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Coal Fines Recovery and Utilization

Final Report

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16. Abstract
A process for recovery of energy from waste coal fines was investigated. The process, which was developed through laboratory, bench, and pilot plant scale experiments, consists of mechanical cleaning followed by high temperature oil agglomeration and pelletization. The process can produce a quality product under an economically and environmentally acceptable condition. Waste coal fines with ash less than 35% and HHV greater than 6,000 BTU/lb have been upgraded to a product with less than 15% ash and HHV greater than 11,500 BTU/lb.

A computer model has been developed to optimize the processing costs and to perform economic evaluation of specific sites. Ultimately the model can be utilized to establish a priority listing for a region in assisting the determination of reclamation strategy.

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INTRODUCTION

The world trading of coal has increased about twelve percent annually (from 197,891 to 252,405 million metric tons per year between 1978 to 1980) during recent years (43). This rate of increase has surpassed the acceleration of energy consumption over the same period of time. It reflects the shift by many nations toward the use of steam coal in place of petroleum products to meet energy demand. If these trends continue, coal will become the chief energy resource in the future (41). In order to supply clean coal for energy consumption, such as coal-fired boilers in power generation, mechanical cleaning processes are used to produce the desired fuel. It is estimated that between ten to twenty percent of the coal processed in the preparation plants is lost as slurry or tailings. On a national basis, this represents around 30 million tons of raw coal that are lost yearly as coal fine wastes.

There are thousands of abandoned slurry ponds and piles dispersed in the coal producing states. A conservative estimate of the number of abandoned waste piles and impoundments in the coal fields east of the Mississippi River alone is between three to five thousand, which contain over three billion tons of coal refuse. Some of this coal waste is potentially valuable, having heating values between 6,000 to 10,000 Btu per pound on a dry basis, and capable of being recovered as a high quality product. Unfortunately, coal slurry also contains clay, sludge and pyrites. These impurities have to be sufficiently removed to insure the product quality. When one attempts to recover the carbon from a slurry pond or pile and to reclaim the sites during or after the recovery operation, the main questions to be asked are:

1. Are the quantity and quality of the coal fines on the site sufficiently large and good for a recovery operation?
2. How much will it cost to recover the coal fines and to make a saleable product in an economical and environmentally acceptable manner?
3. Is a profit to be realized in coal fines recovery and utilization?
4. Is the overall reclamation cost reduced with the recovery operation?

In order to generate scientific and engineering data to furnish the answers to the questions listed above, the researchers of this project have embarked on a systematic investigation to achieve the following specific objectives:

1. To develop a "Coal Fines Recovery and Utilization" process for the economical recovery of carbon from slurry ponds and piles utilizing an elevated temperature oil agglomeration technique.
2. To determine overall mass and energy balances for the process and develop predictive equations to estimate coal yields, volume of refuse generated and net energy production.
3. To evaluate and characterize the products and all waste streams generated by the recovery operation.
4. Through design, construction and operation of a pilot plant recovery operation, determine and demonstrate the workability of the process. The sensitivity of process performance to operating variables will be determined.
5. Develop a model for the recovery operation that recognizes site specific characteristics (location, quantity and quality) of a given slurry pond or ponds, as well as process characteristics.
6. To integrate the predictive equations developed from the laboratory and pilot plant process data with the model of the recovery operation. This will permit a generalized economic and environmental assessment of the process. The assessment procedures developed should permit determination of the process economics, and provide the basis for environmentally acceptable disposition of wastes generated.

LITERATURE REVIEW

The fine coal washers principally employed in the United States today are wet concentrating tables, jigs, cyclones, and launders. The Humphrey spiral and froth flotation are also used in a few cases.

In the wet concentrating table process, the fines to be treated are fanned out over the table by differential motion and gravitational flow. This stratification occurs due to specific gravity differences between the particles (1). Cross flowing water removes successive layers from top to bottom. The concentrating table is generally effective only for coal sizes above 48 mesh (2), making it unattractive for recovery of finer sizes of coal.

A jig involves using pulsations of a coal-water mixture in which the motion produces stratification of the particles according to specific gravity. Several jig modifications are described by Leonard (3) and Zimmerman (4). Little reduction in ash is obtained in the minus 48 mesh material (3).

Another process for fine coal cleaning is the coal launder. In the process, solids move along an inclined surface with flowing water. The separation of the coal from refuse is a function of the particle's properties (specific gravity, size, and shape), the fluid flow, and the geometry of the launder. Launders can generally clean fines down to 60 mesh (3).

The Humphreys coal spiral is a six-turn helix that combines centrifugal action and sluicing to achieve a separation between coal fines particles and refuse (5). This method, when used in series with a hydrocyclone, has been found to remove between 57-59% of coal fines greater than 200 mesh.

The previously mentioned coal fines cleaning methods use mechanical devices with water as a separating medium. Froth flotation is a chemical process. In this method of cleaning coal fines, a suitable chemical reagent is added to a coal-water mixture. The purpose of the reagent is to provide a hydrophobic or air-absorbing surface on the coal particles to be collected. Air is then injected into the coal-water mixture and the desired coal fines are floated to the surface and collected. Flotation techniques under various operating parameters have been described by Cavallaro (9) and Bluck (10). Differences in reagent properties have been discussed by Klimpel (11). An ash reduction from 23% to 9% has been reported by Miller (12) with 77% total solids recovery. Although froth flotation is an effective method for cleaning fines, its cost generally limits its use to metallurgical grade coals.

A literature search indicates agglomeration has been considered as a part of the subject of cleaning and drying of coal fines for a number of years (14-22). The variables affecting oil agglomeration of fine coal have been identified (23-27).

Nationally, coal recovery operations are starting up on a small scale. Maneval (13) has reviewed some coal recovery operations in the U.S. and Europe. Methods of treatment include direct recovery, flotation, cyclone separation, and mechanical pelletization. However, the large amount of fine particles makes transport of the product more difficult. Oil agglomeration and pelletization overcome this difficulty.

Mezey, Min and Folsom (40) have conducted an important study on the application of selective oil agglomeration of finely ground coal waste from slurry ponds. They reported on the amount of coal recovery, ash reduction and pyrite reduction with different treatments of new, aged and old slurry ponds. They have verified that new coal waste needs to be treated differently than old slurry for pyrite removal. Min (35) states that oxidation of the pyrite produces a hydrophilic surface which enhances selective oil agglomeration. Investigators of Iowa State University (28) have utilized alkaline solutions containing dissolved oxygen to alter the relative floatability of coal and pyrites.

The use of elevated temperature may have important effects on the performance of selective oil agglomeration. This factor has not been reported in the oil agglomeration literature. The tests performed in this research indicate that elevated temperature oil agglomeration has good promise for cleaning and recovering coal fines waste from slurry pits (27).

Investigators with the Ontario Research Headquarters of Toronto, Canada (30) conducted laboratory through pilot plant (1100 lb. coal/hr.) experiments to test what effects coal feed particle size would have on oil agglomeration of run-of-the-mine western Canadian bituminous coal (17-18% ash). From their pilot plant operations they showed that the use of finer sizes of coal (96% = -200 mesh (.00291 in.)) resulted in slightly higher yields (98%) and better ash removal (50%) as compared to those (97% yield and 34% ash removal) resulting from the use of coarser coal (60% = -200 mesh). Drawbacks to using finer coal were that it required nearly a five times longer mixing time (25 minutes) and a three times greater amount of oil (28% by weight of feed coal) than the coarser coal. The agglomeration process, a three-stage one, in which ball mill grinding was followed by high speed (tip speed = 26 m/s) mixing in a baffled reaction vessel and dewatering/pelletization in a drum pelletizer, produced low moisture, high strength pellets having a mean diameter of ½-inch.

A series of oil agglomeration experiments conducted by the Broken Hill Propriety Co. Ltd. (BHP) of Australia (31,32) involved pre-emulsifying the oil in water prior to adding it to the coal. This was reported to have enhanced oil-coal contact, thus allowing for the use of heavier, less expensive oils. Based on preliminary laboratory and bench scale experiments, BHP constructed and tested a pilot plant at New Castle, South Wales, to treat slurry pond wastes. Material proportions of 10-20% No. 2 oil and 30-37% slurry concentrations, both by weight of feed coal, were sufficient to produce fine-sized, low moisture, low ash pellets from high ash waste coal materials. Stationary screens were used to dewater the agglomerates.

