), and painted. It is being modified slightly in that the motor is being relocated to underneath the mill due to space constraints. After this has been completed, the ball mill will be installed (leveled and anchored) and associated piping and pumps will be installed.

The MCWM preparation circuit includes several moyno progressive cavity displacement pumps, a 30-inch screen, several tanks (process, blend, waste water), a sand mill, and a filter press. The pumps and sand mill were donated by CE, as part of the cost-sharing component of the program, and were part of their pilot-scale coal-water mixture preparation facility. Penn State personnel inspected each piece of equipment, disassembled it, and determined its operability. Equipment that was in working condition was cleaned, reassembled, and painted. A list of the equipment that have been reconditioned is detailed in Appendix B.

The goal of the overall site (boiler and MCWM preparation facility) is for it to be a zero-discharge facility. Consequently, a filter press is being procured to process waste water. This

includes water that is generated from flushing lines, off-specification MCWM, and water used to clean the facility (equipment and floors). The solid material will be removed from the water and the water will be reused in the production of MCWM.

3.0 TASK 2: COAL COMBUSTION PERFORMANCE

3.1 Subtask 2.1 Boiler Retrofit

Work was initiated on this subtask. CE will provide a single High-Efficiency Advanced Coal Combustor (HEACC) modified to accommodate both MCWM and MC, as well as the natural gas support fuel required to start up and transit from natural gas to MCWM or MC. This burner will be installed on Penn State's 15,000 lb steam/h demonstration boiler for evaluation and optimization. The burners to be designed for the DOD retrofit will not be capable of firing both MCWM and PC in conjunction with support fuels (natural gas and/or heavy fuel oil). Rather, the retrofit burners will be designed to fire either MCWM or PC with the capability of firing natural gas and/or heavy fuel oil.

The burner is being designed to the following target specifications:

- > 98% carbon conversion;
- > 3:1 burner turndown;
- > 4,000 hour atomizer tip life;
- excess air < 30%;
- combustion air preheat required < 400°F;
- capable of sustaining combustion without support fuel;
- burner pressure drop < 8 in. W.C.;
- maximum droplet diameter and droplet volumetric median diameter of 300 and 80 μm , respectively (when firing MCWM);
- capable of air or steam atomization (when firing MCWM);
- atomizing air/fuel ratio < 0.15 (when firing MCWM);
- CO emissions < 200 ppm; and
- NO_x emissions < 475 ppm.

3.2 Subtask 2.2 Fuel Evaluation in the Research Boiler

In this subtask, candidate fuels will be evaluated in Penn State's 1,000 lb steam/h research boiler. Details of the boiler and auxiliary components are contained in Appendix C.

During this reporting period, no combustion tests were performed; however, the research boiler system was overhauled. Components were modified (*e.g.*, quarl, micronized coal feed), repairs were made (*e.g.*, micromotion MCWM flow meters), and the system was repainted.

Figure 3-1 is a schematic diagram of the end and side views of the modified quarl section. The quarl is used to maintain flame stability when firing coal-water mixtures into the natural gas/oil-designed boiler. The original quarl design is shown in Figure C-2. The major modification is that the tertiary air is now staged through two sets of three ports (for a total of six ports) located tangentially at the top and bottom of the quarl, whereas the previous design introduced the tertiary air through four ports located at 90° intervals.

The research boiler has pulverized coal firing capabilities which were also modified. Modifications included mounting the hopper and screw feeder on a load cell and changes to the eductor and piping. A general layout of the system is shown in Figure C-1.

3.3 Subtask 2.3 Performance Evaluation of MCWM and Dry, Micronized Coal in the Demonstration Boiler

Evaluate Erosion/Deposition Characteristics

The objective of this portion of the subtask is to obtain a better understanding of the fundamental mechanisms of erosion, corrosion, and deposition of ash and char particles in the convective pass of an industrial-package boiler. The work is an expansion of a study that was conducted in a previous DOE program in which a superclean coal-water mixture (~3.5 and <0.9 wt.% ash and sulfur, respectively, in the coal) was fired in the demonstration boiler. The work will address identifying the erosion and deposition regimes and matching simultaneous erosion and deposition phenomena. During the two 1,000-hour tests to be conducted on the demonstration boiler, the heat transfer performance will be determined, a procedure for determining optimum convective section gas velocity will be developed, and the performance of three tube materials will be compared.

Reported here are highlights of the work completed on erosion-corrosion modeling for carbon steel in the convective section of the demonstration boiler (Miller et al., 1993b) when firing a coal-water mixture. Application of the model to boilers which are candidates for retrofitting to MCWM is emphasized. Erosion is expected to be less than 50 nm/hour if gas velocities are kept below 12 m/s, under the conditions of temperature, gas composition, particle composition, and particle concentration investigated for superclean coal-water fuel combustion.

Experimental

The measurements were made in the convective section of the demonstration boiler while cofiring superclean coal-water slurry fuel and natural gas. At the location of the measurements, the convective section gas velocity was 4.0 m/s, the flue gas temperature was 850 K (1,070°F), and the particle concentration was 2.7 g/m³ (calculated).

Previous work on the development of the methods used in the present investigation is described by Walsh and coworkers (1992; 1993). The probe is shown in Figure 3-2. Specimens, cut from 25.4 mm O. D. ASTM 192 carbon steel tube, were mounted in the 38 mm long cutout portion of the probe, as indicated in Figure 3-2. The composition of the tubing from which the samples were obtained was (wt. %): C, 0.08; Mn, 0.42; P, 0.027; S, 0.017; Si, 0.030; Al, 0.048; and Fe, balance. A flat area, 38 mm x 10 mm, was machined on the outside of each test piece and polished so that the roughness was less than 0.05 μ m. The ends of the specimen were covered with graphite tape and held in place on the probe by hose clamps. The tape was intended to preserve some of the polished surface and provide a reference height for the profile measurements.

A small gas jet, which entrained flue gas and particles, was oriented with its axis perpendicular to the polished area of the test specimen. The jet orifice, having an inside diameter of 1.7 mm, was located at a distance of 13.5 mm from the sample surface. The initial jet gas velocity was fixed at 200 m/s. The radial distributions of the impaction velocity, flux, and energy, and the impaction angle of the particles at the target surface were determined by summing the contributions from large numbers of particles for each size present in significant concentrations in the flue gas. The computation procedure has been previously detailed (Miller et al., 1993b). Typical results for particles with diameters of 1, 20, and 120 μm are shown in Figure 3-3.

The parameters varied during the tests were jet gas oxygen content (0, 21, and 100 vol % O_2 in N_2) and metal temperature (450, 550, and 650 K). The temperature of the target was measured using two thermocouples located in recesses drilled into the back side of the sample, one on the axis of the jet and the other 10 mm away, as shown in Figure 3-2. The difference in temperature indicated by the thermocouples was 10 K for the highest sample temperature. Each sample was exposed to the effects of the high velocity jet, entrained flue gas, and particles for 2 hours.

After each test, the shape of the surface of the sample was measured using a profilometer and the erosion craters and surface structure were examined using a scanning electron microscope. Energy dispersive x-ray analysis was used to distinguish metal and oxide scale from fly ash deposited on the surface.

Erosion profiles observed from the experimental results show good agreement with the impaction energy distribution shown in Figure 3-3. Maximum erosion occurred at a location 1.5–2.0 mm from the jet axis where the impaction energy is highest. The erosion rates measured at this location are shown in Figure 3-4. In the nitrogen jet, the erosion rate increased with increase in metal temperature. In the presence of air as the jet gas, the erosion rate first increased, then decreased with increasing metal temperature. Under the oxygen jet, the maximum erosion rate remained at 0.6 $\mu\text{m}/\text{h}$ for all three metal temperatures.

Erosion-Corrosion Model

In order to make the connection between the accelerated erosion measurements (due to the high gas velocity) and the erosion expected in a boiler under long-term normal operating conditions, an erosion-corrosion model has been developed. The model is intended for conditions under which surface erosion and oxidation occur at comparable rates. The impacting particles are allowed to interact with the growing oxide scale in various ways. Depending upon the severity of the particle impacting with the surface, the thickness of the oxide scale, and the properties of the metal substrate, the erosion event may lead to the removal of fragments of the oxide scale, to the shedding of the oxide at the oxide-metal interface, or to the removal of substrate metal.

The scale thickness attained in a time interval t_i , between successive particle impacts is

$$x_i = [(z+1) k_o t_i]^{\frac{1}{z+1}} \quad (3-1)$$

where x_i is the thickness of oxide scale, k_o is the oxidation rate constant, and z is the order of the oxidation kinetics ($z=0$, linear kinetics and $z=1$, parabolic kinetics).

Many studies have been made of the rate of oxidation of iron at elevated temperatures. It is generally agreed that the growth of oxide scales on iron follows a parabolic rate law, while considerable disagreement exists in the literature as to which oxide species are stable in the temperature range of interest. The discussion here will focus on the temperature range below 570°C, and magnetite is assumed to be the major component of the oxide scale. Under such conditions, a parabolic rate constant was obtained in the experimental work of Davies et al. (1951)

$$k_o = 1.8466 \times 10^{42} \exp\left(-\frac{780,000}{R T}\right) \quad \text{m}^2/\text{s} \quad (3-2)$$

If each impacting particle penetrates the growing oxide scale to the metal substrate, erosion losses are most likely to consist of composites of the oxide and metal. A reverse rule of mixtures was found to be in good agreement with a series of erosion processes, where one component must first be removed before the second can be eroded (Hovis et al., 1986). Using this rule for the erosion of the oxide/metal composite, the total loss of surface volume is given by:

$$\frac{1}{E_t} = \frac{1-f}{E_d} + \frac{f}{E_b} \quad (3-3)$$

where f is the volume fraction of the oxide scale in the eroded mixture and E_d and E_b are the erosion losses of ductile metal and brittle oxide, respectively, by the same impact. Equation (3-3) represents a linear combination of the erosion resistances of the metal and the oxide. The volume of the oxide scale eroded by a number, N , of particle impacts on surface area S is $x_i S$, and the volume fraction f of oxide eroded by each impact is then

$$f = \frac{\left(\frac{x_i S}{N}\right)}{E_t} = \left(\frac{x_i S}{N}\right) \left(\frac{1-f}{E_d} + \frac{f}{E_b}\right) \quad (3-4)$$

Considering that the oxide which contributes to the volume is formed by metal oxidation, the total erosion-oxidation loss of metal volume accounting for the conversion is:

$$E_m = E_t - \frac{x_i S}{N} \frac{(c-1)}{c} \quad (3-5)$$

where c is a metal system constant, the ratio of the volume of the oxide formed to the volume of the metal consumed.

If each particle impact cannot penetrate the growing oxide scale, a continuous oxide layer will be present which balances the competing rates of oxidation and oxide erosion. Therefore, the volume fraction f equals 1 in Equation 3-5, E_t equals E_b , and the loss of metal is due to the loss of oxide erosion.

Although the study of the interaction between metal erosion and oxidation has only recently become an active area of investigation, the fundamental nature of metal erosion at room temperature has long been distinguished from that of oxide erosion. Whereas the erosion of ductile metal is characterized by two mechanisms, oblique cutting and normal yield deformation, the erosion of oxide is described by Hertzian cone cracking under indentation impression.

According to Neilson and Gilchrist (1968), the erosion of ductile metal is the sum of two terms corresponding to the two erosion mechanisms. Based on a theoretical estimation by Engel (1978), the threshold velocity at incipient erosion is negligible relative the values of interest here. If E_p is denoted as the impact kinetic energy of a particle, the model of Neilson and Gilchrist can be written in the following form:

$$E_d = C_d \epsilon_p \eta_\alpha E_p \quad (3-6)$$

$$\text{where } \eta_\alpha = \begin{cases} \cos^2 \alpha \sin(n\alpha) + \zeta \sin^2 \alpha & (\alpha \leq \frac{\pi}{2n}) \\ \cos^2 \alpha + \zeta \sin^2 \alpha & (\alpha > \frac{\pi}{2n}) \end{cases} \quad (3-7)$$

is the impact angle efficiency determined by the importance of erosion resulting from oblique cutting and normal yield deformation, α is the angle of particle impingement with respect to the metal surface, and n is a parameter which characterizes the maximum erosion rate at a certain α value. The ratio of the erosion rate under normal impact to the maximum oblique erosion rate is provided by the factor ζ , C_d is the reciprocal of the erosion resistance of the ductile target material, and ϵ_p is the erosivity of the impacting particle. The quantity $C_d \epsilon_p$ is the erosion rate constant. It has been found in the literature that the factor ζ falls within the narrow range of 0.15 to 0.40 for most ductile metals. The experimental data provided by Shida and Fujikawa (1985) show that the value of ζ for carbon steel is about 0.3, and the metal has its maximum erosion rate at an oblique angle of 30° , corresponding to a value of $n=2$.

The erosion rate constant $C_d\epsilon_p$ has been determined from the present erosion measurements. As shown in Figure 3-4, the erosion of carbon steel by ash and char particles in the nitrogen jet increases with increasing metal temperature. The rate constant was correlated by

$$C_d\epsilon_p = 9.4224 \times 10^{-14} T^{-6.0842} \exp\left(-\frac{35635}{RT}\right) \quad \text{m}^3/\text{J} \quad (3-8)$$

For oxide erosion, a distinguishing feature is the maximum erosion rate at normal incidence. Based on the work of Sheldon (1970) on the Hertzian contact core and Evans (1976) for plastic impact response to the formation of local cracks, the following equation is an approximation of the erosion rate of brittle oxide:

$$E_b = C_b\epsilon_p (\sin \alpha)^{3.4} E_p^{1.7} A_p^{0.5} \quad (3-9)$$

where C_b is a property parameter of the target material and A_p is the specific surface area of the impinging particle. The value $C_b\epsilon_p$ is defined as the rate constant for brittle erosion. As shown in Figure 3-4, when the carbon steel is oxidized in the oxygen jet, the erosion of oxide is independent of the temperature. The rate constant $C_b\epsilon_p$ determined from the observed erosion rate is $1.7630 \times 10^{-6} \text{ m}^2\text{kg}^{0.5}/\text{J}^{1.7}$.

Once the ductile metal erosion E_d and the brittle oxide erosion E_b have been determined by Equations 3-6 to 3-9, the erosion-corrosion loss E_m can be obtained from Equations 3-3 and 3-4. The volume loss of eroded material is then converted to loss of thickness.

Comparison Between Experimental and Modeling Results

In the air jet, the oxidation of carbon steel and the erosion of surface material occur at comparable rates. As shown in Figure 3-4, the erosion of carbon steel measured at 450 K is relatively low. An increase in metal temperature, from 450 to 550 K, increases the erosion rate of the metal in the air jet, similar to the result found for the nitrogen jet. However, increasing the metal temperature increases the rate of oxidation of carbon steel in the presence of oxygen. A surface oxide layer covers the metal substrate. With further increase in metal temperature to 650 K, the erosion rate decreases to the value obtained in the oxygen jet. The prediction from the erosion-corrosion model agrees well with the observed changes in erosion rate. The model indicates that maximum erosion occurs at a temperature of 600 K.

Application

The erosion-corrosion loss was calculated for the conditions which exist in the fuel oil-designed boiler firing superclean coal-water fuel: particle concentration 2.7 g/m^3 , mean particle size $87 \text{ }\mu\text{m}$, particle density $1,250 \text{ kg/m}^3$, 30° impaction angle, 50% of particles colliding with tube

surface, and 600 K metal temperature. The erosion rate is given as a function of the convective section gas velocity in Figure 3-5. At relatively low velocity, erosion occurs in the surface oxide layer, and the erosion rate is low. Increasing the gas velocity increases the erosion rate. At a velocity slightly greater than 12 m/s, the surface oxide layer becomes thin. At higher gas velocities erosion results in direct removal of metal, and the erosion rate increases rapidly.