Oil agglomeration as earlier proposed by Capes et al. (33,34) was tried by both the Central Fuel Research Institute (CFRI) of Dhanbad, India (35,36) and the Shell Company (37). Early CFRI laboratory studies in which pulverized coal (80% = -200 mesh) was preconditioned with light oil (No. 2) then agglomerated with further oil additions, showed that little significant improvement in yield or ash reduction accompanied total oil inputs of 4% or slurry feed concentrations in excess of 2.5%, both by weight of feed coal. Later CFRI studies involved light oil preconditioning followed by agglomeration with heavy oils (No. 6) and subsequent dewatering on a stationary, sieve bend-type screen. Twelve percent oil by this method was required to treat difficult-to-wash, non-caking coal. In the Shell Co. process a coal slurry was treated with a No. 2 - No. 6 mixture of 15% oil by weight of feed coal in a Shell Pelletizing Separator (SPS), a single large multiblade reactor vessel originally designed to remove soot from aqueous waste streams in gasification operations. Pellets from the SPS were dewatered on a sieve bend-type stationary screen.

Although oil agglomeration has been proven effective in reducing the ash and, with some contribution from the added oil, in increasing the heating value of coal fines, most studies showed that it provided only slight reductions in microscopic crystalites of iron pyrite, a substance that contributes appreciably to the sulfur bearing material in many coals (38,39). The reasons are due in part to similarities in the surface properties of coal and pyrite; both tend to be hydrophobic, attracting oil dispersants and repelling water (40,41). The most effective, in terms of their low cost and the relative shortness in the amount of time required for them to react, were basic chemical oxidants. Most notable was sodium carbonate; in selective oil agglomeration experiments in which the coal (-200 to +250 mesh) was pretreated with a hot 2% by weight sodium carbonate solution under pressure with air (P_{o2} = 2.8 atm.), 67% of the pyrite, 100% of the sulfate and portions of the organic sulfur were removed (42). At similar conditions without $NaCO_3$ pretreatment only 29% of the pyrite was removed.

In summary, oil agglomeration is proving to be an attractive alternative to conventional commercial method for cleaning coal fines, especially at elevated temperatures. Many of the economic shortcomings associated with its early history have been or are being worked out. Grinding the coal to fine sizes, a necessary pre-step to agglomeration according to many researchers, and high oil requirements are still associated cost factors that stand in need of improvement. A partial solution has been to eliminate the grinding step altogether. In this research it has been found to be detrimental to the extraction of a quality agglomerate product from aged slurry pile wastes from several southern Illinois mine sites. In markets where there is a demand for fine-sized, grindable coal products (i.e., pulverized-coal boiler operations), costs can further be cut by holding oil additions down to an amount needed only to affect: (1) desired ash and moisture contents; and (2) to provide dusting-free properties in the agglomerates.

EXPERIMENTAL METHODOLOGY

The research methodology involved laboratory studies and small bench-scale tests to determine important parameters for operating a pilot plant scale coal-fines recovery process. The process included washing, elevated temperature oil agglomeration, and pelletization steps. Coal quality parameters, i.e., ash, sulfur and HHV were determined at each step.

Batch type laboratory tests were followed by bench scale semi-continuous tests to verify important parameters for pilot plant operation. The results of these tests were applied to the pilot plant operations of the process. Product produced by the pilot plant was also evaluated for handling characteristics.

Washing

Small bench-scale batch tests, using the flow chart of Figure 1 indicated a water/coal ratio of 10 to 20:1 was effective, with a 10:1 ratio being slightly more effective. The tests used an impeller/tank diameter ratio of 0.25 and an impeller speed of approximately 1140 ft./min. The effect of temperature from 45 to 85°F was studied, with the conclusion that washing at elevated temperature was not a significant improvement over washing at ambient water temperatures above 65°F. A high-shear operation time of 10 to 15 minutes produced similar cleaning results with a settling time of 1 to 2 minutes.

A continuous laboratory-scale process, shown schematically in Figure 2, was studied to better determine parameter values for larger scale operation. Coal fines of -14 mesh were fed at 2.0 to 2.7 lb./min. into the high-shear mixing tank and stirred for 5 to 10 minutes. Then the mixture was pumped to the settling tank for gravity separation. Cleaned coal was removed from the bottom of the tank and clay and suspended materials overflowed to the flocculation tank. For most of these experiments a top speed of 1040 ft./min. with an impeller/tank diameter ratio of 0.25 was used. The settling tank used a L/D ratio of 1.2 to 2.0 with a settling time between 0.5 and 3 minutes. The water/coal ratio was varied from 10 to 30.

Conclusions drawn from tests on seven different coal samples for a laboratory scale continuous process were:

$$10 < \text{water/coal} < 20$$

$$.8 < \text{settling time} < 1.5 \text{ min.}$$

$$1000 < \text{tip speed} \leqq 2000 \text{ ft./min.}$$

$$65 < \text{water temperature} < 85°\text{F}$$

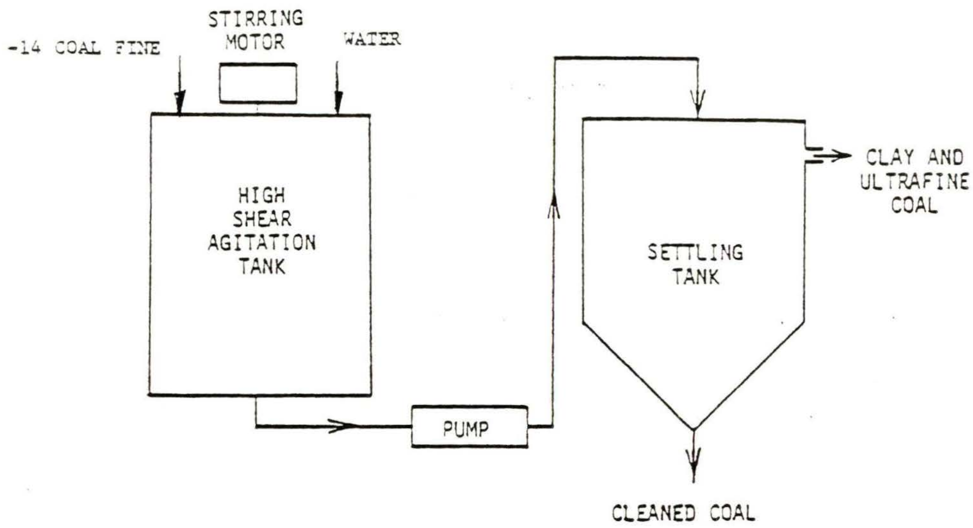


Figure 1. Schematic diagram of batch mechanical cleaning operation.

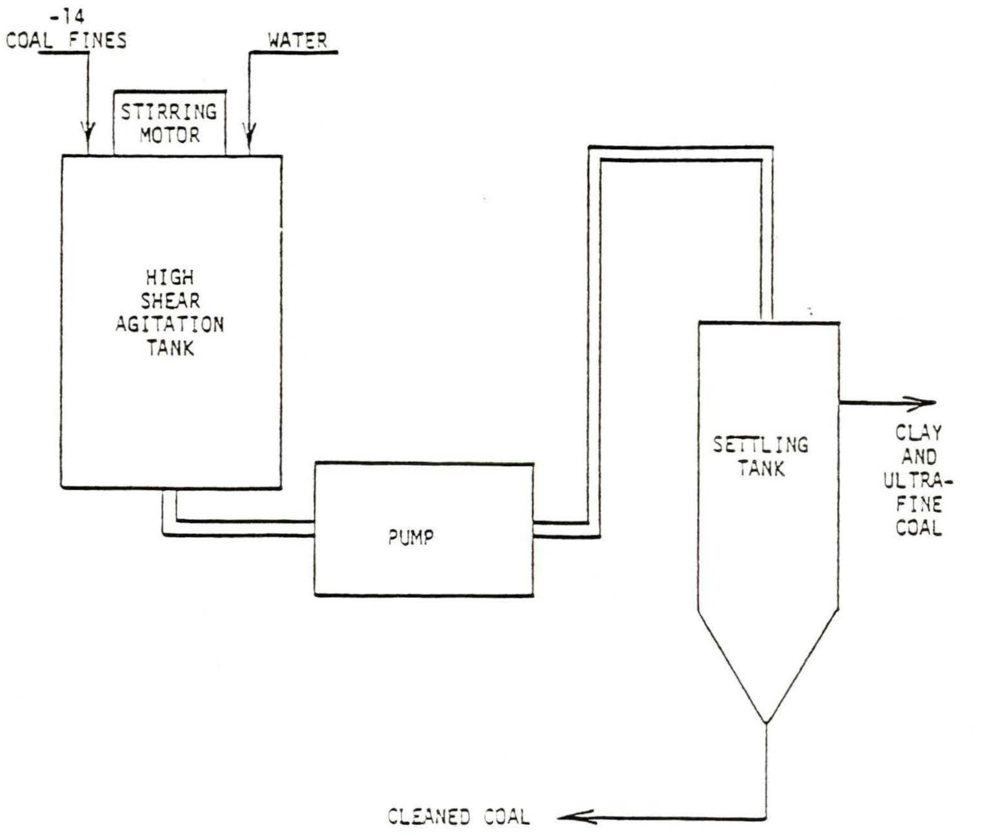


Figure 2. Schematic diagram of continuous laboratory scale cleaning operation.

Further testing was carried out in a small bench-scale continuous cleaning apparatus on coal fines waste from two Illinois seams. The bench-scale continuous cleaning produced heating value and ash improvement fairly close to the laboratory continuous process cleaning results. However, the percent combustibles recovered was lower than previous tests. This was attributed to a 2000 fpm tip speed. The cleaned coal showed 72% of all the particles were in the size range +100 to -14 mesh with 90% of heating value in this material. This was consistent with the laboratory scale tests. Total sulfur reduction from 4.2 to 3.7 and 3.4 to 3.1 was achieved. Much of the reduction was believed to be due to sulfate removal.

Water treatment studies were made of the waste water. A suitable flocculant dosage was determined as 1.5 mg/l of Herfloc 1031 in water with a pH of 7. Water recycle is feasible with these conditions, as suspended solids of over 32,000 mg/l were reduced to about 5000 mg/l.

From bench scale studies, it was also found that wet screening of coal fines at 14 mesh on a vibrating screen followed by high-shear agitation in a baffled tank and then gravity separation in a settling tank produced a significant improvement in HHV values and produced reduction in ash content. These studies were used to determine effects of scale up of the washing step and of the washing operation and agglomeration steps run in series.

A pilot plant capable of washing 2 T/day coal fines was designed and built, using the ranges of parameters from previous tests. The flow sheet, Figure 3, used an auger to feed coal fines waste to the wet screen. The over-size material was collected for analysis and mass balance. The under-size slurry was washed in a high-shear tank, then separated into cleaned coal and ash-laden waste water.

The first pilot plant experiments were based upon the earlier studies. However, mechanical problems in removing the clean coal from the bottom of the settling tank required use of a rotary valve. The resulting underflow material had over 30% moisture and lower HHV and higher ash and sulfur than expected. Analysis of the cleaned coal fines by size range indicated that the size below 70 mesh had the lowest quality (high ash, low HHV, high sulfur).

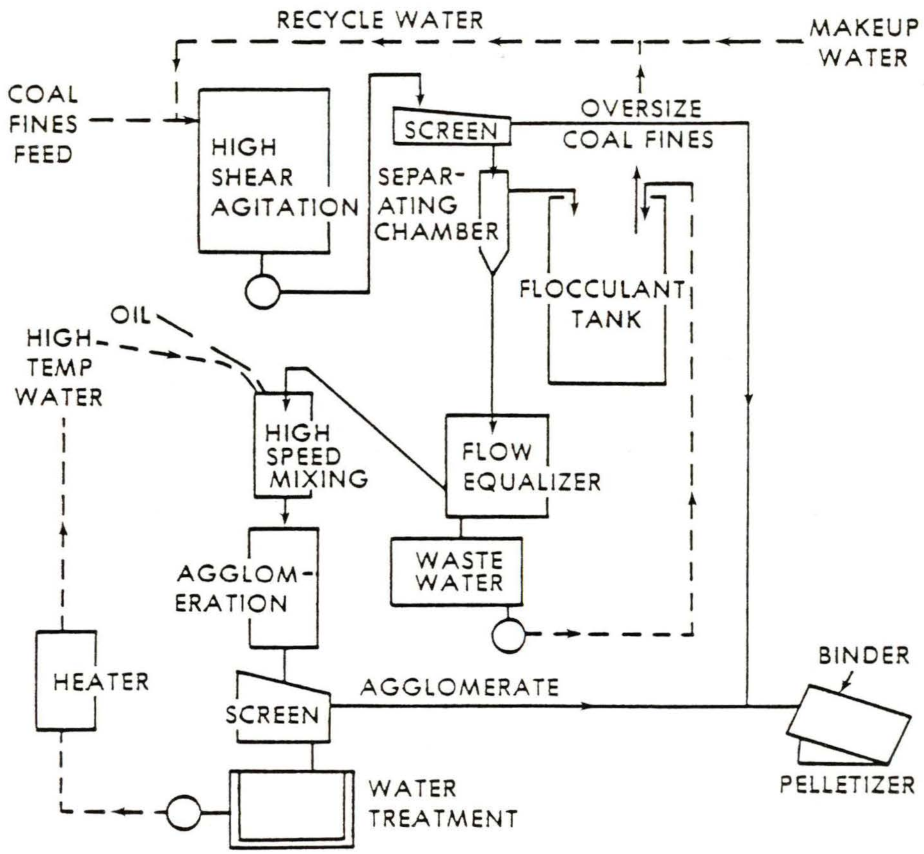


Figure 3. Schematic flow diagram of coal fines recovery - initial concept.

The apparatus was redesigned to use a vibrating wet screen with 50 or 70 mesh screen following the high-shear agitation. The 70 mesh screen produced the best results, comparable to the bench scale tests. Mass recovery and quality of coal fines was improved over use of the settling tank. This apparatus was then used to determine good operating conditions.

Finally, the washing step was operated as a continuous feed to the oil agglomeration step.

Elevated Temperature Oil Agglomeration

Initially, laboratory batch tests were conducted on freshly ground coal and on coal fines waste, cleaned as described above, in small table top experiments. A small amount of coal was placed in 175°F water (3:1 ratio) in a blender. Hot oil (0.10 to .20 oil/coal ratio) was added and the mixture stirred for two minutes. The mixture was then transferred to a beaker and stirred at low speed for up to 10 minutes to attempt to form spherical agglomerated pellets. New coal ground to -40 mesh agglomerated easily into 1/16 inch spheres. Cleaned coal-fines waste ground to -40 mesh also formed agglomerate.

A larger scale apparatus which could be scaled up was needed, so a table top agglomerator using a baffled, stirred tank was used. Number 6 oil was used as agglomerating liquid, as heavier oils had worked in previous research. A 3:1 water/coal ratio; and a 4-5:1 coal/oil ratio were used at 175°F. Tests on coal and coal fines waste from three different seams showed significant improvement (Table 1).

The pilot plant oil agglomeration apparatus (Figure 4) was designed to provide hot water and oil to a high-shear baffled tank where coal, oil and water were mixed and agitated by a four-bladed bar impeller with tip speed of 25.2 ft./sec. and a diameter of 6 inches, which is 0.27 of the tank diameter. After residing in this tank for 6 to 20 minutes, the mixture overflowed into a baffled tank where it was slowly agitated for up to 26 minutes. The agglomerate formed in the tank was removed by overflow or by a rotary valve placed at the lower opening of the conical bottom of the tank. The agglomerate was dewatered on a vibrating screen. The hot water and suspended solids were returned to an insulated tank. Here the suspended solids were precipitated and the clari-

Table 1
Table Top Agglomeration Study

Sample	Coal/Water* Mass Ratio	Oil/Coal* Mass Ratio	Oil Type	Temperatures Water/Oil/Mix	Sulfur % orig./agglom.		Heating Value orig./oil/agglom.	Ash orig./agglom.	
A	0.34	0.25	6	165/185/160	2.8	2.2	13354/18674/15053	20.9	13.3
B	0.34	0.15	6	165/185/165	2.8	2.3	12755/18674/13975	20.9	10.6
C	0.33	0.25	6	165/185/160	4.5	2.6	10832/18674/13462	21.0	16.0
A	0.33	0.19	6	165/185/160	2.8	1.8	13386/18674/14975	20.9	12.5
C	0.33	0.19	6	165/185/160	4.5	2.4	10832/18674/13082	21.0	15.8
D	0.34	0.19	6	167/185/155	3.7	2.1	12034/18674/13529	14.6	7.5
D	0.34	0.19	6	170/200/163	3.7	1.8	11798/18674/13753	14.6	6.6
E	0.33	0.19	6	194/280/178			11182/18674/12862	19.4	13.2

* Based upon 7500gm coal input Tip speed = 1390 ft/min

A. Ill. No. 6, 14-size, new coal, uncleaned
B. Ill. No. 6, 40-size, new coal, uncleaned
C. Ill. No. 2, 14-size, aged coal slurry, uncleaned
D. Ill. No. 5, 40-size, 5 yr. coal slurry
E. Ill. No. 6, cleaned coal slurry, 40- to 100+

fied water reheated for re-use. The dewatered agglomerate was collected for testing and as feed to the pelletization step. Test samples were taken for analysis at regular intervals throughout each test.

Pelletization

Agglomerate may be used as fuel for pulverized-coal-fired boilers or for industrial boilers which require coal particles over ¼-inch diameter. Thus, pelletization of the agglomerate was studied.