An erosion rate producing a tube thickness loss of 50 nm/h is considered to be the maximum acceptable rate, representing 5 mm wastage in 100,000 hours of operation. According to this limit, the flue gas velocity in the convective section should not exceed about 12 m/s for the conditions of temperature, particle size, and particle concentration investigated.

3.4 Evaluate Emissions Reductions Strategies

No work was scheduled or conducted this reporting period.

4.0 TASK 3: ENGINEERING DESIGN

Preliminary work was initiated on Task 3. A plan for implementing the designs was developed and it is summarized in Figure 1-1. The designs will begin upon selection of the boiler and site.

5.0 TASK 4: ENGINEERING AND COST ANALYSIS

5.1 Subtask 4.1 Survey Boiler Population/Identify Boilers for Conversion

Boiler Selection

EFRC personnel, working in conjunction with the U.S. Army Corps of Engineers, Construction Engineering Research Laboratory (CERL) and personnel at several military installations, have identified candidate boilers for conducting the retrofit designs. CERL scanned their computerized database and identified ~300 boilers based on the following criteria provided by Penn State:

- boiler of heavy fuel oil design;
- design capacity of 50-60 million Btu/h/burner;
- boiler located in a coal mining state and nonmetropolitan area;
- plant currently manned;
- cooperative base and boiler house staff;
- excess steam capacity;
- natural gas available for startup; and
- space to accommodate conversion.

Penn State then reduced the list, which contained boilers with a range of firing rates, boilers of watertube and firetube design, and boilers that produced saturated steam and hot water, to 32 boilers located at 11 military installations. This was done by identifying boilers with a capacity of

≥ 50 million Btu/h or 40,000 lb steam/h, that produce saturated steam, are of watertube design, and are not currently in use. Figure 5-1 shows the locations of the boilers.

Upon further investigation, it was determined that several of the military installations were either closed or are on installation closure lists. In addition, others are in metropolitan areas or have stringent air quality/coal usage regulations. Consequently, the boilers shown in Figure 5-1 were eliminated as candidates for the boiler conversion except for those at the Great Lakes Naval Training Center.

Additional boilers were identified through conversations with, and information received from CERL and other civilian and military personnel and these are shown in Figure 5-2. Of the four sites shown in Figure 5-2, three are actively being pursued as the candidate conversion site. They are: the Naval Surface Warfare Center Crane Division (Crane), New Cumberland Defense Logistics Agency (NCDLA), and Dover Air Force Base (Dover). Crane and NCDLA were visited by Penn State personnel to discuss the program and see the boilers. A trip to Dover is currently being scheduled.

Crane

Crane has three, and possibly five candidate fuel oil/natural gas designed boilers (natural gas is currently primary fuel). The boilers are contained in two boiler houses. The first one contains three Cleaver Brooks D-type watertube boilers firing natural gas with No. 6 fuel oil backup. Two of the boilers were installed in 1989 and have a firing rate of 25.2 million Btu/h. The third boiler was installed in 1972 and has a firing rate of 18 million Btu/h. The boilers are good candidates for a retrofit design. The two larger boilers have been installed such that they are raised off of the floor by $\sim 1.5'$, which would facilitate ash removal from the convective pass. There is space outside the building to accommodate coal (or coal-water slurry fuel) and ash storage and handling. In addition, there is a rail spur that services the building. At most, only two of the three boilers are operated simultaneously.

The second boiler house contains two Cleaver Brooks D-type boilers with firing rates of 17-20 million Btu/h. A retrofit would not be as easy at this site because there are underground oil storage tanks between the building and the rail spur.

NCDLA

NCDLA has three candidate boilers that were originally stoker-fired but were converted (including retubing) to fire No. 6 fuel oil in 1972. Each of the three boilers is rated at 50,000 lb steam/h. They are Erie City boilers and are of 1940's vintage.

The boilers are amenable to a conversion. There is adequate space for coal (or coal-water slurry fuel) storage and handling. Because the boilers were originally designed for coal, provisions for ash handling and storage can be added fairly easily. Steam demand is such that all three boilers are never operated at the same time, nor are they operated in the summer. The

boilers are good candidates for a conversion and can be converted with a high degree of confidence in being successful.

Dover

CERL is currently arranging a site visit to Dover to discuss the program with Air Force personnel. Dover has one heavy fuel oil-designed boiler (50,000 Btu/h) that has been partially converted to fire MCWM. The boiler produces high temperature hot water.

The boiler/site selection will be finalized in mid May, 1993 after visiting Dover. Discussions with personnel at Crane and NCDLA are also being conducted in order to finalize the selection.

5.2 Subtask 4.2 Identify Appropriate Cost Estimating Methodologies

A critical review of several cost-engineering methodologies has been performed. These methodologies, termed Appropriate Cost Estimating Methodologies, are those whose primary definitions and categories have been standardized by the American Association of Cost Engineers, and are consistent with the data requirements of the optimizing model which is being developed (Subtask 4.4). In addition to providing a unifying language, they permit the user to perform cross-comparisons and sensitivity analysis with respect to the degree of detail of engineering data and uncertainty factors. The spectrum of covered methodologies encompasses ranges of accuracy within -30% and +50% (order-of-magnitude, estimate made without detailed engineering data), within -15% and +30% (budget estimate, estimate prepared using layout information), and within -5% and +15% (definitive estimate, prepared from defined engineering data). Cost uncertainty stems from three sources: ordinary variability of input parameters (fuel price, capital costs, etc.), loss-of-load and other costs related to quality attributes of steam production (maintainability, burning rate, etc.), and special economic costs (adjustment, learning, irreversible investment, pollution, etc.). The following methodologies were given primary attention:

- order-of-magnitude estimation;
- power factor estimations;
- multiplicative factor estimation;
- definitive estimation;
- other simple cost-engineering methods;
- process analysis; and
- stochastic cost analysis.

A summary assessment of these methodologies is currently underway. The research team is leaning toward a manageable spreadsheet program approach for initial estimation. Several more sophisticated approaches are being considered for subsequent analyses.

A brief description of each model's characteristics and types of projects/systems that they are used for follows.

Factor Estimating

This category includes Power Factor estimating (Cost-Capacity Factor Method) and Multiplicative Factor estimating (the Equipment Installation Cost-Ratio Method, the Lang Factor Method, the Hand Factors Method, the Chilton Method, the Peters and Timmerhaus Method, and the Federal Energy Regulatory Commission Account Structure.

Power Factor Estimating

The Cost Capacity Factor Method

The relationship between cost and capacity is expressed as

$$C_2/C_1 = (Q_2/Q_1)^x \quad (5-1)$$

where C_2 is the desired cost of capacity of Q_2 and C_1 is the known cost of capacity Q_1 . The exponential factor x is usually in the range 0.6-0.8. Steam-electric generating plants generally have a cost-capacity factor of about 0.8. The cost-capacity factor for a steam boiler facility may be 0.75 (units are lb/h).

Multiplicative Factor Estimating

The Equipment Installation Cost-Ratio Method

Multiply the purchase cost by an equipment installation cost ratio. The installed cost is the addition of the FOB cost, transportation, buildings foundation, erection, etc. The installed cost is about 1.5 times the purchase cost.

The Lang Factor Method

Multiply the total delivered cost of equipment by the following factors to obtain total process plant costs: 3.1 for solid process plants, 3.68 for solid-fluid plants, and 4.74 for fluid process plants.

Hand Factors Method

Use factors based upon different pieces of equipment to affect the purchase cost of individual equipment and then add factored components to obtain the battery limits installed cost.

Chilton Method

List the additional physical costs: piping, instrumentation, buildings, auxiliaries, outside lines and site development, multiply the installed equipment cost by a Chilton factor (given in handbook tables), find engineering and construction costs, contingencies and contractor's fee, and size factor by multiplying the total physical cost by the respective Chilton factor, and add these indirect costs to total physical cost to find total plant cost.

Peters and Timmerhaus Method

This is a combination of the Lang and Chilton methods, based on delivered equipment costs but retaining Lang's classification of solid, solid-fluid, and fluid processing plants.

Federal Energy Regulatory Commission (FERC) Account Structure

The FERC has defined a code of accounts for Account Code 312 Boiler Plant Equipment. The total cost is the sum of the individual account costs and is denoted as the total direct cost (TDC); adding the indirect capital cost to the TDC produces the total plant cost (TPC). The total capital cost (TCC) is calculated by multiplying TPC by a construction factor F.

Process Analysis Models

Process analysis models provide a structural, input/output representation of the energy flows through a set of production, transformation, pollution abatement and end-use current and most likely technologies that may compete to meet a final demand (*e.g.*, steam of a given quality). The description can be easily translated into a spreadsheet approach containing technical and cost coefficients, and cost-estimating procedures to produce cost descriptions per process that feed the optimizing module.

Stochastic Cost Analysis

Stochastic cost analysis is intended to produce empirical probability distributions for output parameters (*i.e.*, costs) given the distribution of input parameters. Through a technique known as "Monte Carlo simulation", some software packages lined to spreadsheet programs are able to forecast the entire range of results possible for a given situation, including certainty levels for specific value ranges. These models are designed to explore and show how diverse assumptions affect the forecast results.

The above mentioned Cost Estimating Methodologies are routinely applied by Cost Engineers in any kind of material-energy transforming projects, especially in the chemical industry. Process analysis models are mainly used to assess long range energy/environment/technology choices. New stochastic sensitivity analysis software packages enable one to study the impact of uncertainty in project evaluation, and is becoming an indispensable practice in finance, engineering economics, and feasibility studies.

The work was synthesized into an interim report, and one of the faculty investigators has a summary evaluation report in progress. Building on insights from many years of observation, the summary evaluation report concludes that the basic methods of cost engineering are straightforward in principle. One collects the best possible information about the engineering details of the project, gets good cost estimates, and uses the many well-established economic techniques for describing outcomes. Increasingly, these techniques examine the range of possible

outcomes. The main problems are practical--getting the correct engineering information for the project.

Modeling of global prospects for coal conversion at military installations has also been started. A model framework has been developed which will start with a linear programming model, conduct sensitivity analysis, use advanced mathematical tools to decompose price variations into those components whose variation cancels out over time and those components that must be explicitly incorporated into the analysis, and then discuss what assurances must be provided when switching to coal.

5.3 Subtask 4.3 Estimate Basic Costs of New Technologies

Two models prepared for DOD--the Institute of Gas Technology's Coal-Fired Boiler Evaluation Program and the BLAST Life Cycle Cost in Design program both were placed on line on computers and evaluated. The Coal-Fired Boiler Evaluation Program proved much more applicable than the Life Cycle Cost in Design program. The Coal-Fired Boiler Evaluation Program deals directly and comprehensively with converting boilers to coal. The incorporated written discussion provided a good review of available technologies. The data base portion of the program gives extensive valuable information on costs as of the time of the report, an inventory of military bases, and the coal resources available to them. A program for conducting cost analyses also is provided. It appears to be a well-designed, straightforward method for computing total costs given inputs and their costs. The program provides first a tool to evaluate the costs at the target base once it is selected. Then the models can help in the national conversion prospect assessment outlined in Subtask 4.3. In contrast, the Life Cycle Cost in Design program is designed for energy consumers and is not appropriate for boiler cost approval.

5.4 Subtask 4.4 Process Analysis of MCWM and Dry, Micronized Coal

In conducting a process analysis, the objective is to develop a cost minimizing model for retrofitting an existing fuel oil-fired boiler to fire coal-based fuels (initial work focuses on MCWM). A linear programming model is currently under development using the General Algebraic Model Solver (GAMS).

GAMS is designed to make the construction and solution of large and complex mathematical programming models more straightforward for programmers and more comprehensible to users of models. The GAMS language can be easily read by both modelers and computers. Appendix D contains:

(1) the introductory chapter of the GAMS manual that describes the software in more detail, (2) the initial model of the retrofit evaluation program, and (3) the output of the model. The initial model is included to show the basic structure of GAMS programs and the input to this particular model. The SETS, SCALARS and PARAMETERS are all input, and the entries are defined for

clarity. The output (titled **** report summary) is the present value of retrofit costs, retrofit cost savings (i.e., costs of firing oil), and the net benefits of retrofitting. The output gives these values for a range of boiler plant capacities and boiler derated capacities in percentages. The boiler derated capacities range from 80-100%. The fuel differential cost in this case is \$1.00 per million Btu (see input). The model, at this stage, performs no data validation, and currently refinements are being made to the model.

The model is based on work by Carpenter and Berg (1984), Combustion Engineering (1989), and Miller, et al. (1993b). The model is structured along the lines of the first two references and utilizes cost data from the third. The cost data from Miller, et al. are being used because they are more current than those used in the other two sources and are for a boiler of a size which is representative (15,000 lb steam/h) of the DOD boilers under consideration.

Initial runs of the model confirm the results of the prior spreadsheet analysis, while adding additional insight to the retrofit scenario. (Note that the GAMS model is a representation of the spreadsheet model including a consideration of retrofit capital requirement variation with boiler derating. Boiler age is another variable considered in the GAMS model which is absent from the spreadsheet model. The conclusions of the GAMS model are therefore more general. The spreadsheet model was developed in Microsoft Excel 4.0.) Important factors are: boiler age, capacity, level of acceptable derating, and differential fuel cost. The model indicates that some boilers will realize a net benefit from retrofitting while others will not. This is dependent on the economic factors of interest but in general, the greater the boiler capacity the more economically feasible is the retrofit. Also, the longer the useful life, the greater the benefits from retrofitting. A differential fuel cost of \$2.00/million Btu is required for all the retrofits considered to realize positive net benefits. In general, net benefits decreased with increasing boiler derated capacity. Refinements are currently being made to the model.

5.5 Subtask 4.5 Analyze/Identify Transportation Cost of Commercial Sources of MCWM and Cleaned Coal for Dry, Micronized Coal Production

This aspect of the study is still in the early stages, and attention is initially focused on Pennsylvania. All DOD facilities in the state and all coal production sites in the state have been mapped. A map of all state freight rail lines has been obtained from the state office of the Bureau of Rail Freight, Ports, and Waterways. Currently, the feasibility and cost of rail transport of micronized coal (which has some technical difficulties) is being assessed. Truck, barge, and pipeline transport are also being considered.

5.6 Subtask 4.6 Determine Community Spillovers

A review of the environmental issues surrounding boiler retrofits has been conducted. Areas of main concern are coal selection, boiler selection, and the disposal of the ash.

During the processing and milling of the coal, dust control and water quality and availability must be considered, as well as the cost of the water and water transport. Dust and water are regulated by the Resource Conservation and Recovery Act, Permanent Program Performance Standards for Surface and Underground Mining, OSHA, the Clean Water Act, the Safe Drinking Water Act, and the National Environmental Policy Act.

The regional boiler site selection should in part depend on both the convenience to the coal source, the processing site of the coal, and any disturbances to surrounding communities, including increased traffic, dust, and noise. Some of these aspects are governed by Department of Transportation regulations, the National Environmental Policy Act, and the Clean Air Act, as well as local ordinances.

The ash generated by the boiler, both fly ash and bottom ash, must be disposed of. Depending on the presence of certain trace elements (particularly chlorobenzenes, benzenes, and ethylbenzenes), the ash may be classified as hazardous, in which case disposal is more difficult, more expensive, and more highly regulated. Additional considerations are ash volume and landfill availability, acid neutralization and pH control, dust and erosion control, and water runoff from waste piles. Existing legislation includes the Toxic Substances Control Act, the Resource Recovery and Conservation Act, the National Environmental Policy Act, the Safe Drinking Water Act, and the Clean Water Act.