Initial batch bench-scale tests were made with starch, molasses and asphalt binders incorporated into agglomerate in a pan pelletizer. The starch and molasses produced pellets with poor strength, unless the moisture content was quite low, below 5%. Asphalt showed promise of producing useful pellets.

Further pellet testing was carried out using a continuous, rotating cylindrical pelletizer. The pelletizer is a 3 ft. diameter by 8 ft. length screen attached to an axis so it can rotate at low speeds. The axis can be tilted to change the hold-up of the pelletizer. Agglomerate from various runs was fed into the pelletizer with asphalt binder and the product pellets were evaluated.

Product Evaluation

The intended use of the product from the recovery process dictates the form of the end product. If the product is used in a pulverized-coal burner, it must have good grindability, as indicated by the Hardgrove Grindability Index. A minimum amount of oil in the agglomerate is necessary for transportation without excessive loss of the fine particles. Too much oil inhibits the grindability of the product. Grindability tests were performed on agglomerate of varying moisture and oil content.

MODELING AND COMPUTER SIMULATION

Process Simulation Program

The coal fines recovery process is simulated by this computer model. Based on a quality characterization of the input slurry material

LEGEND FOR FIGURE 4

Mixed Materials Handling and Processing Equipment

I. Filter pump aspirator

II. Coal feed auger

III. High speed mixing vessel

IV. High speed motor

V. Growth vessel motor

VI. High speed vessel overflow tube

VII. Agglomerate growth vessel

VIII. Growth vessel overflow tube

IX. Rotary star valve

X. Star valve motor

XI. Vibrating screen

XII. Agglomerate transport trough

Water and Steam Supply Equipment

A. Water clarifier/storage/

B. Water pump

C. Water pump recycle line

D. Water flow meter

E. Wastewater return line

F. Steam supply line

G. Steam jacket vent line

H. Steam trap

Hot Oil Supply Equipment

a. Oil storage and heating vessel

b. Oil circulation pump

c. Oil circulation pump motor

d. Oil circulation line

e. Oil metering feed pump

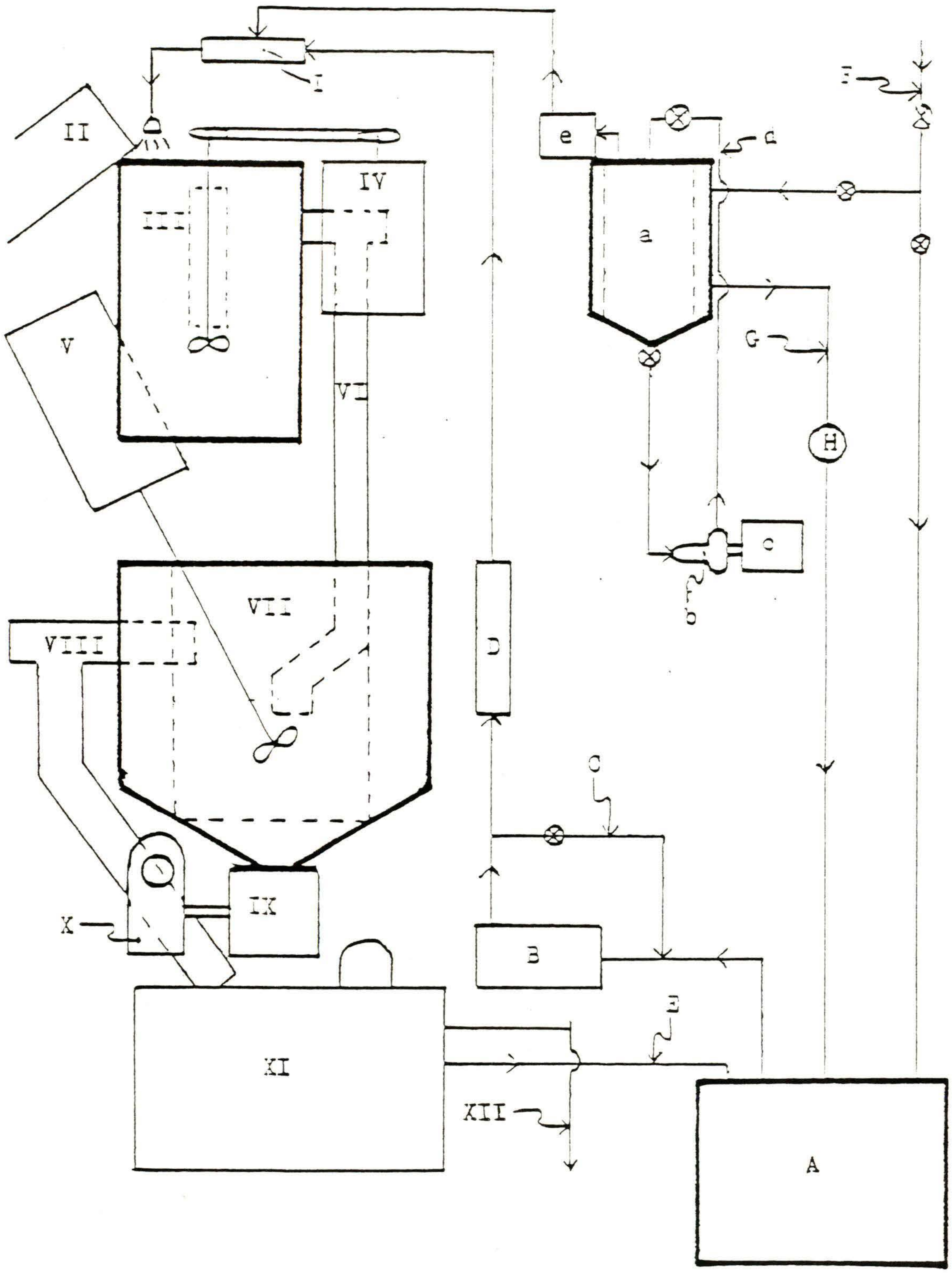


Figure 4. Agglomeration equipment.

(particle size distribution, heating value, ash, sulfur) the product yield and quality are predicted. Effects of other process variables (including % oversize of input coal fines, oversize inclusion/exclusion option, wash tank inclusion/exclusion option, oil/coal ratio, agglomeration mix time, and binder characteristics) on product yield and/or quality are also modelled.

Originally, the program was written based on the lab and bench-scale studies of the coal fines recovery process. The program has been modified to incorporate the performance data from the pilot-plant studies; the equations derived from this data and utilized for the process simulation are given in the "Results" section.

Equations relating the process simulation factors of equipment size and product quality to the process economic components of capital investment, material costs, energy costs, and labor and overhead costs are integrated within the process simulation program. Total costs are determined by summation of cost estimates for each of the major process segments. The model permits application to actual potential recovery sites, where site specific factors are reflected in the process simulation.

The program has been written in PL/I programming language; a flow diagram of the program is given in Figure 5. As an aid to interpretation of the computer program flow diagram, a brief description of the coal fines recovery process follows; factors pertinent to the simulation model are emphasized.

Coal Fines Recovery Process

The process flow chart is given in Figure 6. The input to the pilot-plant process is coal slurry from the slurry ponds, void of large-size impurities. In a real plant, an initial dry screening is recommended and this dry screen is taken into consideration for the economic model. The process is divided into three parts: washing, agglomeration and pelletization. These processes produce the final product, oil agglomerate or pellets. These product forms reduce problems associated with transportation of coal fines, as well as provide a product higher in Btu and lower in ash and sulfur than the original fines processed.

Washing. In the pilot plant, the coal fines are augered to a 14 mesh wet screen. The water spray tends to break up the particles. The +14 mesh material is collected as oversize which, depending on the quality, can be added to the agglomerated product before pelletization. The -14 mesh particles are fed to the wash-mix tank, where these particles are subjected to high shear agitation (for some coals, this step may be by-passed). Then the fine particles and water are pumped to a second screen (50 mesh or 70 mesh). The particles that stay on the screen are then fed to the agglomeration step.

The particles that pass through the screen are collected as waste. The waste is taken into another mix-tank where coagulant is added to flocculate the waste, and the clear water overflows into a tank where it can be recycled back to the process. The waste that has settled is collected separately.

Agglomeration. The cleaned coal collected from the washing process is augered to a high speed mix-tank where hot oil (No. 6 oil) and water are added. The overflow from this tank runs into a low-speed growth tank. In the high speed mix-tank the coal, oil and water are mixed under high shear conditions, whereas in the low-speed growth tank they are stirred slowly. When the growth tank starts overflowing, the star valve at the bottom of the tank is switched on and set to maintain a slight overflow condition. Most of the product passes through the star valve and, together with the overflow, drops on to another screen (70 mesh). Agglomerates stay on the screen and flow to storage or directly to the next step in the process, pelletization. The waste passes through the screen and flows into the recycling trough. In the recycling trough, oil and water are separated. Water is recycled back to the process and oil is collected. The waste solids settle and are collected separately.

Pelletization. The oil agglomerate is gravity fed to the pelletizer, where hot asphalt (or other suitable binder) is applied to it. The pelletizer rotates at a slow speed, promoting pellet formation. The pellets are discharged from the pelletizer, and, after additional drying, result in a transportable product.

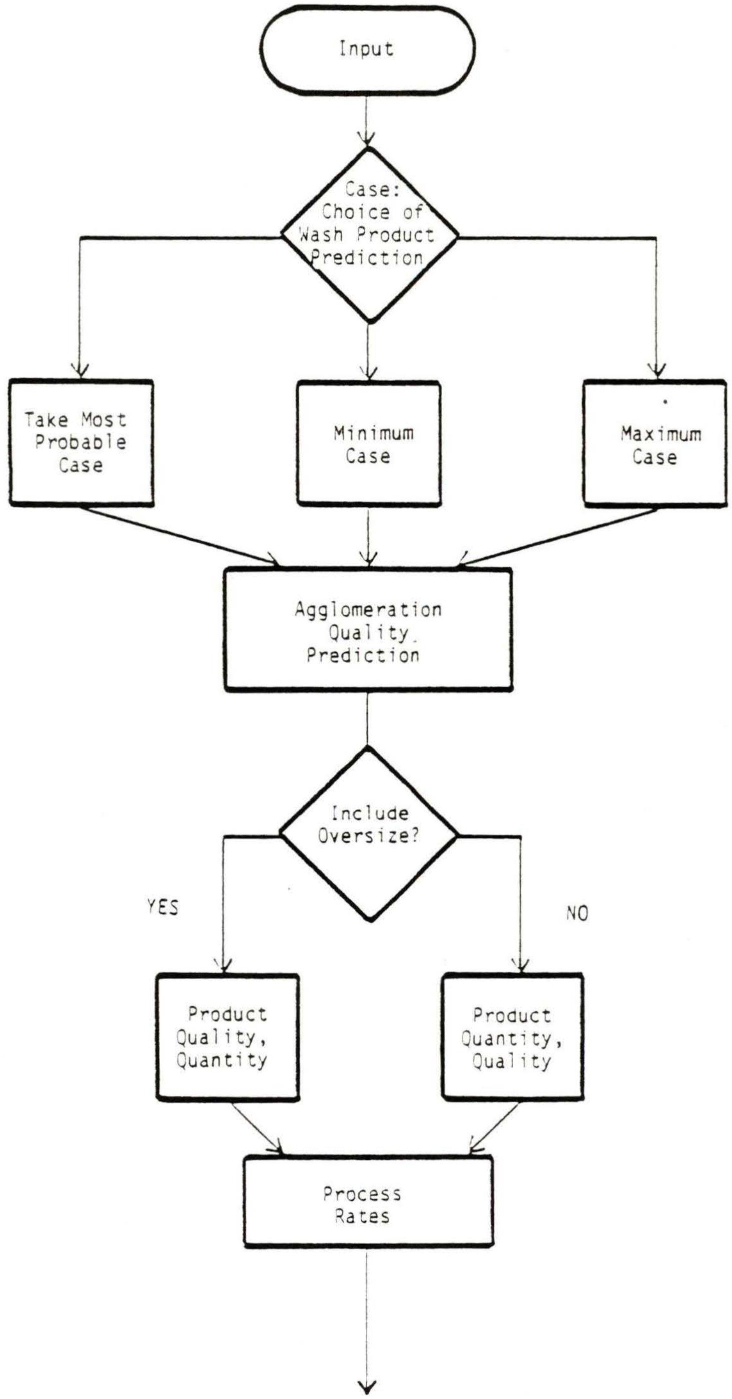
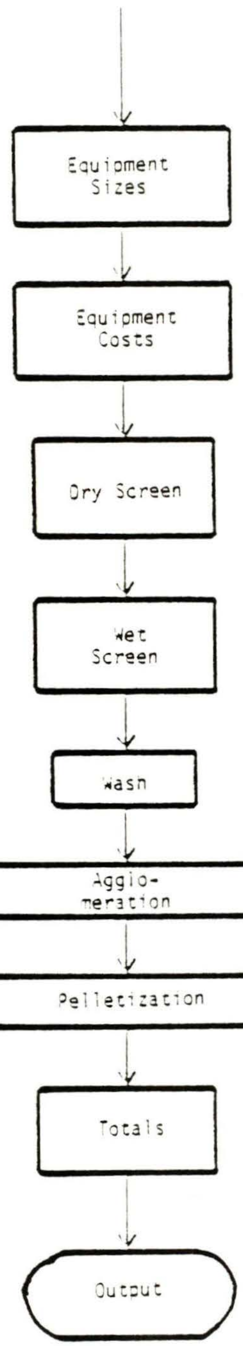


Figure 5. Process simulation program flow diagram.


Equipment Sizes
Equipment Costs
Dry Screen
Wet Screen
Wash
Agglo-meration
Pelletization
Totals
Output

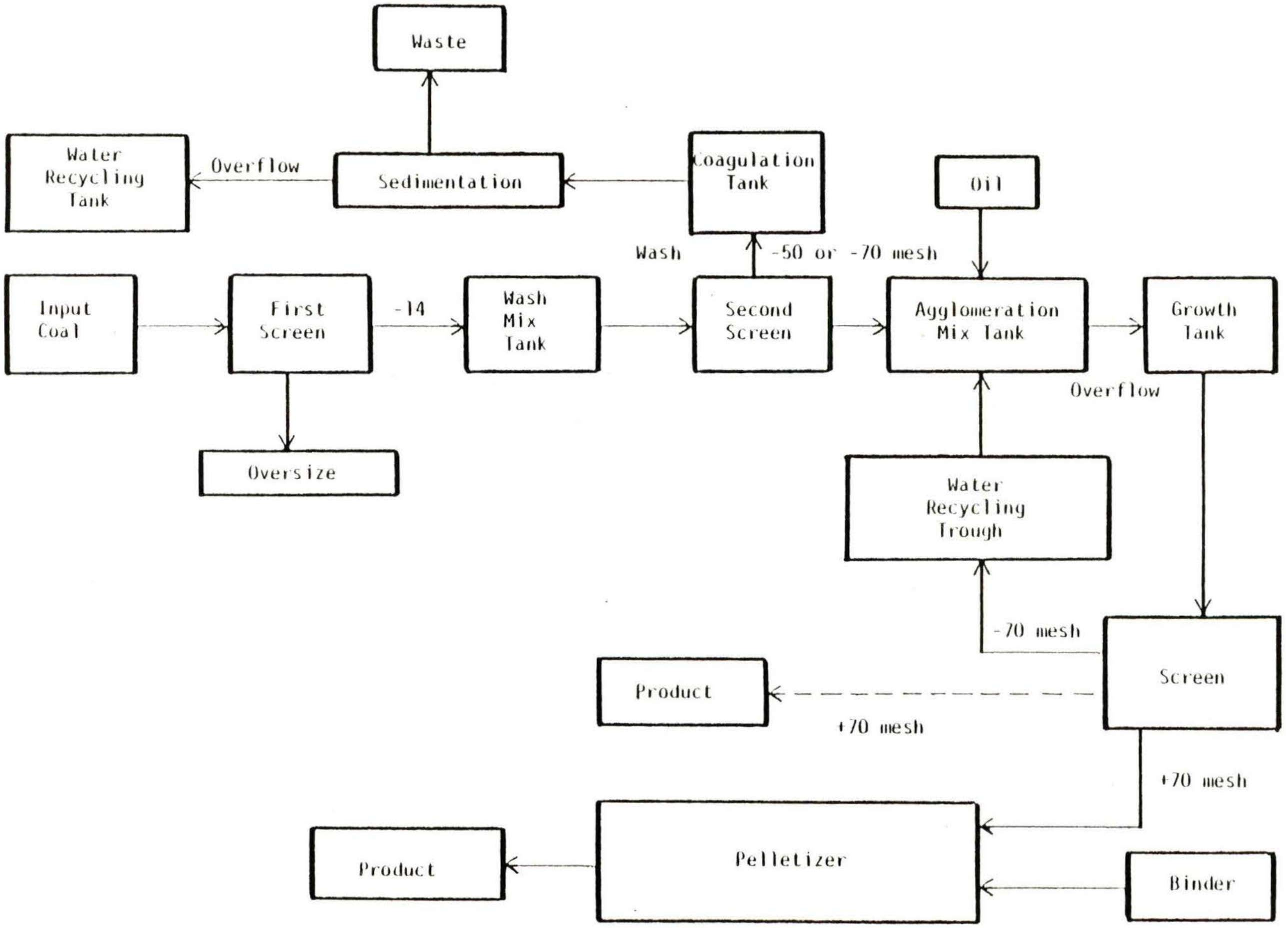


Figure 6. Coal fines recovery process flow chart.