5.7 Subtask 4.7 Regional Market Considerations and Impacts

A regional economic impact analysis is underway. The most up-to-date version of the IMPLAN System, a database and modeling capability developed by several U.S. government agencies to perform economy-wide analyses, has been obtained. Appendix E contains a copy of the IMPLAN User's Guide. This system can generate input-output tables for any county or county grouping in the U.S., which will enable a regional impact analysis for a retrofitted boiler at any proposed site to be performed. Multiplier effects on such major economic indicators as output, employment, and income can be determined. A six-county I-O table for Central Pennsylvania has been generated to illustrate the model's capability. (Preliminary modeling work has focused on Pennsylvania until the boiler site is selected.) Currently, Penn State is developing the expertise to run the IMPLAN Modeling System for application to any region of the U.S. An extension of the IMPLAN methodology to perform analyses on the economic impacts across socioeconomic groups is being developed.

The research team was recently made aware of an alternative regional economic modeling system--Regional Interindustry Program (RIP)--developed by the U.S. Corps of Engineers Institute for Water Resources. A preliminary assessment of RIP, and discussions with the Army Corps staff member who took the lead in developing it, indicate RIPS is not as well-suited as IMPLAN for our purposes. The innovative features of RIPS are its variable coefficient format,

which is tailored to the analysis of infrastructural improvements, such as waterways, harbors, roads, bridges, etc. Infrastructural enhancements result in major productivity changes, which translate into changes in structural I-O coefficients (either technical requirements or regional trade patterns). These are not relevant to boiler retrofit cases. The more conventional impact analysis capability of RIPS is not extensively developed. It depends on aggregate RIMS II multipliers developed by the U.S. Department of Commerce, as opposed to the detailed industry and social accounts embedded in the full input-output tables in IMPLAN. Since there are no infrastructural improvements associated with coal-water mixtures, our analysis focuses on impacts on output, employment, income, which are IMPLAN's strengths.

Creation of a Computable General Equilibrium (CGE) Model for analyzing energy and environmental policy in Pennsylvania has been started. This model focuses on the electric utility sector and fuel substitution possibilities in the State. In addition, it is capable of analyzing the effects of new environmental regulations on the electricity sector and the economy as a whole. The CGE approach is more powerful than the I-O approach discussed above. At the same time, it is much more costly in terms of construction time and model complexity, and CGE Models cannot readily be built for substrate regions. The modeling insights developed using Pennsylvania will be beneficial when applying the CGE methodology to the selected boiler site. Computable general equilibrium modeling is a secondary but important part of the subtask. CGE represents the state-of-the-art of economic impact modeling and is capable of incorporating three important features that I-O analysis omits: nonlinearities, supply constraints, and price changes. These are likely to be relevant for large-scale scenarios, such as the retrofit of all coal-fired boilers at government installations (military and nonmilitary) within a state. In this case, there are likely to be strains on the availability of construction materials and specialized labor, and pressure on freight rates, all of which are likely to stunt the positive regional impacts of a retrofit strategy. Even if the results show little discernible differences between the I-O and CGE analyses, this will help validate the use of simpler I-O approaches in future analyses. It must be emphasized that the CGE modeling effort is not an entirely different direction of research. It builds on the I-O and SAM capabilities of IMPLAN and the identification and valuation of technical input requirements of both the construction and operation of a new technology.

5.8 Integrate the Analysis

No work was scheduled or conducted this reporting period.

6.0 TASK 5: FINAL REPORT/SUBMISSION OF DESIGN PACKAGE

No work was conducted on Task 5.

7.0 MISCELLANEOUS ACTIVITIES

Penn State's cost sharing component of the program, the construction of the Coal Utilization Laboratory, was completed. Occupancy is planned for May 1993. The building will

house: bench- and pilot-scale coal characterization and combustion testing facilities; office, meeting, and conference room space; and a centralized location for the Penn State academic/research groups (whose offices are located throughout the campus) to work in close proximity in order to bring the program to successful completion.

A paper was prepared for the Ninth Annual Coal Preparation, Utilization, and Environmental Control Contractors Review Meeting at Pittsburgh, Pennsylvania July 19-22, 1993. The title of the manuscript is "Development of Coal-Based Technologies for Department of Defense Facilities," authored by Bruce G. Miller and Alan W. Scaroni.

8.0 NEXT SEMIANNUAL PERIOD ACTIVITIES

During the next reporting period, the following will be done:

- The site will be selected for the boiler conversion;
- The list of candidate coals will be finalized;
- The conversion design will be initiated, and the designs for the fuel system, burner (HEACC), and ash handling system will be completed;
- The candidate coals will be procured and characterized;
- MCWM will be produced from the candidate coals and tested in Penn State's 1,000 lb steam/h research boiler;
- The HEACC will be constructed and installed in Penn State's 15,000 lb steam/h demonstration boiler;
- The 1,000-hour demonstration firing dry, micronized coal will begin.
- Economic models will be refined.

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11.0 NOMENCLATURE

A_p	particle specific surface area (m^2/kg)
C_b	reciprocal of the erosion resistance to brittle erosion
C_d	reciprocal of the erosion resistance to ductile erosion
E_b	volume loss of the target material by brittle erosion (m^3)
E_d	volume loss of the target material by ductile erosion (m^3)
E_m	volume loss of metal by erosion-corrosion (m^3)
E_t	volume loss of the target material by erosion-corrosion (m^3)
E_p	particle kinetic energy (J)
N	number of particle impacts
R	universal gas constant (8.314 J/mole K)
S	surface of target material (m^2)
T	metal temperature (K)
c	volume factor for the conversion from metal to oxide
f	volume fraction of oxide eroded
k_o	oxidation rate constant (m^2/s)
t_i	time interval between particle impacts (s)
x_i	thickness of oxide scale formed during time t_i (m)
z	oxidation reaction order

α	particle impaction angle
ε_p	particle erosivity
ζ	correction factor for ductile erosion at normal impaction

Figure 1-1. Milestone Schedule

Task 1 - Coal Beneficiation/Preparation 1992
(cont.)

1993

1994

Task 2 - Combustion Performance Evaluation

1992

1993

1994

Sept Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sept Oct Nov Dec Jan Feb Mar Apr

Subtask 2.1 Boiler Retrofit

Subtask 2.1.1 Finalize Burner/Atomizer Design

Subtask 2.1.2 Procure and Install Burner

Subtask 2.1.3 Optimize Burner Firing

Subtask 2.1.4 Optimize Burner Firing CWM Dry, Micronized Coal

Subtask 2.2 Fuel Evaluation in Research Boiler

Subtask 2.2.1 Test Sample of Type I CWM

Subtask 2.2.2 Test Sample of Type II CWM

Subtask 2.2.3 Test Sample of Type III CWM

Subtask 2.3 Performance Evaluation of MCWM and Dry, Micronized Coal in Demonstration Boiler

Subtask 2.3.1 100-Hour Milestone

Subtask 2.3.2 200-Hour Milestone

Subtask 2.3.3 300-Hour Milestone

Subtask 2.3.4 400-Hour Milestone

Subtask 2.3.5 500-Hour Milestone

Subtask 2.3.6 600-Hour Milestone

Subtask 2.3.7 700-Hour Milestone

Subtask 2.3.8 800-Hour Milestone

Subtask 2.3.9 900-Hour Milestone

Subtask 2.3.10 1,000-Hour Milestone

Subtask 2.3.11 Technical Advisement by CE

**Task 2 - Combustion Performance
Evaluation(cont.)**

MCWM Testing

- Subtask 2.3.12 100-Hour Milestone
- Subtask 2.3.13 200-Hour Milestone
- Subtask 2.3.14 300-Hour Milestone
- Subtask 2.3.15 400-Hour Milestone
- Subtask 2.3.16 500-Hour Milestone
- Subtask 2.3.17 600-Hour Milestone
- Subtask 2.3.18 700-Hour Milestone
- Subtask 2.3.19 800-Hour Milestone
- Subtask 2.3.20 900-Hour Milestone
- Subtask 2.3.21 1,000-Hour Milestone
- Subtask 2.3.22 Technical Advisement by CE

Evaluate Erosion / Deposition Characteristics

- Subtask 2.3.23 Identify Erosion and Deposition Regimes
- Subtask 2.3.24 Match Simultaneous Erosion and Deposition
- Subtask 2.3.25 Compare Heat Transfer Surface Performance
- Subtask 2.3.26 Procedure for Determining Optimum Convective Section Gas Velocity
- Subtask 2.3.27 Comparison of Performance of Three Tube Materials

1994

Subtask 3.1 Micronized CWM Dry,

Micronized Coal Preparation Facilities

Subtask 3.1.1 Design of MCWMF Facility - AMAX

Subtask 3.1.2 Design of Dry, Micronized Coal Preparation System - EER / PS^{VI}

Subtask 3.2 Fuel Handling

Subtask 3.2.1 Design of Fuel System - EER

Subtask 3.2.2 Technical Support and Fuel System Design - PSU

Subtask 3.3 BurnerSystem

Subtask 3.3.1 Burner Design - CE

Subtask 3.3.2 Auxiliary Component Design - EER

Subtask 3.4 Ash Removal, Handling and Disposal

Subtask 3.4.1 Design of Ash System - EER

Subtask 3.5 Air Pollution Control

Subtask 3.5.1 Design of Emission Control - EER

Subtask 3.6 Integrate Engineering Design

Subtask 3.6.1 Integrate System Components

Subtask 3.7 Project Management and Support

Subtask 3.7.1 Project Management and Technical Advisement

Subtask 3.7.2 Penn State Technical Review

Subtask 3.7.3 Drafting / Technical

Secretarial Support

Subtask 3.7.4 Budget Management / Project Administration

1994

Preparation

Subtask 5.3 Report Preparation Support Services

TABLE 1-1. MILESTONE DESCRIPTION

<u>Milestone</u>	<u>Description</u>	<u>Planned Completion Date</u>	<u>Actual Completion Date</u>
Task 1. Coal Beneficiation/Preparation			
Subtask 1.1. Identify/Procure Coals			
Subtask 1.1, No. 1	Establish selection criteria	10/15/92	10/15/92
Subtask 1.1, No. 2	Preliminary list of candidate coals	02/01/93	02/01/93
Subtask 1.1, No. 3	Short list	03/01/93	03/01/93
Subtask 1.1, No. 4	Final list based on boiler selection	05/01/93	
Subtask 1.1, No. 5	Procure samples	06/01/93	
Subtask 1.2. Determine Liberation Potential			
Subtask 1.2.1. Conventional Washability Analysis on Type I and Type II Samples			
Subtask 1.2.1, No. 1	Review of published data	06/01/93	
Subtask 1.2.1, No. 2	Analysis of Type I complete	06/15/93	
Subtask 1.2.1, No. 3	Analysis of Type II complete	07/01/93	
Subtask 1.2.2. Fine Washability Analysis on Type II and Type III Samples			
Subtask 1.2.2, No. 1	Review of published data	06/01/93	
Subtask 1.2.2, No. 2	Analysis of Type II complete	07/01/93	
Subtask 1.2.2, No. 3	Analysis of Type III complete	07/15/93	
Subtask 1.3. Produce Laboratory-Scale Quantities of MCWM			
Subtask 1.3.1, No. 1	Identify Cleaning Strategies	08/01/93	
Subtask 1.3.2. Evaluate Conventional Gravity Separations			
Subtask 1.3.2, No. 1	Test work on Type I complete	08/01/93	
Subtask 1.3.2, No. 2	Test work on Type II complete	09/15/93	
Subtask 1.3.2, No. 3	Test work on Type III complete	10/01/93	
Subtask 1.3.3. Evaluate Fine Gravity Separations			
Subtask 1.3.3, No. 1	Cyclone test rig set-up	11/30/92	11/30/92
Subtask 1.3.3, No. 2	Initiate magnetite classification studies	12/01/92	12/01/92
Subtask 1.3.3, No. 3	Initiate batch centrifuge testing	02/01/93	
Subtask 1.3.3, No. 4	Preliminary centrifuge data evaluation	05/01/93	
Subtask 1.3.3, No. 5	Procure continuous centrifuge	05/15/93	
Subtask 1.3.3, No. 6	Initiate selectivity studies on Type III coals	06/01/93	
Subtask 1.3.3, No. 7	Magnetite classification studies complete	06/15/93	
Subtask 1.3.3, No. 8	Procure saturation magnetization analyzer	07/01/93	
Subtask 1.3.3, No. 9	Procure variable speed pump	07/15/93	
Subtask 1.3.3, No. 10	Preliminary test work complete	12/31/93	
Subtask 1.3.4. Evaluate Advanced Froth Flotation			
Subtask 1.3.4, No. 1	Reagent selection	06/01/93	
Subtask 1.3.4, No. 2	Initiate test work on Type II samples	06/15/93	
Subtask 1.3.4, No. 3	Initiate test work on Type III samples	07/01/93	

<u>Milestone</u>	<u>Description</u>	<u>Planned Completion Date</u>	<u>Actual Completion Date</u>
Subtask 1.3.4, No. 4	Type II test work complete	07/31/93	
Subtask 1.3.4, No. 5	Type III test work complete	08/31/93	
Subtask 1.3.4, No. 6	Data evaluation completed	10/31/93	
Subtask 1.3.5. Evaluate Column Flotation			
Subtask 1.3.5, No. 1	Complete column design	05/01/93	
Subtask 1.3.5, No. 2	Procure bubble generators	06/01/93	
Subtask 1.3.5, No. 3	Complete column fabrication	06/15/93	
Subtask 1.3.5, No. 4	Complete test work	12/31/93	
Subtask 1.3.6. Evaluate Selective Agglomeration			
Subtask 1.3.6, No. 1	Initiate wetting studies	01/15/93	01/15/93
Subtask 1.3.6, No. 2	Initiate 3-phase aggregation studies	01/31/93	01/31/93
Subtask 1.3.6, No. 3	Fabricate test cell	02/15/93	02/15/93
Subtask 1.3.6, No. 4	Complete preliminary test work on Type II samples	07/31/93	
Subtask 1.3.6, No. 5	Complete preliminary test work on Type III samples	09/15/93	
Subtask 1.3.6, No. 6	Complete detailed studies on Type II samples	12/31/93	
Subtask 1.3.7. Investigate Solid-Liquid Separations			
Subtask 1.3.7, No. 1	Preliminary evaluation complete	08/01/93	
Subtask 1.3.7, No. 2	Initiate studies on test coals	08/31/93	
Subtask 1.3.7, No. 3	Complete studies on test coals	10/31/93	
Subtask 1.3.8. Select Cleaning Flowsheet(s)			
Subtask 1.3.8, No. 1	Establish flowsheet for Type I sample	12/01/93	
Subtask 1.3.9. Establish Required Size Consist for Slurry Formulation			
Subtask 1.3.9, No. 1	Complete for Type I samples	06/30/93	
Subtask 1.3.9, No. 2	Complete for Type II samples	07/15/93	
Subtask 1.3.9, No. 3	Complete for Type III samples	08/15/93	
Subtask 1.3.10. Investigate Conventional Ball Milling			
Subtask 1.3.10, No. 1	Complete test work for Type I samples	07/31/93	
Subtask 1.3.10, No. 2	Complete test work for Type II samples	09/01/93	
Subtask 1.3.10, No. 3	Complete test work for Type III samples	10/31/93	
Subtask 1.3.11. Stirred Media Milling			
Subtask 1.3.11, No. 1	Procure stirred media mill	07/15/93	
Subtask 1.3.11, No. 2	Complete test work on Type I samples	08/15/93	
Subtask 1.3.11, No. 3	Complete test work on Type II samples	10/01/93	
Subtask 1.3.11, No. 4	Complete test work on Type III samples	12/01/93	
Subtask 1.3.12. Investigate Attrition Milling			
Subtask 1.3.12, No. 1	Establish test procedure	09/15/93	
Subtask 1.3.12, No. 2	Evaluate preliminary data	10/15/93	
Subtask 1.3.12, No. 3	Complete evaluation	12/31/93	