Product Quality Predictions

The three steps - washing, agglomeration, and pelletization enhance the product quality. Each of them has been considered separately.

Washing. The factors that affect the product here are the quality of the various size fractions of the coal, water to coal ratio, shaker screen sizes, and inclusion/exclusion of the wash mix tank. The product quality enhancement is measured on the basis of HHV increase, ash reduction, and sulfur reduction. Optimum ranges for process variables were determined from the pilot plant data and, using these ranges, quality enhancement for different coals were found. Quality enhancement that can be obtained from washing may be predicted by knowing the input coal quality. The most probable, minimum, and maximum quality of the product are predictable for a given coal based on quality determinations of the sample screen fractions. These relations are given in the "Results" section, Figures 12 and 13, describing the observed performances of three coals, representing a range of quality, during pilot plant processing. These plots were the basis for arriving at the equations for predicting the washed coal quality. The minimum and maximum quality relations were determined from the $\pm 1.96\sigma$ (95% confidence) values determined for each of the three coals evaluated.

Agglomeration. Since process responses varied with the quality of the input coal, the predicted HHV increase, ash reduction and sulfur reduction are based on quality enhancement factors which depend on the quality of coal processed.

Pelletization. The pelletization improves the transportability of the product, but affects the quality parameters of HHV, ash, and sulfur only to the extent that binder quality and binder/coal ratio are varied. Predictive equations are included in the model.

Process Yield Predictions

The product quantity is calculated from the input slurry feed rate and yield factors in the four steps: dry screen, wash, agglomeration and pelletization. The yields are considered separately.

Dry screen. Large objects, rocks, etc., are removed here; a 99% yield is assumed.

Washing. In the original model, the yields were left as input values. For the current model, wash yield is calculated based on the size fractions of the input coal. Thus, if the input coal size distribution is known, the wash yield is calculated for three different cases -- most probable, minimum, and maximum yields. The equations were derived similar to the derivations for HHV increase and ash reduction (95% confidence limits). The first wet screen yield has been left as an input variable. This will also depend on the input size fraction given by the sample screen analysis.

Agglomeration. Based on the pilot plant data, yield was found to be a function of agglomeration mixing time. This relation is included in the model.

Pelletization. The pelletization yield factor has been left as an input variable.

Process Economics Program

The economic model, which is integrated with the process simulation program, gives the cost of a proposed operation and the product quality. The total processing cost of the operation is determined from four component costs: equipment costs, material costs, energy costs, and labor and overhead costs. The product quantity is calculated based on slurry fines input rate and process yields.

Equipment Costs

Equipment sizes and costs are calculated based on coal processing rates. Equipment costs are given as annualized capital costs. The general procedure used for calculation of equipment sizes and costs is given below:

Equipment size = Output from previous step in the process/unit processing rate of the equipment.

Equipment cost = Size of equipment x unit cost of equipment. Where appropriate, an exponential function is used instead of a multiplication factor.

Material Costs

These are calculated based on the input costs used for oil, binder and other materials used. The amount of material used is dependent upon the coal processing rates and process yields. Coal slurry costs ($/ton) are dependent on the market value of the uncleaned coal, and include transportation to the processing site. Since the coal slurry cost is dependent on the specific site, it is also left as an input variable.

Energy Costs

The costs considered here are the cost for the power used in the process, and heating costs for the agglomeration step. Power requirements for various pumps and motors used in the pilot plant process were measured and are presented in the results section. Power for mixing during agglomeration was compared with predictions from the bench scale study, utilizing the scale-up procedures given by Rushton (46).

Labor Costs

These are calculated on number of man hours required to operate the plant, and are estimated for each step in the process.

Labor cost for a step = labor required for the step x hrs./day x days/year x $/hr.

As the program has been written to handle more than one data set at a time, it is possible to see the effect of any of the input variables on the cost in one run of the program. Also, the unchanged input variables need not be repeated in the data set. This is an inherent advantage of the "GET DATA" statement of the PL/I programming language. A sample input data set is given in Appendix A.

If one wants to predict only the processing costs and product quality, it is possible to operate this program independently from the reclamation and decision making programs. Only a dry screen analysis, including quality of the size fractions of coal from the slurry pond, and a cost of the slurry material ($/ton) are required. Other input cost factors should be reviewed for their applicability to a particular site.

Reclamation Analysis Program

One part of the surface mine planning program written by Montana State University's Department of Industrial Engineering/Computer Science dealt with reclamation analysis (45). The whole program is called 'SEAMPLAN'© and the reclamation program is called 'CLAIM'©. As many of the environmental factors and some of the grading factors considered in the program 'CLAIM'© seemed to fit the needs of slurry pond reclamation, the program 'CLAIM'© was obtained from Montana State University.

The program has been modified to do cost and feasibility analyses of slurry pond reclamation. The original program has been shortened; the retained modules of the 'modified CLAIM'© program are presented in Figure 7. A description of each subroutine follows.

GDE: General Description Executive

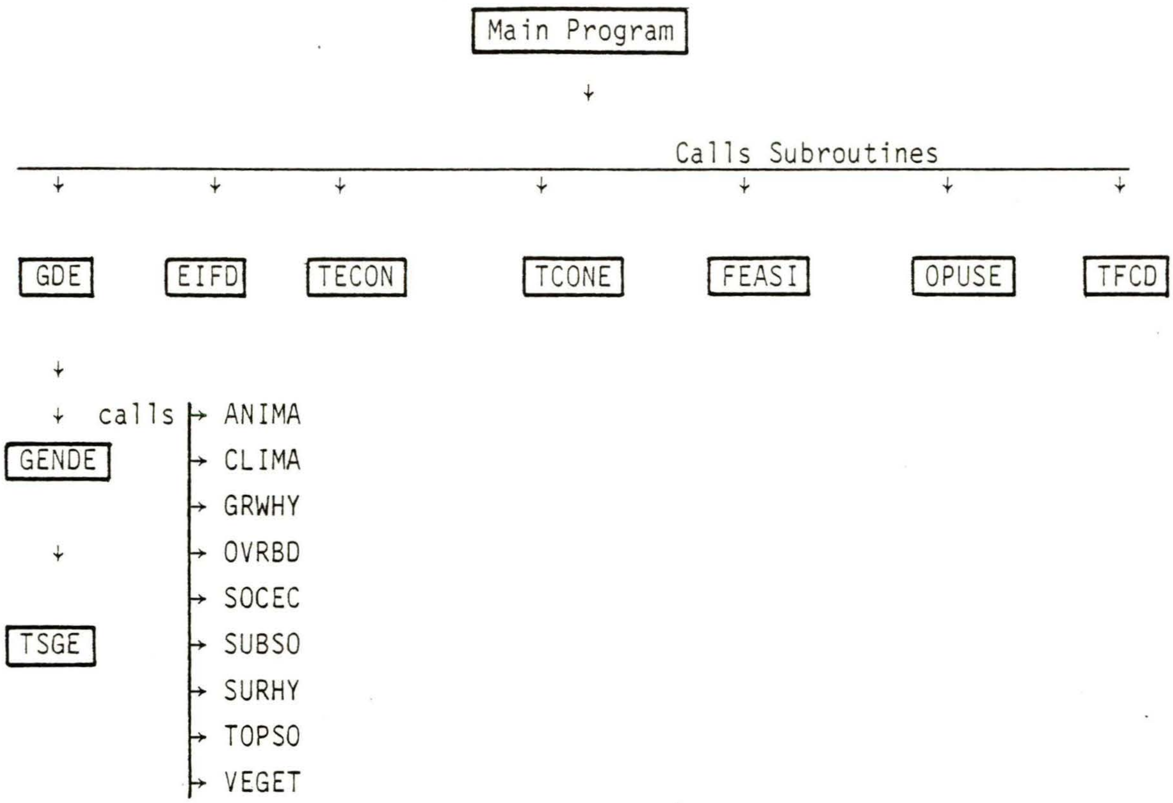
This module handles grading for the site, and calls subroutines 'GENDE' and 'TSGE'. These routines together handle site description and grading. These modules can be called in the input or edit mode. The truck and shovel grading mode is utilized.

EIFD: Environmental Input Full Display

The original 'CLAIM'© program has two kinds of display for environmental input: (a) Abbreviated Display; and (b) Full Display.

As it was desired to make the program as short as possible, the Abbreviated Display module was removed. EIFD can input and edit environmental data. This module has nine subroutines:

1. ANIMA: For the purposes of future land use, one factor considered here is wildlife present in the area. It may play an important role while considering wildlife preservation. This routine handles input and edit mode of data in this category.
2. CLIMA: Climate in the area plays a part in reclamation. This routine handles data input and data editing in this category.
3. GRHWY: Handles data regarding groundwater present in the area.
4. OVRBD: Handles data about overburden rocks and soil in the area.
5. SOSEC: Handles socioeconomic factors.
6. SUBSO: Subsoil data is handled by this routine.