<u>Milestone</u>	<u>Description</u>	<u>Planned Completion Date</u>	<u>Actual Completion Date</u>
Subtask 1.3.13. Lab-Scale Slurry Production			
Subtask 1.3.13, No. 1	Type I produced	09/15/93	
Subtask 1.3.13, No. 2	Type II produced	10/30/93	
Subtask 1.3.13, No. 3	Type III produced	12/31/93	
Subtask 1.3.14, No. 1	Modify viscosity and sedimentation rate models to account for PSD; compare model predictions to experimental observations	06/30/93	
Subtask 1.3.15, No. 1	Modify viscosity and sedimentation rate models to account for inter-particle attractive forces; compare model predictions to experimental observations	06/30/93	
Subtask 1.3.16, No. 1	Modify models to include effect of polymer additives, oxidation, and aggregate phenomena	03/01/94	
Subtask 1.4. Develop Dry Coal Cleaning Technique			
Subtask 1.4.1. Dry Grinding Studies			
Subtask 1.4.1, No. 1	Procure compressor system	03/15/93	03/15/93
Subtask 1.4.1, No. 2	Set up closed-circuit grinding system	05/15/93	
Subtask 1.4.1, No. 3	Procure pilot-scale jet mill	05/30/93	
Subtask 1.4.1, No. 4	Procedure established for Type III samples	07/31/93	
Subtask 1.4.1, No. 5	Produce micronized product for dry beneficiation studies	08/31/93	
Subtask 1.4.2. Deagglomeration Studies			
Subtask 1.4.2, No. 1	Establish standardized test procedure	08/01/93	
Subtask 1.4.2, No. 2	Initiate humidity and reagent testing	08/15/93	
Subtask 1.4.2, No. 3	Procure laser diagnostic system	09/01/93	
Subtask 1.4.2, No. 4	Complete humidity testing	12/01/93	
Subtask 1.4.3. Dry Separations			
Subtask 1.4.3, No. 1	Procure power supplies	03/01/93	03/01/93
Subtask 1.4.3, No. 2	Fabricate prototype test unit	05/01/93	
Subtask 1.4.3, No. 3	Complete preliminary testing	08/31/93	
Subtask 1.4.3, No. 4	Complete testing	12/31/93	
Subtask 1.5. Produce MCWMs and Micronized Coal from Dry, Clean Coal			
Subtask 1.5.1, No. 1	Produce Micronized Coal from Dry, Clean Coal	02/01/94	
Subtask 1.5.2, No. 1	Product MCWM from Dry, Clean Coal	03/01/94	
Subtask 1.6. Produce MCWM and Dry, Micronized Coal for the Demonstration			
Subtask 1.6.1, No. 1	Shakedown dry, micronized coal circuit	05/31/93	
Subtask 1.6.2, No. 1	Complete CWM Preparation Facility	05/01/93	
Subtask 1.6.2, No. 2	Procure automated valves	06/01/93	
Subtask 1.6.2, No. 3	Install CWM equipment	06/30/93	
Subtask 1.6.3, No. 1	Shakedown CWM circuit	08/31/93	
Subtask 1.6.4, No. 1	Coal Cleaning	10/01/93	
Subtask 1.6.5, No. 1	Coal Micronizing	12/31/93	
Subtask 1.6.6, No. 1	MCWM Preparation	04/01/94	

<u>Milestone</u>	<u>Description</u>	<u>Planned Completion Date</u>	<u>Actual Completion Date</u>
Subtask 1.7. Project Management and Support			
Subtask 1.7.1, No. 1	Project Management and Technical Advisement	04/01/94	
Subtask 1.7.2, No. 1	Drafting/Technical Secretary Support	04/01/94	
Subtask 1.7.3, No. 1	Budget Management/Project Administration	04/01/94	
Task 2. Combustion Performance Evaluation			
Subtask 2.1. Boiler Retrofit			
Subtask 2.1.1, No. 1	Finalize burner/atomizer design	05/31/93	
Subtask 2.1.2, No. 1	Procure and install burner	08/31/93	
Subtask 2.1.3, No. 1	Optimize burner firing dry, micronized coal	09/30/93	
Subtask 2.1.4, No. 1	Optimize burner firing CWM	12/31/93	
Subtask 2.2. Fuel Evaluation in Research Boiler			
Subtask 2.2.1, No. 1	Test sample of Type I CWM	10/15/93	
Subtask 2.2.2, No. 1	Test sample of Type II CWM	11/30/93	
Subtask 2.2.3, No. 1	Test sample of Type III CWM	01/31/94	
Subtask 2.3. Performance Evaluation of MCWM and Dry, Micronized Coal in Demonstration Boiler			
<u>Dry, Micronized Coal Testing</u>			
Subtask 2.3.1, No. 1	Procure fire suppression system for the baghouse	06/01/93	
Subtask 2.3.1, No. 2	Modify conditioning screw	07/01/93	
Subtask 2.3.1, No. 3	100-hour milestone firing dry, micronized coal	10/22/93	
Subtask 2.3.2, No. 1	200-hour milestone firing dry, micronized coal	10/29/93	
Subtask 2.3.3, No. 1	300-hour milestone firing dry, micronized coal	11/05/93	
Subtask 2.3.4, No. 1	400-hour milestone firing dry, micronized coal	11/12/93	
Subtask 2.3.5, No. 1	500-hour milestone firing dry, micronized coal	11/19/93	
Subtask 2.3.6, No. 1	600-hour milestone firing dry, micronized coal	11/26/93	
Subtask 2.3.7, No. 1	700-hour milestone firing dry, micronized coal	12/03/93	
Subtask 2.3.8, No. 1	800-hour milestone firing dry, micronized coal	12/10/93	
Subtask 2.3.9, No. 1	900-hour milestone firing dry, micronized coal	12/17/93	
Subtask 2.3.10, No. 1	1,000-hour milestone firing dry, micronized coal	12/31/93	
Subtask 2.3.11, No. 1	Technical Advisement by CE	12/31/93	
<u>MCWM Testing</u>			
Subtask 2.3.12, No. 1	100-hour milestone firing micronized CWM	01/28/94	
Subtask 2.3.13, No. 1	200-hour milestone firing micronized CWM	02/04/94	
Subtask 2.3.14, No. 1	300-hour milestone firing micronized CWM	02/11/94	
Subtask 2.3.15, No. 1	400-hour milestone firing micronized CWM	02/18/94	
Subtask 2.3.16, No. 1	500-hour milestone firing micronized CWM	02/25/94	
Subtask 2.3.17, No. 1	600-hour milestone firing micronized CWM	03/04/94	
Subtask 2.3.18, No. 1	700-hour milestone firing micronized CWM	03/11/94	
Subtask 2.3.19, No. 1	800-hour milestone firing micronized CWM	03/18/94	
Subtask 2.3.20, No. 1	900-hour milestone firing micronized CWM	03/25/94	
Subtask 2.3.21, No. 1	1,000-hour milestone firing micronized CWM	04/01/94	
Subtask 2.3.22, No. 1	Technical advisement by CE	04/01/94	
<u>Evaluate Erosion/Deposition Characteristics</u>			
Subtask 2.3.23, No. 1	Identify erosion and deposition regimes	11/30/92	11/30/92
Subtask 2.3.24, No. 1	Model simultaneous erosion and deposition	09/30/93	

<u>Milestone</u>	<u>Description</u>	<u>Planned Completion Date</u>	<u>Actual Completion Date</u>
Subtask 2.3.25, No. 1	Procure Zirconia/Platinum sensor/recorder	10/15/93	
Subtask 2.3.25, No. 2	Compare heat transfer surface performance firing micronized dry coal and CWM	02/28/94	
Subtask 2.3.26, No. 1	Develop procedure for determining optimum convective section gas velocity	02/28/94	
Subtask 2.3.27, No. 1	Comparison of performance of three tube materials	03/31/94	
Subtask 2.4. Evaluate Emissions Reduction Strategies			
Subtask 2.4.1, No. 1	Determine emissions from micronized coal testing	12/31/93	
Subtask 2.4.2, No. 1	Determine emissions from CWM testing	04/01/94	
Subtask 2.5. Project Management and Support			
Subtask 2.5.1, No. 1	Project management and advisement	04/01/94	
Subtask 2.5.2, No. 1	Staff supervision, test planning, and quality control	04/01/94	
Subtask 2.5.3, No. 1	Data reduction and interpretation	04/01/94	
Subtask 2.5.4, No. 1	Drafting/technical secretarial support	04/01/94	
Subtask 2.5.5, No. 1	Budget management/project administration	04/01/94	
Task 3. Engineering Design			
Subtask 3.1. Micronized CWM/Dry, Micronized Coal Preparation Facilities			
Subtask 3.1.1, No. 1	Design of micronized CWM preparation facility by Amax	11/15/93	
Subtask 3.1.2, No. 1	Design of dry micronized coal preparation system by EER	10/15/93	
Subtask 3.2. Fuel Handling			
Subtask 3.2.1, No. 1	Design of fuel system by EER	10/15/93	
Subtask 3.2.2, No. 1	Technical support and design of fuel system by PSU	10/15/93	
Subtask 3.3. Burner System			
Subtask 3.3.1, No. 1	Design of burner by CE for selected boiler	09/15/93	
Subtask 3.3.2, No. 1	Design of auxiliary components by EER	11/15/93	
Subtask 3.4. Ash Removal, Handling, and Disposal			
Subtask 3.4.1, No. 1	Design of ash system by EER	09/30/93	
Subtask 3.5. Air Pollution Control			
Subtask 3.5.1, No. 1	Design of emission control by EER	11/15/93	
Subtask 3.6. Integrate Engineering Design			
Subtask 3.6.1, No. 1	Integrate system components	01/15/94	

<u>Milestone</u>	<u>Description</u>	<u>Planned Completion Date</u>	<u>Actual Completion Date</u>
Subtask 3.7. Project Management and Support			
Subtask 3.7.1, No. 1	Project management and technical advisement	01/15/94	
Subtask 3.7.2, No. 1	Penn State technical review	01/15/94	
Subtask 3.7.3, No. 1	Drafting/technical secretarial support	01/15/94	
Subtask 3.7.4, No. 1	Budget management/project administration	01/15/94	
Task 4. Engineering and Economic Analysis			
Subtask 4.1, No. 1 Survey Boiler Population/Identify Boilers for Conversion		08/31/93	
Subtask 4.2, No. 1 Identify Appropriate Cost-Estimating Technologies		05/31/93	
Subtask 4.3, No. 1 Estimate Basic Costs of New Technologies		08/31/93	
Subtask 4.4. Process Analysis of MCWM and Dry, Micronized Coal			
Subtask 4.4.1, No. 1	Penn State Analysis	08/31/93	
Subtask 4.4.2, No. 1	Industrial Participants Assistance/Advisement	08/31/93	
Subtask 4.5, No. 1 Analyze/Identify Transportation Cost of Commercial Sources of MCWM and Cleaned Coal for Dry, Micronized Coal Production		09/30/93	
Subtask 4.6, No. 1 Determine Community Spillovers		07/31/93	
Subtask 4.7, No. 1 Regional Market Considerations and Impacts		08/31/93	
Subtask 4.8. Integrate the Analysis			
Subtask 4.8.1, No. 1	Penn State Review of Industrial Participants Contribution	01/31/94	
Subtask 4.8.2, No. 1	Penn State Integration of the Analysis	01/31/94	
Subtask 4.8.3, No. 1	Industrial Participants Assistance in Preparing, and Review of, the Integrated Analysis	01/31/94	
Subtask 4.9. Project Management and Support			
Subtask 4.9.1, No. 1	Project Management and Advisement	02/01/94	
Subtask 4.9.2, No. 1	Drafting/Technical Secretarial Support	02/01/94	
Subtask 4.9.3, No. 1	Budget Management/Project Administration	02/01/94	
Task 5. Final Report/Submission of Design Package			
Subtask 5.1, No. 1	Industrial Participants Submission to Penn State/Review Final Package	04/30/94	
Subtask 5.2, No. 1	Penn State Technical Preparation	04/30/94	
Subtask 5.3, No. 1	Report Preparation Support Services	04/30/94	

Table 2-1. Preliminary list of test coals.

Sample Designation	I-1	II-1	II-2	II-3	III-1	III-2
Seam	Hazard 5A	Lower Kittanning	Lower Freeport	Indiana VII	Upper Freeport	Pittsburgh
State	Kentucky	Pennsylvania	Pennsylvania	Indiana	Pennsylvania	Pennsylvania
County	Breathitt	Armstrong	Indiana	Sullivan	Indiana	Greene
Mine(s)	StarFire	Canterbury	Greenwich, Keystone	Amax	Helvetia, Keystone	Consol, USS, Cyprus
Estimated Reserves (Million tons)	300	480	430	400	8000	6000
Classification ^a	Type I	Type II	Type II	Type II	Type III	Type III

^aClassification into Types I, II or III is on the basis of relative ease of cleaning to meet required specifications (see text for more detail).

Table 2-2. Cleaning characteristics of test coals.

Coal		I-1	II-1	II-2	II-3	III-1	III-2
Seam		Hazard 5A	Lower Kittanning	Lower Freeport	Indiana VII	Upper Freeport	Pittsburgh
Proximate Analysis, Raw Coal (Dry Basis)	Volatile Matter %	37.7	34.3	28.1	35.0	23.3	34.4
	Fixed Carbon %	58.8	51.3	55.9	55.7	46.3	51.9
	Ash %	3.5	14.4	16.1	9.3	30.4	13.7
	Total Sulfur %	0.7	2.6	2.8	0.9	2.0	1.4
Prescribed (Conventional) Cleaning Conditions	Top Size	14 mesh	14 mesh	14 mesh	100 mesh	200 mesh	200 mesh
	Specific Gravity of Separation	1.5	1.3	1.3	1.5	1.4	1.9
	Theoretical Yield %	97.6	51.7	46.7	87.0	53.9	86.7
Proximate Analysis, Upgraded Coal (Dry Basis)	Volatile Matter % ^a	38.4	39.1	32.6	36.9	31.8	37.9
	Fixed Carbon % ^a	59.9	58.4	64.8	58.7	63.3	52.7
	Ash %	1.7	2.5	2.6	4.5	4.9	4.9
	Total Sulfur %	0.7	0.8	0.9	0.3	0.7	0.9

^aEstimated values.

Table 2-3. CWM formulation data for test coals.

Coal	I-1	II-1	II-2	II-3	III-1	III-2
Seam	Hazard 5A	Lower Kittanning	Lower Freeport	Indiana VII	Upper Freeport	Pittsburgh
CWM Characteristics	% Loading	66	NA ^a	62.0	71.0	70.6 ^b
	Viscosity (cp at 100 sec ⁻¹)	1500	NA	1000	1000	1000

^aNot available.

^bProjected, based on Berggren, M.H. and Bhasin, A.K., "Correlation of Coal-Water Slurry Fuel Solids Loadings with Coal Characteristics", Presented at Seventh International Symposium on Coal-Slurry Fuels Preparation and Utilization, New Orleans, Louisiana, May 21-24, 1985.

Figure 2-1. Comparison of Partition Curves for Ideal and Actual Separations Showing Misplaced Material

Figure 2-2. Effect of Decreasing Particle Size on the Partition Curves

Figure 2-3. Schematic Diagram of the "Batch" Centrifugal Separator

Table 2-4. Size distribution of the feed and products when classifying quartz in the "batch" centrifuge.