1) <u>INPUT</u>: a) SITE DESCRIPTION (GDE, TSGE)
   b) COSTS (TSGE)
   c) ENVIRONMENTAL INPUT (EIFD)

2) EDIT: EDIT DATA
   EDIT COSTS (TCONE)
   EDIT EXPECTATIONS

3) TEST FOR COMPLETE DATA (TFCD)

4) DATA ANALYSIS (TECON, FEASI, OPUSE)

Figure 7. Modified 'CLAIM'© program.

7. SURHY: Surface water hydrology is handled by this routine.
8. TOPSO: Topsoil conditions are input through this routine.
9. VEGET: Vegetation in the area is considered here.

TECON:

Techniques required for the reclamation to the land-use considered are handled by this routine. This does the main cost calculations.

TCONE:

Cost factors used by 'TECON' can be edited by this routine.

FEASI:

This routine handles the feasibility rankings for the different land uses considered.

OPUSE:

This routine combines results from TECON and FEASI to come up with optimum use factors.

TFCD: Test for Complete Data

This routine is called when the user wants to find out if he has completed data input for the program. If data is incomplete, this routine will point out the data entries to be completed.

Thus, in general, if one has information on geology of the slurry pond site, the modified 'CLAIM'© program can be used to determine the feasibility of desired land use and cost for reclamation options.

Program Outputs

The program outputs three factors:

1. Feasibility Rankings: These are based on the expectation of success values for the category responses. The expectation of success values are from zero to four. "Zero" means impossible and "four" means obligatory. The feasibility rankings are listed for the six land uses and are arranged from best to worst.

2. Cost Factors: Techniques applied for each land use with cost/acre are listed. The final cost for reclaiming to that use is also listed. The land uses are listed based on cost/acre and are arranged from least-cost to maximum cost (best to worst).

3. Optimum Use Factors: The decision on these is based on feasibility rankings and cost/acre. These optimum use factors are listed for each land-use and are arranged from best to worst.

Exceptions: If there is a particular category response which will force the reclaimer to go to a particular land use due to various restrictions (like government regulations, etc.) then this is flagged with a warning message that this has to be done irrespective of the feasibility rankings and optimum use factors. The reason for taking that decision is also printed out.

Environmental Input

In each heading of the environmental input, we have different subheadings, e.g., in 'CLIMA' we have:

(a) amount of precipitation

(b) average wind speed, etc.

These subheadings have different categories. The programmer responds to the inquiry by the program with a category response. The program has standard expectation values (which the programmer could edit) for each category of different ultimate land use. These responses are noted and the ultimate decision is determined based on the expectation of success values for each category.

Analysis and Results

The program lists six ultimate land uses.

1. Cropland
2. Native Vegetation
3. Wildlife
4. Water Recreation
5. High Use
6. "Other" Use

"Other use" is completely user defined. The user has to input the expectation of success values for each category under each subheading in the environmental input.

Decision-Making Program

The results from the two programs, the process simulation program and the modified 'CLAIM'© reclamation program, provide the input to the decision-making program. The output from this program may be used as a basis for decision-making on a given coal fines recovery operation, and for comparative evaluations of several sites.

Dry screen analyses give the quality of coal fines by size fractions. This is an input to the process simulation program. The process simulation program output will give the product quality, production rate in tons/hr, process cost in dollars/ton and cents per million Btu.

The modified 'CLAIM'© program gives as an output the cost for reclamation in dollars/acre, and the optimum land use based on characterization of the slurry pond site and environmental considerations. These two outputs form the main part of the program logic input for the decision-making program. If reclamation costs for a given site have been estimated by other means, these values may serve as input to the decision-making program, thus obviating the need for the modified 'CLAIM'© program.

The flow diagram for the decision-making program is given in Figure 8. As the program has been written to be run in an interactive manner, there is no special formatted data-sheet required for running this program. The input values are prompted by the program.

Provision is made in the decision-making program to provide for handling the waste from more than one slurry pond at a single processing site. This could significantly reduce the reclamation costs. If the waste generated by the process is of the quality that it can be put back in one of the ponds (sites) from where the fines were taken, then one of the major costs in reclamation, grading cost, will be cut to a minimum. Thus, if there is more than one slurry pond in a region, the process economic program should be run for each pond. The reclamation program will be run twice for each pond, regardless of the number of ponds considered. It will be run once with the option of waste generated from the process being put back in the pond, and next time without this

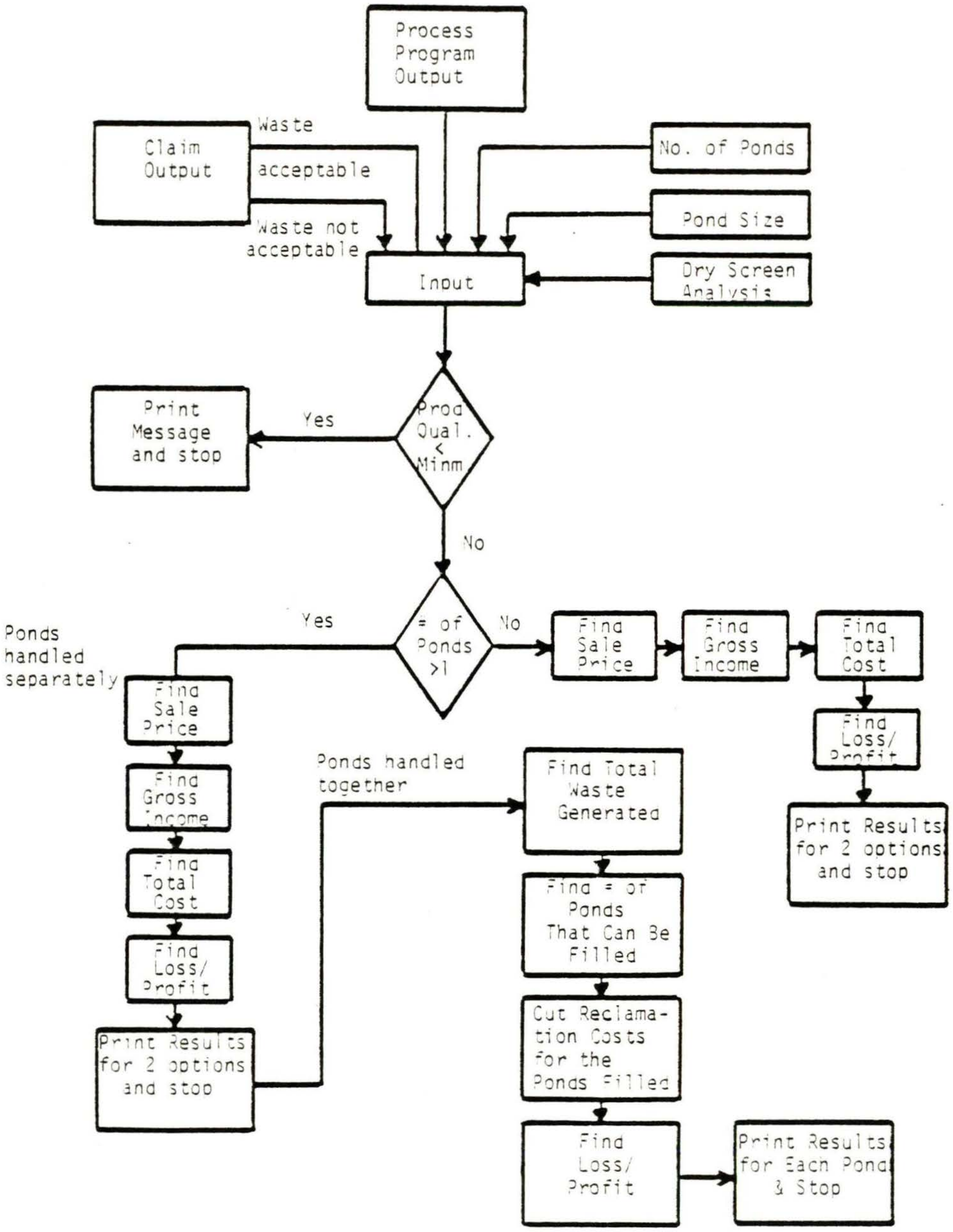


Figure 8. Decision-making program flow diagram.

option. The results from these two runs of the modified 'CLAIM'© program, and the output of the process economic program, will be input for each pond considered when running the decision-making program.

The program listing, input variables, descriptions, and a sample run of the program are given in Appendix C; therefore, no attempt to explain each of the variables, or to explain how to run the program, will be made here. Instead, the program logic and the output will be discussed.