Size, μm	Cumulative % Less Than Size		
	Feed	Product	Refuse
176	100.0	100.0	100.0
125	93.51	100.0	92.65
88	80.50	100.0	77.85
62	71.88	100.0	68.05
44	64.06	100.0	59.15
31	48.77	95.80	42.25
22	43.20	94.80	36.05
16	37.08	90.00	29.75
11	30.12	81.90	22.95
7.8	26.93	71.50	20.75
5.5	21.56	59.80	16.25
3.9	16.29	49.70	11.65
2.8	10.23	30.10	7.45
1.9	5.54	13.10	4.45
1.4	2.45	2.10	2.45

Figure 2-4. Kinetics of Flotation of hvA Bituminous Coal from Upper Freeport Seam

Frother: 0.65 Lb/T MIBC;

Collector: 1.3 Lb/T dodecane

a) Flotation Kinetics of total material

b) Flotation kinetics of individual size fractions

● +20M; ▽ 28 x 48 M; ▼ 48 x 100 M;

□ 100 x 200 M; ■ 200 x 400 M; △ -400 M

Table 2-5. Statistical parameters of fitting classical first-order model to individual size fractions in coal flotation (Frother: 0.65 Lb/T MIBC).

	Size Fraction, Mesh						
	+28	28x48	48x100	100x200	200x400	-400	Total
a) No Collector							
R_{∞}	24	64	76	82	87	72	70
k_1	2.44	2.62	2.30	1.86	1.49	0.85	1.79
r^2	0.986	0.999	0.999	0.997	0.998	0.994	0.995
MRS	1.256	0.868	2.249	3.237	2.587	5.181	3.812
b) Collector: 1.3 Lb/T dodecane							
R_{∞}	24	61	79	85	85	71	71
k_1	3.54	4.29	3.64	3.09	2.18	1.34	2.73
r^2	0.994	0.998	0.997	0.997	0.997	0.991	0.994
MRS	0.552	1.005	2.869	3.520	3.098	7.655	4.996
c) Collector: 2.6 Lb/T dodecane							
R_{∞}	38	72	83	88	89	74	76
k_1	4.97	5.02	4.01	3.13	2.48	1.31	3.01
r^2	0.999	0.999	0.999	0.999	0.999	0.986	0.996
MRS	0.201	0.467	0.872	0.990	1.581	12.790	3.64
d) Collector: 5.2 Lb/T dodecane							
R_{∞}	37	74	86	89	90	73	78
k_1	4.40	4.82	3.86	3.09	2.60	1.45	3.08
r^2	0.981	0.976	0.976	0.990	0.985	0.978	0.965
MRS	0.263	1.036	2.589	1.994	4.000	8.558	5.047

Figure 2-5. Experimental Set-Up To Determine Rate of Emulsification of Dodecane
V: Vessel; S: Stirrer; C: Flow-Through Cell;
P: Peristaltic Pump

Figure 2-6. Effect of Surfactant Concentration on Kinetics of Emulsification of Dodecane

Surfactant concentration:
▼ None; □ 0.0001%; ■ 0.001%; Δ 0.1%

Table 2-6. Estimates of the heights of transfer unit for the different column applications.

Reference	Application	D_c , m	d_p , μm	U_R , m/s	HTU, m
Luttrel et al [1988]	Coal	0.05	5	0.0067	0.29
Bensley et al. [1985]	Coal	0.10	-75	0.0039	0.28
Reddy et al. [1988]	Coal	0.10	-500	0.0043	0.43
Kho and Sohn [1989]	Talc	0.06	16	0.0066	0.26
Ounpuu and Tremblay [1991]	Sphalerite	1.20	-38	0.0063	0.48
Ynchausti et al. [1988]	Fluorite	0.06	-300	0.0114	0.70
	Pyrolusite	0.06	-210	0.0052	1.50

Figure 2-7. Determination of Design Parameters for Column Flotation

Figure 2-8. Effective Viscosity of Coal-Water Mixtures

Data set # 1
 $\langle r \rangle = 9.75 \mu, \sigma = 1.77$

Data set # 2
 $\langle r \rangle = 3.54 \mu, \sigma = 2.04$

Data set # 3
 $\langle r \rangle = 3.36 \mu, \sigma = 1.95$

Data set # 3
 $\langle r \rangle = 1.54 \mu, \sigma = 1.38$

Figure 2-9. Log-Normal Size Distribution of Coal Particles

Figure 2-10. Sedimentation in Coal-Water Mixtures

Figure 2-11. Coal - Water Mixture Profile

Figure 2-12. Equilibrium Profile - Non Stabilized Coal Particles

TOP VIEW

SIDE VIEW

Figure 2-13. Schematic Diagram of the Triboelectrostatic Separator

Figure 2-14. Overall Site View Showing the Location of the Fuel Preparation Facility and Future Emissions Control Site

Figure 2-15. Schematic Diagram of the Equipment Train in the Fuel Preparation Facility

SIDE VIEW

END VIEW

INSIDE DIAMETER - 18.0 INCHES
 OUTSIDE DIAMETER - 29.5
 INCHES
 3000 °F REFRACTORY
 SIX 1/4 " AIR PORTS
 .25 INCH PLATE
 CONSTRUCTION
 SHOWN WITHOUT FLANGES

Figure 3-1. Schematic Diagram of Air-Staged Quarl

Figure 3-2. Probe Used To Measure Erosion by Ash and Char Particles in the Convective Section of an Industrial Boiler

Figure 3-3. Properties of the Particles and Their Collisions with the Sample Surface, as Functions of Distance from the Jet Axis: Particle Velocity, Particle Flux, Particle Kinetic Energy and Impaction Angle

Figure 3-4. Erosion Rates as Functions of Temperature and the Jet Gas Oxygen Content

The solid lines are fits to the data measured from the nitrogen jet and oxygen jet. The curve for erosion in the air jet was calculated using the parameters obtained from the fitting results.

Figure 3-5. Estimate of the Erosion Rate of Carbon Steel by Fly Ash and Unburned Char from Superclean Coal-Water Fuel Combustion under the Following Conditions:

Particle Concentration 2.7 g / m^3 ,
Particle Size $87 \text{ } \mu\text{m}$,
Particle Density 1250 kg / m^3 ,
 30° Impaction Angle,
50% of Particles Colliding with the Surface
600 K Metal Temperature

Figure 5-1. Candidate Boilers Identified from CERL's Database

Figure 5-2. Candidate Boilers

Appendix A. Commercial Equipment Procured for the Dry Beneficiation System

Appendix A. Commercial equipment for the dry beneficiation system.

Equipment Description	Company	Model	Specifications
Rotary Screw Compressor	Kaeser	SM8	<u>Capacity:</u> 30 cfm free air <u>Discharge Pressure:</u> 110 psig <u>Discharge Air Quality:</u> 99.999 + % removal of liquid oil & H ₂ O
Receiver Tank			60 gallon rated @ 200 psig working pressure
Refrigerated Air Dryer	Kaeser	KRD-025	Dry 25 cfm to 35°F pressure dewpoint, rated at 175 psig
Power Supply (2)	Hippotronics	875-13	<u>Input:</u> 110V AC, 60 Hz, 14A <u>Output:</u> 75KV @ 13 mA <u>Polarity:</u> Reversible <u>Duty:</u> Continuous <u>Ripple:</u> 2% rms <u>Regulation:</u> 15% NL/FL
Volumetric Feeder	Tecnetics	E5	<u>Max. Rated Capacity:</u> 7.0 ft ³ /hr <u>Helix Sizes:</u> 1/4" and 1-1/4"
Balance	Mettler	PM4800	Delta range
Hygrometer	Hanna	HI9065	<u>Relative Humidity Range:</u> 0-100%

Appendix B. ABB CE Equipment Details

SUMMARY INFORMATION

Information contained in this Appendix includes a list of equipment from ABB CE that has been reconditioned and barcoded (Penn State Inventory) by Penn State, and equipment details for the following:

- **PUMPS**
 - Control Volume Pumps
 - Moyno Pumps
- **MIXERS**
 - Chemineer Mixers
 - Lightnin Mixers
 - Reliance Mixers
- **OTHER EQUIPMENT**

The equipment details include, where applicable, model and serial numbers, capacities, electrical requirements, notes on condition, and the company name, phone number, and person contacted for more information.

Explanation of Information:

- The equipment was stored in the two trailers that were used to transport the equipment to Penn State and was removed for reconditioning. One trailer was emptied while the other still contains some equipment.
- Items marked with a (•) are those that have been retrieved from the trailers. Some of these items have been barcoded, others will be after it is determined that they will be used. Items that are not marked are either missing (from the ABB CE list) or are in the trailer awaiting reconditioning.
- Most of the items have been wrapped in plastic for storage at the demonstration boiler site until the fuel preparation facility is completed. Several pieces of equipment are in The Combustion Laboratory.
- There is also a list of items that were not on the original ABB CE equipment list, but were donated to Penn State.

ABB CE Equipment List

PSU BAR CODE

• Acrison - Digital SCR Controller & Weigh Feeder Controller, SN 811754	
• Doric Digitrent 235, SN 10418	
LeBow Model 7530 Torque Indicator SN 3299	
Farrel Control Panel SN 810410	
• Fischer & Porter Digital Totalizer SN 8401A246802	
• Morehouse Mill SN LA-8, Model 40-25	161301
Farrel mixer SN M28850-TIPG	
• Lliquatex Seperator SN L-310186	161038
• Air Operated 55 Gal. Drum Vacuum Adaptor	161300
Laboratory Press (Carver) SN 24000-696, Model C	
• Isotemp Oven (Fisher) Model 175	161043
• Ribbon Mixer	161299
• Batch Ball Mill	161044
• Union Process Batch Attritor Mill	161037
• P-010 Moyno Pump MTR #F-6012-09-965, Pump #AS 69652	161033
• P-020 Moyno Pump MTR #P-56H3665M, Pump #AM 10383-11	161035
P-310 Moyno Pump MTR #P-56G3457P-VG, Pump #A-4012-2	
• P-320 Moyno Pump MTR #F-6145-04-847, Pump #GSA05952	161030
• P-250 Moyno Pump MTR #P-56H3665M-ZL, Pump #A533853	161036
• Spare Moyno Pump MTR #P56H3454M, Pump #G-5A06073	161032
• Spare Moyno Pump MTR #F8123-09-931, Pump #AS69651	161031
Spare Moyno Pump MTR #80108215-YC, Pump #AS33217	
• P-250 (water metering pump) (Milroyal) SN 132018-3	
• P-240 (ammonia pump) (Milroyal) MTR #P56H3003M, Pump #159689-1	161042
• P-220 (A.P. pump) (Milroyal) MTR #P56H039M-ZH, Pump #167332-1	161302
• P-230 (Stab pump) (Milroyal) MTR #P56H5039M-ZH, Pump #159889-2	161303
• P-210 (A.P. pump) (Milroyal) MTR #P56H5039M-X#, Pump #159171-A	161304
• Wrap Around Drum Heater	
• T-210 Stainless Steel 24"x36" Mix Tank	
• T-211 Stainless Steel 24"x36" Mix Tank	
T-220 Stainless Steel 24"x36" Mix Tank	
T-230 Stainless Steel 24"x36" Water Tank	
T-020 Stainless Steel 31"x42" Mix Tank	
T-110 Stainless Steel 250 Gallon Tank	
• T-120 Stainless Steel 250 Gallon Tank	
• T-010 Fiberglass 24"x42" Mix Tank	
T-310 Fiberglass 24"x42" Mix Tank	
T-320 Fiberglass 24"x42" Mix Tank	
• A-240 (water tank mixer) (Reliance) SN P48H2302M-WH	
• A-210 (A.P. mixer) (Reliance) SN C48H2502M-VF	
• A-220 (A.F. mixer) SN P48H2302M-WH	
• A-211 (A.P. mixer) (Reliance) SN C48H2502M-VF	
• A-310 (3rd tank mixer) (Chemineer) SN 1-75919-2	161987
• A-320 (4th tank mixer) (Lightnin) SN 81/977711	161985
• A-110 Mixer (Chemineer) SN 1-75417-2	161306
• A-120 Mixer (Chemineer) SN 1-75417-1	161307

ABB CE Equipment List

• A-010 (1 tk mixer) (Lightnin) MTR #6200589287	161308
• A-020 (2 tk mixer) (Lightnin) MTR #P2163319D	161309

Items That Are Not On The CE List

• SE Series Fadri Basket Filter SN 82043E1	161039
• SE Series Fadri Basket Filter SN 82043E2	161040
• Control Volume Pump MTR #P56G2337T-VG	161041
• Pneumatic Mixer (Lightnin) SN 84 227008	
• General Electric Mixer Model 5KC35MN73	
• Reliance Mixer (Chemineer) MTR #P56H3003M-PE, Mixer #1-74050-4	
• Reliance Mixer MTR #B77V0006MNJ, Mixer #83-168337	
• Lightnin Mixer MTR#5K39GG402A, Mixer #7116246	
• Lightnin Mixer SN 80/801234	
• Lightnin Mixer SN 80/801234	
• Lightnin Mixer SN 82/137627	161896
• Moyno Pump (US Electric) MTR #F-6012-07-931, Pump #A3014-1	161034
• Spare Varidrive Motor MTR #F3070-05-921	
• Reliance Mixer Motor with Drive Control (mounted on cart) FR #EA56C	161305
-

CONTROL VOLUME PUMPS

CV PUMP #1

CONTROLL VOLUME PUMP - BAR CODE NUMBER

MILTON ROY CO.

PUMP (ALLOY 20)

MODEL FR-145-72

CAP SIDE 4.7 G.P.H.

PRESSURE 1500 P.S.I.

SERIAL # 132028-3

CENTURY MOTOR

HP 3/4 PH 1 INSUL CLASS A HZ 60

FRAME K56C VOLTS 115,230

TYPE CS AMPS 10.4

DESIGN CODE L GEAR RATIO

SF 1 SERIAL # S10

TIME RATING CONT PART# 8-120682-02

NOTES

DOES NOTE WORK, PROBLEM WITH ELECTRIC MOTOR

DATE TAGGED

MILTON ROY CO

(215)-441-0800

JACK GIBBONS

CV PUMP #2

CONTROLL VOLUME PUMP - BAR CODE NUMBER (161041)

MILTON ROY CO.

PUMP

MODEL FR-161-96

CAP SIDE 57.0 G.P.H.

PRESSURE 100 P.S.I.

SERIAL # 154788

RELIANCE MOTOR

ID # P56G2337T - VG

HP 3/4 PH 3 INSUL CLASS B HZ 60

FRAME K56C VOLTS 230,460

TYPE P AMPS 3,1.5

DESIGN CODE K RPM 1725

AMB TEMP 40 C F# T347302

TIME RATING CONT NEMA DESIGN# UA 998

NOTES

NO KNOWN DEFECTS, WORKS FINE.

DATE TAGGED 1/25/93

MILTON ROY CO

(215)-441-0800

JACK GIBBONS

CY PUMP #3

CONTROLL VOLUME PUMP - BAR CODE NUMBER (161042)

MILTON ROY CO.

PUMP

MODEL D2-1-30SM

CAP SIDE 2.1 G.P.H.

PRESSURE 660 P.S.I.

SERIAL # 159689-1

RELIANCE MOTOR

ID # P56H3003M

HP 1/4 PH 3 INSUL CLASS B HZ 60

FRAME EA56 VOLTS 230,460

TYPE P AMPS 1.1, .55

DESIGN CODE L RPM 1725

AMB TEMP 40 C

TIME RATING CONT

NOTES

NO KNOWN DEFECTS, WORKS FINE.

DATE TAGGED 1/25/93

MILTON ROY CO

(215)-441-0800

JACK GIBBONS

CY PUMP #4

CONTROLL VOLUME PUMP - BAR CODE NUMBER (161302)

MILTON ROY CO.

PUMP

MODEL DB-1-1178

CAP SIZE 3.16 G.P.H.

PRESSURE 1000 P.S.I.

SERIAL # 167332-1

RELIANCE MOTOR

DUTYMASTER A.C. MOTOR

ID # P56H5039-M-ZH

HP 1/4 PH 3 INSUL CLASS B HZ 60

FRAME GA56C VOLTS 230,460

TYPE P AMPS 1.1, .55

DESIGN CODE M RPM 1725

AMB TEMP 40 C NEMA DESIGN UA 590 T

TIME RATING CONT F # TB08944

NOTES

NO KNOWN DEFECTS,

DATE TAGGED 2/1/93

MILTON ROY CO

(215)-441-0800

JACK GIBBONS

CV PUMP # 5

CONTROLL VOLUME PUMP - BAR CODE NUMBER (161303)

MILTON ROY CO.

PUMP

MODEL D2-1-60SM

CAP SIZE 4.2 G.P.H.

PRESSURE 650 P.S.I.

SERIAL # 159889-2

RELIANCE MOTOR

DUTYMASTER A.C. MOTOR

ID # P56H5039-M-ZH

HP 1/4 PH 3 INSUL CLASS B HZ 60

FRAME GA56C VOLTS 230,460

TYPE P AMPS 1.1, .55

DESIGN CODE V RPM 1725

AMB TEMP 40 C NEMA DESIGN UA 590 TE

TIME RATING CONT F # U74009

NOTES

NO KNOWN DEFECTS

DATE TAGGED 2/1/93

MILTON ROY CO

(215)-441-0800

JACK GIBBONS

CV PUMP # 6

CONTROLL VOLUME PUMP - BAR CODE NUMBER (161304)

MILTON ROY CO.

MILROYAL PUMP

MODEL A MR 1-28-49SM

CAP SIZE 30 G.P.H.

PRESSURE 140 P.S.I.

SERIAL # 159171-A

RELIANCE MOTOR

DUTYMASTER A.C. MOTOR

ID # P56H5039-M-X#

HP 1/4 PH 3 INSUL CLASS B HZ 60

FRAME 3A56C VOLTS 230,460

TYPE P AMPS 1.1, .55

DESIGN CODE M RPM 1725

AMB TEMP 40 C NEMA DESIGN UA590

TIME RATING CONT F # T808073

NOTES

NO KNOWN DEFECTS

DATE TAGGED 2/1/93

MILTON ROY CO

(215)-441-0800

JACK GIBBONS

MOYNO PUMPS

PUMP#1

REEVES PUMP - BAR CODE NUMBER (161032)

REEVES MOTOR DRIVE

IDENT NO. 30006653-SF CASE NO. 79183-20K

SIZE 0112 OUTPUT MAX 324

ASSEM. 105 (RPMS) MIN 32.4

BELT 605036-29B GEAR RATIO 14.4

HP 3/4 M1001207B

ELECTRIC MOTOR

IDENT NO. P56H3454M FR FB56C TYPE P PH 3

HP RPM 1725 VOLTS 230/460 AMPS 4.6/2.3 HZ 60

TIME RATING CONT INS CLASS B AMB C 40 CODE N

PUMP

FRAME/TYPE 2L3 SSO

FORM GF

SERIAL NO. GSA06073

NOTES

Needs a new electric box cover

DATE TAGGED 1/18/93

WM WAGNER SALES (STEVE WILLIAMS)

(717)-524-4411

PUMP#2

REEVES PUMP - BAR CODE NUMBER (161035)

REEVES X-V MOTOR DRIVE

IDENT NO. 30014457-TK CASE NO. 079283-20-MR

SIZE B112 OUTPUT MAX 452

ASSEM. 105 (RPMS) MIN 50

BELT 605036-29-6 GEAR RATIO 9.3

HP 1-1/2 M10C1805

DUTY MASTER A.C. MOTOR

IDENT NO. P56H366SM-SK FR FD56CZ TYPE P PH 3

HP RPM 1725 VOLTS 230/460 AMPS 6.8/3.4 HZ 60

TIME RATING CONT INS CLASS B AMB C 40 CODE J

MOYNO PRODUCTS PROGRESSING CAVITY PUMP

FRAME/TYPE 2L4 CDO

FORM LD

SERIAL NO. AM10383-11

TRIM AAA

NOTES

Ready to run

DATE TAGGED 1/18/93

WM WAGNER SALES (STEVE WILLIAMS)

(717)-524-4411

PUMP#3**REEVES PUMP -BAR CODE NUMBER (161036)****REEVES MOTOR DRIVE****IDENT NO. 30017262-NM CASE NO. 079283-20-MR****SIZE B0112 OUTPUT MAX 324****ASSEM. 105 (RPMS) MIN 32.4****BELT 605036-29-C GEAR RATIO 9.3****HP 1-1/2 M1001805****DUTY MASTER A.C. MOTOR****IDENT NO. P56H3665M-ZL FR FD56CZ TYPE P PH 3****HP RPM 1725 VOLTS 230/460 AMPS 6.8/3.4 HZ 60****TIME RATING CONT TE INS CLASS B AMB C 40 CODE J****MOYNO PRODUCTS PROGRESSING CAVITY PUMP****FRAME/TYPE 2L4 CDO****FORM****SERIAL NO. A533835****TRIM AAA NC****NOTES**

Ready to run

DATE TAGGED 1/18/93**WM WAGNER SALES (STEVE WILLIAMS)****(717)-524-4411****PUMP#4****US ELECTRICAL PUMP - BAR CODE NUMBER (161033)****BA VARIDRIVE MOTOR****HP 1.5 PH 3 INSUL CLASS B HZ****FRAME 6-145-5 VOLTS 200,230,460****TYPE VAV-TFGD AMPS 6.7,6.5,3.25****DESIGN B CODE M GEAR RATIO 9.46****MOTOR RPM 1740 RPM MIN 45 RPM MAX 452****CONT. RATING 40 C MAX AMB ID# F-6012-09-965****PUMP****FRAME/TYPE 2L4 550****FORM GK SERIAL # AS69652****TRIM AAC****NOTES**

Needs electrical box cover

DATE TAGGED 1/18/93**WM WAGNER SALES (STEVE WILLIAMS)****(717)-524-4411**

PUMP#5

US ELECTRICAL PUMP - BAR CODE NUMBER (161030)

N VARIDRIVE MOTOR

HP 2 PH 3 INSUL CLASS B HZ 60

FRAME 10-145T-7 VOLTS 200,230,460

TYPE VAV-TF-GD AMPS 7.9,7.2,3.6

DESIGN B CODE M GEAR RATIO 9.46

MOTOR RPM 1725 RPM MIN 45.2 RPM MAX 452

CONT. RATING 40 C MAX AMB ID# F-6145-04-847

PUMP

FRAME/TYPE 1L4 550

FORM GS SERIAL # A05952

TRIM

NOTES

Needs electrical box and box cover

Generates loud noises during operation possibly caused by notches in belt of varidrive.

Belt dressing may quiet noise, perhaps the belt should be replaced prior to pump installation in fuel prep facility.

DATE TAGGED 1/18/93

WM WAGNER SALES (STEVE WILLIAMS)

(717)-524-4411

PUMP#6

US ELECTRICAL PUMP - BAR CODE NUMBER (161031)

BA VARIDRIVE MOTOR

HP 1 PH 3 INSUL CLASS B HZ 60

FRAME 6-145T-5 VOLTS 200,230,460

TYPE VAV-TFGD AMPS 5.5,5.2,2.6

DESIGN B CODE R GEAR RATIO 9.46

MOTOR RPM 1755 RPM MIN 45 RPM MAX 452

CONT. RATING 40 C MAX AMB ID# F-8123-09-931

PUMP

FRAME/TYPE 1L3 SSB

FORM GK SERIAL # AS69651

TRIM AAC

NOTES

Ready to run

DATE TAGGED 1/18/93

WM WAGNER SALES (STEVE WILLIAMS)

(717)-524-4411

PUMP#7

US ELECTRICAL PUMP - BAR CODE NUMBER (161034)

ABE VARIDRIVE MOTOR

HP 1 1/2 PH 3 INSUL CLASS B HZ 60

FRAME 6-145-5 VOLTS 200,230,460

TYPE VAV-TF-CD AMPS 6.7,6.5,3.25

DESIGN B CODE M GEAR RATIO 9.46

MOTOR RPM 1740 RPM MIN 45 RPM MAX 452

CONT. RATING 40 C MAX AMB ID# F-6012-07-931

PUMP

FRAME/TYPE 1L3 SSAD

FORM BD SERIAL # A3014-1

TRIM

NOTES

From parts missing stator, stator clamp, electric box missing, need varibelt # 6.1.

DATE TAGGED 1/18/93

WM WAGNER SALES (STEVE WILLIAMS)

(717)-524-4411

US ELECTRICAL -

B VARIDRIVE MOTOR

HP 1/2 PH 3 INSUL CLASS B HZ 60

FRAME 6-56-5 VOLTS 200,230,460

TYPE VAV-JF-GD AMPS 3.2,3.0,1.5

DESIGN B CODE M GEAR RATIO 20.6

MOTOR RPM 1710 RPM MIN 21 RPM MAX 208

CONT. RATING 55 C RISE ID# F-3070-05-921

NOTES

For parts , varidrive motorunit only, missing both back cover plates, varidrive control froze, fan cover also missing.

WM WAGNER SALES (STEVE WILLIAMS)

(717)-524-4411

CHEMINEER MIXERS

MIXER #7

RELIANCE MIXER BARCODE NUMBER

DUTYMASTER A-C MOTOR

ID # P56H3003M-PE

HP 1/4 HZ 60 TYPE P

RPM 1725 VOLTS 230, 460

SF PH 3 AMPS 1, .55

AMB 40 C INS CLASS B CODE L

TIME RATING CONT NEMA DESIGN

SER NO STK NO FR EA56C

MIXER

CHEMINER INC.

MODEL # PG-2 TYPE

STYLE SER # 1-74050-4

RPM 430 EOPT # B6-LM4

NOTES

DOES NOT WORK

DATE TAGGED

CHEMINEER INC.

PFS DIST.

(412)-561-8218

MIXER #12

MIXER LARGE MODEL BARCODE NUMBER (161987)

RELIANCE MOTOR

DUTYMASTER AC MOTOR

ID # P18K1014C

HP 3 HZ 60 TYPE P

RPM 1740 VOLTS 230, 460

SF 10 PH 3 AMPS 9.6, 4.8

AMB 40 C INS CLASS B DESIGN B

GRADE K DUTY CONT FR 182 T

DRIVE END BEARING 308C02XPP30A26

OPP DRIVE END BEARING 258C02XP30A26

CHEMINEER MIXER

MODEL # VLA-30

SER # 1-75919-2

RPM 430

NOTES

NO KNOWN DEFECTS

DATE TAGGED 1/25/93

CHEMINEER INC.

PFS DIST.

(412)-561-8218

MIXER #15

MIXER LARGE MODEL BARCODE NUMBER (161306)

MOTOR

RELIANCE

ID # T56H1717M-QF

FRAME EF56C

RPM 1725 VOLTS 180

INS CLASS F AMPS 3.7

AMB 40 C TIME RATING CONT 44

CHEMINEER MIXER

MODEL # MLBX-7

SER # 1-74517-2

RPM 240/24

NOTES

NO KNOWN DEFECTS

DATE TAGGED 2/1/93

CHEMINEER INC.

PFS DIST.

(412)-561-8218

MIXER #16

MIXER LARGE MODEL BARCODE NUMBER (161307)

MOTOR

PRELIANCE

ID # 56H1717M-YD

FRAME EF56C

RPM 1725 VOLTS 180

INS CLASS F AMPS 3.7

AMB 40 C TIME RATING CONT 44

CHEMINEER MIXER

MODEL # MLBX-7

SER # 1-74517-1

RPM 240/24

NOTES

NO KNOWN DEFECTS, IS ATTACHED TO STEEL FRAME

DATE TAGGED 2/1/93

CHEMINEER INC.

PFS DIST.

(412)-561-8218

RELIANCE MIXERS

MIXER # 2

RELIANCE MIXER BARCODE NUMBER

DUTYMASTER A-C MOTOR

ID # P48H2302M-WH

TYPE P FRAME GA48 PH 3

HP 1/4 HZ 60

RPM 1725 VOLTS 230, 460

NO. F T807079 AMPS 1.1, .55

AMB 40 C INS CLASS B CODE M

TIME RATING CONT NEMA DESIGN UA590

NOTES

NO KNOW DEFECTS, NOT TESTED YET

DATE TAGGED

MARINO ELECT. (JOE)

(215)-521-5230

MIXER # 3

RELIANCE MIXER BARCODE NUMBER

DUTYMASTER A-C MOTOR

ID # C48H2502M-VF

TYPE CS FRAME GD48 PH 1

HP 1/4 HZ 60

RPM 1725 VOLTS 115, 230

NO. F S428774 AMPS 4.4, 2.2

AMB 40 C INS CLASS B CODE K

TIME RATING CONT NEMA DESIGN UA345

NOTES

NO KNOW DEFECTS, NOT TESTED YET

DATE TAGGED

MARINO ELECT. (JOE)

(215)-521-5230

MIXER # 4

RELIANCE MIXER BARCODE NUMBER

DUTYMASTER A-C MOTOR

ID # P48H2302M-WH

TYPE P FRAME GA48 PH 3

HP 1/4 HZ 60

RPM 1725 VOLTS 230, 460

NO. F T80706 AMPS 1.1, .55

AMB 40 C INS CLASS B CODE M

TIME RATING CONT NEMA DESIGN UA590

NOTES

NO KNOW DEFECTS, NOT TESTED YET

DATE TAGGED

MARINO ELECT. (JOE)

(215)-521-5230

MIXER # 5

**RELIANCE MIXER BARCODE NUMBER
DUTYMASTER A-C MOTOR**

ID # C48H2502M-UF

TYPE CS FRAME GD48 PH 1

HP 1/4 HZ 60

RPM 1725 VOLTS 115, 230

NO. F S428118 AMPS 4.4, 2.2

AMB 40 C INS CLASS B CODE K

TIME RATING CONT NEMA DESIGN UA345

NOTES

NO KNOW DEFECTS, NOT TESTED YET

DATE TAGGED

MARINO ELECT. (JOE)

(215)-521-5230

MIXER # 19

MIXER ON CART BARCODE NUMBER (161305)

MOTOR

RELIANCE

ID # T56H1020M-TE

FRAME EA56C PPM 1750

AMB 40 VOLTS 90

INS CLASS F AMPS 3.5

DUTY CONT CODE H FE 1.3

TYPE TPR HP 1/3

TIME RATING CONT

MAX PEAK AMPS 55.0

E54825

RELIANCE CONTROL PANNEL

DRIVE MODEL # 14C10

SER # 017-014C10A-RF-0206

HP 1/4-3/4

AC INPUT 115 V 11 A

DC OUTPUT 90 V 7.5 A

MINPAK PLUS V & S

NOTES

NO KNOWN DEFECTS, MOUNTED ON CART

DATE TAGGED 2/1/93

MARINO ELECT. (JOE)

(215)-521-5230

LIGHTNIN MIXERS

MIXER #1

LIGHTNIN PNEUMATIC MIXER BARCODE NUMBER

SERIAL # 84 227008

MODEL # XJA-33

NOTES

NO KNOW DEFECTS, READY TO USE

DATE TAGGED

LIGHTNIN DIST. (BOB)

(412)-788-6800

MIXER #6

GENERAL ELECTRIC MIXER BARCODE NUMBER

GE A-C MOTOR

MOD # 5KC35MN73

HP 1/3 HZ 60

RPM 1725 VOLTS 115, 230

SF1 PH 1 AMPS 6, 3

AMB 40 C INS CLASS B CODE K

TIME RATING CONT NEMA DESIGN

SER NO FPD STK NO C367 FR 56C

MIXER

LFE EASTERN INDUSTRIES

MODEL # RH-2 TYPE

STYLE SER # 910691-1A

NOTES

NO KNOW DEFECTS, WORKS

DATE TAGGED

LIGHTNIN DIST. (BOB)

(412)-788-6800

IT IS NOT A LIGHTNIN BUT A COMPAREABLE MODEL

MIXER #8

**LIGHTNIN MIXER BARCODE NUMBER
MOTOR**

REF # 605558D801 X-123840

HP 1/3 HZ 60 TYPE PF

RPM 1725 VOLTS 230, 460

SF PH 3 AMPS 1.8, .9

AMB 40 C INS CLASS A CODE L

TIME RATING CONT NEMA DESIGN

SER NO STK NO FR F56CZ

DUTY COND SER FACT 10

LR - 13758

MIXER

MODEL # ND-1 TYPE

SER # 80/801234

NOTES

NOT TESTED YET

DATE TAGGED

LIGHTNIN DIST. (BOB)

(412)-788-6800

MIXER #9

**LIGHTNIN MIXER BARCODE NUMBER
MOTOR**

REF # 605558D801 X-123840

HP 1/3 HZ 60 TYPE PF

RPM 1725 VOLTS 230, 460

SF PH 3 AMPS 1.8, .9

AMB 40 C INS CLASS A CODE L

TIME RATING CONT NEMA DESIGN

SER NO STK NO FR F56CZ

DUTY COND SER FACT 10

LR - 13758

MIXER

MODEL # ND-1 TYPE

SER 80/801234

NOTES

NOT TESTED YET

DATE TAGGED

LIGHTNIN DIST. (BOB)

(412)-788-6800

MIXER # 10

**RELIANCE MIXER BARCODE NUMBER
DUTYMASTER A-C MOTOR**

ID # B77V0006MNJ

HP 1/3 HZ 60 TYPE P

RPM 1725 VOLTS 230, 460

SF PH 3 AMPS 1.6, .8

AMB 40 C INS CLASS B CODE L

TIME RATING NEMA DESIGN

FNO T412158 FR HN56C

MIXER

MODEL # XJO-30 TYPE

SER # 83/168337

NOTES

NOT TESTED YET

DATE TAGGED

LIGHTNIN DIST. (BOB)

(412)-788-6800

MIXER # 11

**LIGHTNIN MIXER BARCODE NUMBER
MOTOR**

CAT # 5K39GG402A

HP 1/3 HZ 60 CODE L

RPM 1725 VOLTS 230, 460

SER W186 PH 3 AMPS 1.6, .8

AMB 40 C INS CLASS A CODE L

SF 1.0 TIME COND

SER NO FGL FR 48Y

MIXER

MODEL # ND1

SER # 7116246

NOTES

NO KNOWN DEFECTS, HAS PLUG CORD INCLUDED.

DATE TAGGED

LIGHTNIN DIST. (BOB)

(412)-788-6800

MIXER #13**MIXER LARGE MODEL BARCODE NUMBER (161985)****MOTOR****GENERAL ELECTRIC**MODEL # 5K1821 L6448AHP 3 HZ 60 NO CTFRPM 1755 VOLTS 230, 460SF 1 PH 3 AMPS 9.2, 4.6AMB 40 C NEMA DESIGN BDUTY CONT 182TYSHAFT END BEARING 35BCO2XPOPP END BEARING 258C02XP**LIGHTNIN MIXER**MODEL # ND-48SER # 81-977711**NOTES**

NO KNOWN DEFECTS

DATE TAGGED 1/25/93

LIGHTNIN DIST. (BOB)

(412)-788-6800

MIXER #14**MIXER LARGE MODEL BARCODE NUMBER (161896)****MOTOR****PACEMAKER**MODEL # 8263799-E1HP 1.5 HZ 60 TYPE AE4BRPM 1735 VOLTS 230, 460SF 1.0 PH 3 AMPS 5.4, 2.7AMB 40 C INS CL BDUTY CONT FR 145TCOPR INST C519 CODE K WDGS 1FRT END BRG 2035EXT END BRG 2075NEMA DESIGN B OP TEMP CODE T3B

02B4ECAA0001

LIGHTNIN MIXERMODEL # NLDG-150VSER # 82/137627BRG 1 # 107KSFFBRG 2 # 304SFBRG 4 # 207SFBELT # 07P00144-0010**NOTES**

NO KNOWN DEFECTS

DATE TAGGED 1/25/93

LIGHTNIN DIST. (BOB)

(412)-788-6800

MIXER # 17

LIGHTIN MIXER LARGE MODEL BARCODE NUMBER (161308)

MOTOR

US ELECTRIC

ID # 62-00589-287

FRAME 215 T TYPE L TE

RPM 1745 VOLTS 230, 460

INS CLASS B AMPS 260, 130

DESIGN B CODE H SF 1.0

PH 3 HZ 60 HP 10

AMB 40 EFF 87.5

OPP END BRG 6206-J/C3

LOWER END BRG 6208-J/C3

G1830013

OUTPUT SHAFT ROTATION

GENERAL SIGNAL MIXING EQUIPMENT CO

MODEL # 72Q10VM

SER # 8212822201

RATIO 5,17

OUTPUT RPM 350/117

RECOM HP 10

NOTES

NO KNOWN DEFECTS, WORKS FINE, FAN COVER HAS SMALL CHIP MISSING,

SHAFT STAMPED #1

DATE TAGGED 2/1/93

LIGHTNIN DIST. (BOB)

(412)-788-6800

MIXER # 18

LIGHTIN MIXER LARGE MODEL BARCODE NUMBER (161309)

MOTOR

RELIANCE

ID # P2163319D

FRAME 215 T PPM 3515

AMB 40 VOLTS 330, 460

INS CLASS F AMPS 2.6, 11.3

DUTY CONT CODE H SF 1.15

PH 3 HZ 60 HP 10

OPP END BRG 30 C02X30X26

DRIVE END BRG 35 C02X30X26

OUTPUT SHAFT ROTATION

GENERAL SIGNAL MIXING EQUIPMENT CO

MODEL # 72Q10

SER # 8524868901

RATIO 5.1

OUTPUT RPM 676/135

RECOM HP 10

NOTES

NO KNOWN DEFECTS, WORKS FINE, SHAFT STAMPED #2

DATE TAGGED 2/1/93

LIGHTNIN DIST. (BOB)

(412)-788-6800

OTHER EQUIPMENT

ATTRITOR

BATCHTYPE ATTRITOR - BAR CODE NUMBER(161037)

UNION PROCESS INC.

TYPE B

SIZE 1 S

NO. 2288

US ELECTRICAL MOTORS

VARIDRIVE MOTOR

HP 2 PH 3 INSUL CLASS B HZ 60

FRAME 15-184T VOLTS 230,460

TYPE VA-LF AMPS 8.8,4.4

DESIGN B CODE K GEAR RATIO

MOTOR RPM 1145 RPM MIN 300 RPM MAX 2000

CONT. RATING 75 C RISE ID# 61-10200-188

(G0820180)

NOTES

RUNS FINE, FAN MISSING ONE FIN BUT SHOULD NOT CREATE A PROBLEM.

DATE TAGGED 1/18/93

UNION PROCESS

(219)-929-3333

VICKY

DO NOT MAKE ANY MORE

BALL MILLER/MIXER FLOOR MODEL

JUG MILL- BARCODE NUMBER(161044)

BALDER MOTOR

CAT # M3538

HP 1/2 HZ 60 CODE L

RPM 1725 VOLTS 208-230, 460

SER W186 PH 3 AMPS 2.1-2.0, 1

AMB 40 C INS CLASS B CODE L

PF 85% SPEC 34-1169-872

FULL LOAD EFF 74% FR 56

GEAR DRIVE

MODEL # 107 SM25

SER # 107 SM 12853

RATIO 25

FRAME

MODEL # 0 JM

SER # A 37339

NOTES

NO KNOWN DEFECTS

DATE TAGGED 1/25/93

PAUL O. ABBE INC

LITTLE FALLS NJ

(201)-256-4242

SE SERIES FADRI-BASKET FILTER

RONNINGEN - PETTER DIV. DOVER CORP. - BAR CODE NUMBER (161039)

TYPE UM W 1979

MAX WP 150 PSI

MAX TEMP. 220 DEG F

MIN TEMP. -20 DEG F

SERIAL # 82043E1

BASKET DRAIN SIZE 3/32

NOTES

NO KNOWN DEFECTS, READY TO USE.

DATE TAGGED 1/18/93

ECCO FITLERS

(215)-353-5608

AM VESSEL WITH 2" FLANGE COMPARABLE MODEL

SE SERIES FADRI-BASKET FILTER

RONNINGEN - PETTER DIV. DOVER CORP.- BAR CODE NUMBER (161040)

TYPE UM W 1979

MAX WP 150 PSI

MAX TEMP. 220 DEG F

MIN TEMP. -20 DEG F

SERIAL # 82043E2

BASKET DRAIN SIZE 1/8

NOTES

NO KNOWN DEFECTS, READY TO USE.

DATE TAGGED 1/18/93

ECCO FITLERS

(215)-353-5608

AM VESSEL WITH 2" FLANGE COMPARABLE MODEL

OVEN

FISHER SCIENCE CO. - BAR CODE NUMBER (161043)

MODEL 175

SERIAL # 739

AMPS 7 HZ 60

NOTES

NO KNOWN DEFECTS.

DATE TAGGED 1/25/93

FISCHER SCIENCE CO

(215)-640-7940

COMPARABLE MODEL

MOREHOUSE SERIES II

QCV PRESSURE SANDMILL- BAR CODE NUMBER (161301)

DISPERSION BY DESIGN

MODEL QCV 10 - 25

SERIAL # LA -8

INDUCTION MOTOR

ALLIS-CHALMERS

SERIAL # 4-5100-03658-4-1

HP 30 PH 3 INSUL CLASS B HZ 60

FRAME 286TCVZ VOLTS 230,460

TYPE RGZZV AMPS 71.4, 35.7

DESIGN B CODE G RPM 1750

AMB TEMP 40 C DUTY CONT

SF 1.0 SH END BRG 55BC02JPP3

OP END BRG 45BC02JPP3

SPEED REDUCER

STERLING POWER SYSTEMS

MODEL # TM-206-3

GEAR RATIO 30.1

ELECTRIC MOTOR FOR HAZARDOUS LOCATION

JEFFERY POWER DIVISION

HP 1.5 PH INSUL CLASS B HZ 60

FRAME GM145TC VOLTS 230,460

MODEL GA-69721 AMPS 6.2, 3.1

DESIGN B CODE K RPM 1725

AMB TEMP 40 C DUTY CONT

CLASS 1 GROUP D OPER. TEMP 165 C

NO S-N - 240629

NO 76 - 1554

CROUSE HINDS

COVERED UNIT ON SIDE

ID # EJB241208NX

NOTES

NO KNOWN DEFECTS

DATE TAGGED 2/1/93

MOOREHOUSE SERIES II 1230

(714)-738-5000

NEW ONE TODAY WITHOUT SOME OF THE CONTROLS

LIQUATEX SEPARATOR

ROTEX INC. - BAR CODE NUMBER (161038)

MODEL # L - 22-1.0

SERIAL # L - 320186

3 SCREEN FRAMES INCLUDED

NOTES

NO KNOWN DEFECTS.

DATE TAGGED 1/18/93

ROTEX

(513)-541-1236

DO NOT MAKE ANYMORE

RIBBION MIXER

THE J.H. DAY COMPANY- BAR CODE NUMBER (161299)

SERIAL # 86169

MOTOR

US ELECTRIC MOTOR

VARIDRIVMOTOR

ID # F-8651-02-337

HP 3 PH 3 INSUL CLASS B HZ 60

FRAME 16-182T-22 VOLTS 230,460

TYPE VA-TF-GH AMPS 11, 5.5

DESIGN B CODE K RPM 1730

AMB TEMP 40 C GEAR RATIO 5.07

MIN RPM 88.8 MAX RPM 888

NOTES

NO KNOWN DEFECTS

DATE TAGGED 2/1/93

J H DAY CO

(606)-525-7600

DO NOT MAKE THEM ANYMORE

VAC U MAX

VAC U MAX CO. - BARCODE NUMBER (161300)

MODEL NUMBERS

MDL-HXPPR-16, AC-013, VPU-5-5T

SERIAL # 111133-3-83

DETECTOR

AUTOMATION PRODUCTS INC

DYNATROL DETECTOR

TYPE CL-10GJ

RATED PRESSURE 3000 PSI AT 100 F

MAX TEMP 300 F

MOTOR

MARATHON ELECTRIC

ID # 184TTGS7071ADW

MODEL KN

HP 5 PH 3 INSUL CLASS B HZ 60

FRAME 184T VOLTS 230,460

TYPE TGS AMPS 13.2, 6.6

DESIGN B CODE J RPM 1735

AMB TEMP 40 C NEMA DESIGN 85.5

TIME RATING CONT F # T808073

ENC EPFC SF 1.0 NOM PH 80.7

MAX CAP KVAR 2.9 COR AMP 11/5.5

SHAFT END BRG 206 OPP END BRG 205

NOTES

DATE TAGGED 2/1/93

VAC U MAX

(201)-759-7121

ROMAN KOMSA

DORIC DIGITRENT
DIGITAL CONTROLLER- BARCODE NUMBER
SERIAL # 10418
NOTES
NO KNOWN DEFECTS
DATE TAGGED
WAVETECH CORP
(619)-495-3200
DO NOT MAKE THEM ANYMORE

FISHER AND PORTER
DIGITAL TOTALIZER - BARCODE NUMBER
MODEL # 10D1475
NOTES
NO KNOWN DEFECTS
DATE TAGGED
FISHER AND PORTER
(215)-674-6000

ACRISON
WEIGH FEEDER- BARCODE NUMBER
SERIAL # 811754
NOTES
NO KNOWN DEFECTS
DATE TAGGED
ACRISON
(908)-613-5353

PROCESS PIPING SPECIALTIES
WRAP IT HEAT, DRUM HEATER - BARCODE NUMBER
55 GAL DRUM, STANDARD HEATER
NOTES
NO KNOWN DEFECTS
DATE TAGGED
PROCESS PIPING SPECIALTIES

TANKS.-
VARIOUS MODELS
TWO SUPPLIERS

ECCO FITLERS
STEVE GOZUR
(215)-353-5608

J H PROCESSING
JOHN HIGHBERGER
(215)-695-0900

Appendix C. Description of the Research Boiler and Auxiliary Components

Description of the Research Boiler and Auxiliary Components

The 1,000 lb/h steam boiler is shown schematically in Figure C-1. The boiler is a 200 psig maximum pressure A-Frame water-tube boiler, designed and built by Cleaver Brooks. The combustion chamber is 3'x3'x7' (63 ft³) with a maximum heat release rate of 42,000 Btu/ft³-h. It contains 288 ft² of heating surface and the maximum fuel firing rate is two million Btu/h.

The boiler is equipped with nine pairs of 3-inch diameter side ports for gaseous and particulate sampling. The combustion gases are split into two convective passes, one on each side of the radiant combustion chamber. There are access doors into each end of the convective section, two ash hoppers under each convective section, and a doorway into the combustion chamber.

To promote and enhance combustion, a ceramic quarl extends the combustion chamber by two feet. The quarl is preheated by a natural gas flame prior to CWF combustion and provides a source of radiant heat to help support the CWF flame. Figure C-2 shows the burner/nozzle/quarl section.

The nozzle is of twin-fluid design and is shown in Figure C-3. The atomizing medium, compressed air, is swirled as it meets the fuel, passes through a restriction, and then expands externally. The swirler and nozzle are made of tool steel.

The CWF is fed from a day tank with 500 lb capacity to a Moyno progressive cavity pump. From the pump the fuel passes through a 1/64" screen to remove any large coal particles and is introduced into the nozzle.

A gas-fired combustion air preheater supplies over 300,000 Btu/h to preheat up to 1,800 lb/h of air to 600°F. The preheated combustion air (secondary air) passes through a conventional swirl ring several inches in front of the gas distribution ring, both of which are 8 inches in diameter. A small portion of unheated primary air is fed to an annulus surrounding the nozzle. This air serves to insulate the nozzle and fuel line from the hot secondary air and prevents overheating of the fuel line which can lead to plugging. Preheated tertiary air is introduced where the quarl enters the main combustion chamber. The percentages of air introduced as atomizing, primary, secondary, and tertiary are typically 6, 1, 68, and 25, respectively.

The products of combustion can be monitored at any point from the flame initiation to the stack exit with a complete analytical package consisting of on-line O₂, CO₂, CO, NO_x, and SO₂ analysis. All instrumentation readings are selectively displayed or stored for future reference by a microcomputer-based data acquisition system. Ash sampling can be performed at many locations with a water-cooled isokinetic probe equipped with a cyclone.

Flue gases are cooled to below 500°F in an economizer prior to passing into a bag filter. The bag filter contains sixteen 5"x8' high-temperature fiberglass bags with out-to-in flow and pulse jet cleaning.

Figure C-1. Schematic Diagram of the Research Boiler and Auxiliary Components

Figure C-2. Burner/Nozzle/Quarl Section

Figure C-3. Schematic of Nozzle

Appendix D. Description of GAMS and Process Model Using GAMS

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GAMS 2.05 IBM CMS

This is the second model in a series of models to evaluate the retrofitting of oil fired industrial steam boilers to fire

coal

slurry, by Sam Addy, MN EC Dept, PSU, March 1993.

```
8
9 SETS
10
11     B Boilers / B1*B7 /
12     S Boiler derated capacities / S1*S5 /;
13
14 SCALARS
15
16     BC    Capital Cost basis boiler plant capacity /15/
17     X      Steam boiler plant power factor /0.75/
18     T92L  1992 lower tot. cap. requirement ($000s) /763.33/
19     T92U  1992 upper tot. cap. requirement ($000s) /1667/
20     E      Inflation (%) /4/
21     T1     Base period /1992/
22     T2     Current period /1993/
23     ASH    Ash content (tons per MM Btu) /0.0017047/
24     CWF    Coal slurry price (dollars per MM Btu) /4/
25     CHR    Coal slurry heat rate (Btu per lb steam) /1346.40/
26     OIL    Fuel oil price (dollars per MM Btu) /5/
27     OHR    Fuel oil heat rate (Btu per lb steam) /1317.86/
28     BE     Boiler efficiency (fraction) /0.8963/
29     N      Boiler plant life (assumed) /20/
30     R      Discount rate (%) /7/
31     AD     Ash Disposal costs ($ per dry ton ash) /5.6/
32     VOM    Variable O&M costs ($ per thousand lb steam) /0.25/
33     IFOM   Incremental fixed O&M costs (% of project cost) /4/
34     MOM    Material fraction of O&M costs /0.6/;
35
36 PARAMETERS
37
38     C(B)   Boiler plant capacity (thousands lb steam per hour)
39     BDC(S) Boiler derated capacity
40     GRD(S) Total capital requirement gradient
41     CF(S)  Boiler plant capacity factor
42     ASG(B,S) Annual steam generated (million lb steam)
43     AC(B,S) Annual coal slurry consumption (MM Btu)
44     AO(B,S) Annual fuel oil consumption (MM Btu)
45     ROM(B,S) Retrofit annual O&M costs ($000s)
46     RFC(B,S) Retrofit annual fuel costs ($000s)
47     BOM(B,S) Base oil annual O&M costs ($000s)
48     BFO(B,S) Base oil annual fuel costs ($000s)
49     PVF    Present value factor
50     TC92(B,S) 1992 Retrofit tot. cap. requirement ($000s);
51
52
53     C(B) = 10*ORD(B);
54     BDC(S) = 75 + 5*ORD(S);
55     GRD(S) = (T92U-T92L)/(100-80);
```

```

56      CF(S) = BE*BDC(S)/100;
57      ASG(B,S) = C(B)*CF(S)*8760/1000;
58      AC(B,S) = ASG(B,S)*CHR;
59      AO(B,S) = ASG(B,S)*OHR;
60      ROM(B,S) = ASG(B,S)*VOM + AD*ASH*AC(B,S)/1000;
1RETROFITTING OIL FIRED BURNERS TO COAL SLURRY
04/06/93 06:45:09  PAGE      2

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GAMS 2.05 IBM CMS

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61      RFC(B,S) = AC(B,S)*CWF/1000;
62      BOM(B,S) = ASG(B,S)*VOM;
63      BFO(B,S) = AO(B,S)*OIL/1000;
64      PVF = ((1 + R/100)**N - 1)/(R/100*(1 + R/100)**N);
65      TC92(B,S) = (T92L + GRD(S)*(BDC(S)-80))*((C(B)/BC)**X);
66
67  VARIABLES
68
69      OBJ1      Objective function model COSTMIN
70      OBJ2      Objective function model COSTSAV
71      OBJ3      Objective function model RETVALUE
72      TCR(B,S)  1993 Retrofit total capital requirement ($000s)
73      RIF(B,S)  Retrofit incremental fixed O&M costs ($000s)
74      COM(B,S)  Retrofit total annual O&M costs ($000s)
75      OOM(B,S)  Base oil total annual O&M costs ($000s)
76      PVCR(B,S) PV of retrofit costs ($000s)
77      PVCB(B,S) PV of base oil costs ($000s)
78      NPVR(B,S) Retrofit NPV ($000s);
79
80
81  POSITIVE VARIABLES  TCR, RIF, COM, OOM;
82
83  EQUATIONS
84
85      eq1(B,S)  1993 Total capital requirement ($000s)
86      eq2(B,S)  Retrofit incremental fixed O&M costs ($000s)
87      eq3(B,S)  Retrofit annual O&M costs ($000s)
88      eq4(B,S)  Base oil annual O&M costs ($000s)
89      minc(B,S) Retrofit cost minimization ($000s)
90      maxs(B,S) Retrofit Cost savings ($000s)
91      npvmax(B,S) Retrofit NPV maximization ($000s)
92      totpvcr   Objective function LHS for model costmin
93      totpvcb   Objective function LHS for model costsav
94      totnpvr   Objective function LHS for model retvalue ;
95
96
97      eq1(B,S) .. TCR(B,S) =E= TC92(B,S)*(1 + E/100)**(T2-T1);
98      eq2(B,S) .. RIF(B,S) =E= IFOM/100*TCR(B,S)*MOM;
99      eq3(B,S) .. COM(B,S) =E= RIF(B,S) + ROM(B,S) + RFC(B,S);
100     eq4(B,S) .. OOM(B,S) =E= BOM(B,S) + BFO(B,S);
101     minc(B,S) .. PVCR(B,S) =E= TCR(B,S) + COM(B,S)*PVF;
102     maxs(B,S) .. PVCB(B,S) =E= OOM(B,S)*PVF;
103     npvmax(B,S) .. NPVR(B,S) =E= PVCB(B,S) - PVCR(B,S);
104     totpvcr .. OBJ1 =E= SUM((B,S),PVCR(B,S));
105     totpvcb .. OBJ2 =E= SUM((B,S),PVCB(B,S));
106     totnpvr .. OBJ3 =E= SUM((B,S),NPVR(B,S));
107

```

```
108
109  MODEL COSTMIN  /eq1, eq2, eq3, eq4, minc, totpvcr/
110      COSTSAV   /eq1, eq2, eq3, eq4, minc, totpvcr, totpvcb/
111      RETVALUE   /ALL/;
112
113  SOLVE COSTMIN USING LP MINIMIZING OBJ1;
114  DISPLAY C, PVC.R.L;
115
116  SOLVE COSTSAV USING LP MAXIMIZING OBJ2;
1RETROFITTING OIL FIRED BURNERS TO COAL SLURRY
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GAMS 2.05 IBM CMS

```
117  DISPLAY C, PVC.R.L, PVC.B.L;
118
119  SOLVE RETVALUE USING LP MAXIMIZING OBJ3;
120  DISPLAY C, PVC.R.L, PVC.B.L, NPVR.L;
```


**** REPORT SUMMARY : 0 NONOPT
 0 INFEASIBLE
 0 UNBOUNDED
 1RETROFITTING OIL FIRED BURNERS TO COAL SLURRY
 04/06/93 06:45:23 PAGE 60
 E X E C U T I N G
 GAMS 2.05 IBM CMS

---- 120 PARAMETER C BOILER PLANT CAPACITY (THOUSANDS LB
 STEAM PER HOUR)

B1 10.000, B2 20.000, B3 30.000, B4 40.000, B5 50.000,
 B6 60.000, B7 70.000

---- 120 VARIABLE PVC.R.L PV OF RETROFIT COSTS (\$000S)

	S1	S2	S3	S4	S5
B1	4493.321	4945.660	5398.000	5850.339	6302.679
B2	8752.879	9588.373	10423.868	11259.362	12094.856
B3	12950.672	14151.041	15351.409	16551.777	17752.146
B4	17112.620	18667.253	20221.887	21776.521	23331.154
B5	21249.851	23151.434	25053.018	26954.602	28856.186
B6	25368.483	27611.512	29854.541	32097.571	34340.600
B7	29472.350	32052.455	34632.560	37212.665	39792.770

---- 120 VARIABLE PVC.B.L PV OF BASE OIL COSTS (\$000S)

	S1	S2	S3	S4	S5
B1	4551.135	4835.581	5120.027	5404.473	5688.918
B2	9102.270	9671.161	10240.053	10808.945	11377.837
B3	13653.404	14506.742	15360.080	16213.418	17066.755
B4	18204.539	19342.323	20480.106	21617.890	22755.674
B5	22755.674	24177.903	25600.133	27022.363	28444.592
B6	27306.809	29013.484	30720.160	32426.835	34133.511
B7	31857.943	33849.065	35840.186	37831.308	39822.429

---- 120 VARIABLE NPV.R.L RETROFIT NPV (\$000S)

	S1	S2	S3	S4	S5
B1	57.814	-110.079	-277.973	-445.866	-613.760
B2	349.390	82.788	-183.814	-450.417	-717.019
B3	702.732	355.702	8.671	-338.360	-685.390
B4	1091.919	675.069	258.219	-158.631	-575.481
B5	1505.823	1026.469	547.115	67.761	-411.593
B6	1938.326	1401.972	865.618	329.265	-207.089
B7	2385.593	1796.610	1207.626	618.643	29.659

**** FILE SUMMARY FOR USER SNA2

INPUT NEWCWF2D GAMS E
 OUTPUT NEWCWF2D LISTING E

EXECUTION TIME = 0.600 SECONDS

Appendix E. IMPLAN User's Guide

INTRODUCTION

Micro IMPLAN is the latest version of Microcomputer IMPLAN. IMPLAN has been in existence since 1979. During this time, IMPLAN has evolved from a main-frame application that ran in batch mode to a menu-driven microcomputer program that is completely interactive. Since the last release of Micro IMPLAN 89-03, several new features have been added and the menu interface has been replaced by a friendlier, more comprehensive menu system. A summary of the new Micro IMPLAN features includes:

- o A menu-driven, professional quality, user interface which is easy to learn and use so that you can come up to speed quickly.
- o An extensive on-line, context sensitive help facility which enables you to access help from anywhere in the program.
- o A new directory structure which takes advantage of PC directory facilities allowing you to more easily store, archive and retrieve models and data files.
- o Greatly expanded Impact Analysis procedures which allow you to input choices through data entry screens and picklists, thus eliminating the need for user-created input files.

For a more complete description of these new features, please refer to the "New Features of Micro IMPLAN" section in the Overview chapter of this User's Guide.

This introduction includes computer system requirements, a description of the Micro IMPLAN software package and a basic overview of the User's Guide. Please take the time to read the rest of this section whether or not you are an experienced Micro IMPLAN user.

- o 640 K of RAM Memory (at least 537 K MUST be available for Micro IMPLAN to run)
- o Color or Monochrome monitor

Software

- o MS-DOS 3.0 or higher

Micro IMPLAN User's Guide - Content

This is a complete User's Guide to the Micro IMPLAN system and can be used as a reference for the Micro IMPLAN System software. This guide supplements the on-line help system with more complete explanations for Micro IMPLAN commands and features. The User's Guide is also the only place where all the error messages are listed along with a complete explanation of what the error means. The Micro IMPLAN User's Guide does **not** cover Input-Output theory, techniques, planning or analysis using Micro IMPLAN. For this kind of information, refer to the Micro IMPLAN Analysis Guide.

How to Use This User's Guide

While the Micro IMPLAN interface has changed substantially since the last release, most of Micro IMPLAN's features have remained the same. We recognize that many experienced users will have little trouble using this version. With this in mind, the User's Guide was designed for both the novice and knowledgeable Micro IMPLAN user. Information is organized so that expert users can skim familiar material and move on to learning the new Micro IMPLAN features.

OVERVIEW

Key Features

Micro IMPLAN is a microcomputer program that performs regional input-output analysis. You can define a model for any region in the United States using secondary source data which are available by state and county, with the county being the smallest unit of measure. Micro IMPLAN's flexibility allows you to incorporate your own data which will increase the accuracy of your results. In addition, aggregated models can be created which consist of industries grouped together for a specific purpose. At each stage of the model building process, you can generate reports which contain information about that region's market structure and industry interrelationships. Once you have generated a model of a specific region, Micro IMPLAN allows you to perform impact analysis on that model. You can introduce new industries for "shock" value to the regional economy, you can remove industries to see the impact on employment and demand plus generate reports detailing the above impacts. With Micro IMPLAN's impact analysis capabilities you can create multiple scenarios for each model to simulate many possibilities. Micro IMPLAN includes its own file management utilities so that you can manipulate the many types of files that you create with Micro IMPLAN, plus manage the data files and data file directories that are imported into the Micro IMPLAN system.

New User Interface

Micro IMPLAN has a redesigned user interface so that it has the look and "feel" of many commercially available PC packages. Micro IMPLAN's interface is based on pull-down menus that remain visible as you step through the options under a main menu category. You can move within the menu system by using the arrow keys or through activating a single letter hot key associated with every menu item. An extensive on-line help system has been included to aid you in learning Micro IMPLAN and will also provide you with an excellent on-line reference system once you become an experienced user. Current Micro IMPLAN users should be able to learn the new interface in a short time, and will find that most of Micro IMPLAN's features have remained the same.

Main Menu Display**Overview of the Micro IMPLAN Menu Structure**

As you can see from the Main Menu figure, Micro IMPLAN has been organized into logical groups of similar functions. There are four main categories on the main menu each with a set of submenus which can be several levels deep.

The first category is called *MODEL CONSTRUCTION* and includes all of the model building options. The next category on the Micro IMPLAN Main Menu is titled *IMPACT ANALYSIS*. Under this category you will be able to assess the impacts of demand changes on a regional economy by altering the demand for goods and services, adding and removing industries, and changing the interrelationships for the regional industries.

END

**DATE
FILMED**

2/01/94