The first condition to be checked in the program is the product quality (Figure 8). If it is below the acceptable quality, then the process is rejected as not a viable alternative for energy recovery. The program will terminate after printing an appropriate message. Then, the number of ponds will be checked. If the number is one, then the program will terminate after the input/output (I/O) has been finished for the pond. If there is more than one pond, each pond will be treated separately, and then the ponds will be handled together.

When there is only one pond, the total costs will be calculated for that pond. The process costs will be calculated from the cents/million Btu value determined from the process simulation program. The total available coal in the slurry pond is calculated from the dry-screen analysis, average depth, and surface area of the pond. Then the product yield factor is applied to this available coal and the total quantity of product from the pond is predicted. Then, from the product HHV and the total processing cost, the cost of the recovery process is determined. Since the reclamation costs are given from the modified 'CLAIM'© program in dollars/acre, the surface area of the pond is sufficient information to calculate the reclamation cost.

The product sale price is calculated based on current market values for coals utilized for power generation in southern Illinois. A slurry value of $3/ton for 8,000 Btu/lb material, and $29.60/ton for 11,400 Btu/lb coal were used to establish a linear cost function over that range of quality. Above 11,400 Btu/lb, an increment of 20 cents for each additional 100 Btu/lb was added to the sale price of $29.60/ton. Then, from the product sale price, which is given as dollars/ton, and the product quantity, the projected gross income for the product is calculated. Profits or losses, as the case may be, are then determined and printed as output.

If the number of ponds is more than one, then costs are found for each pond as explained above. The profits/losses are then printed for each pond. The total waste generated from all the ponds is then calculated. An attempt is made to fill as many ponds as possible with this waste. If a pond can be filled, the reclamation costs are reduced for that pond. This is done for all the ponds. After all the ponds have been searched, the amount of remaining waste is printed, so that this can be used to calculate reclamation costs for one of the ponds that is not filled. Then processing costs, reclamation costs, and profits/losses are printed for each pond, with a special message given for the ponds for which the reclamation costs are reduced due to return of process waste material.

The above process is carried out completely only if the waste generated from the process is of the quality that it can be used to fill the pond without environmental problems. If the waste is not of acceptable quality, then the ponds are handled separately. Profits/losses are calculated separately and printed with a message that the waste is not of acceptable quality for return to the pond.

From the various program outputs, the user can then base a decision on whether it will be a worthwhile effort, economically, to go through the recovery process. Just the profits/losses figures from the program will not be enough to make that decision. Even if there is a loss predicted, the amount that will be actually spent may be less than the cost for only reclaiming the land. Reclamation without this process generally would be more expensive than reclamation with the process.

An additional factor that should be recognized, particularly if federal or state funding were contributing a portion or all of the processing and reclamation costs, is the energy losses incurred when the process waste material is returned to the pond. It is unlikely that tertiary recovery of that material would be economically justified in the foreseeable future. Thus, operation of the recovery process to provide Btu recovery yield above the apparent optimum, as determined only by current market value, processing, and reclamation costs, may be justified in terms of the country's long-term energy needs. All factors have to be weighed, before making a final decision.

RESULTS

Process Performance at Laboratory, Bench and Pilot Plant Scales

Washing Step

Four factors were used to measure cleaning beneficiation. The first factor is called the underflow recovery factor. This factor is defined by the following equation:

$$URF = \frac{(\%\ \text{COMBUSTIBLES}/\%\ \text{NON-COMBUSTIBLES})\ \text{UNDERFLOW}}{(\%\ \text{COMBUSTIBLES}/\%\ \text{NON-COMBUSTIBLES})\ \text{ORIGINAL}}$$

This factor is determined by the % ash in the original and underflow. This term gives a ready comparison between the underflow product and the original sample with a dimensionless factor. This aids in the comparison of several samples tested with a wide range of % ash.

The other factors used in evaluating the cleaning process were heating value of the original sample and the underflow, % total sulfur in original and underflow, and % original combustibles recovered in the underflow.

Tests on washing coal fines waste showed good agreement in going from the laboratory to the bench scale size, Figures 9 and 10. The pilot plant results of wet screening Illinois No. 6 coal from Randolph County followed by high shear agitation and settling tank separation are shown in Table 2. The results of high shear agitation followed by screening are shown in Tables 3 and 4. The results of a second screening without high shear agitation are shown in Table 5.

The hypothesis that sulfur removal occurred from sulfate removal was examined in several tests. The wash water on the initial wet screen was virtually free of sulfates. The waste water contained sulfate levels shown in Table 6.

Relationships between the slurry feed and washed coal characteristics, viz. ash, HHV and yield, were needed for the process simulation and decision-making computer models. Tests were conducted to correlate the washed product yield and quality to the dry screen analyses of the input slurry. The results are presented in Figures 11, 12 and 13.

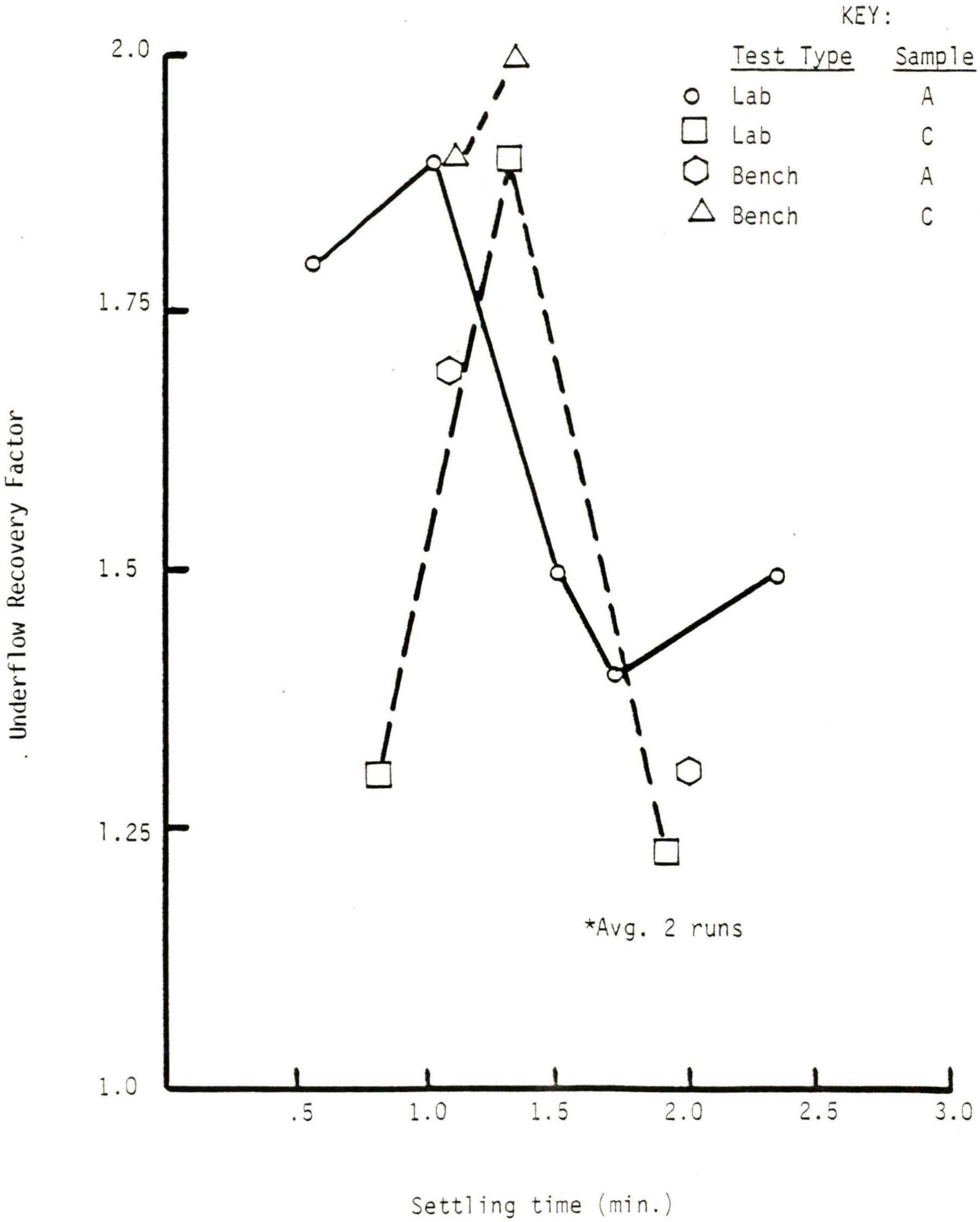


Figure 9. Comparison of mechanical cleaning data from laboratory and bench scale tests. Effect of settling time on underflow recovery factor.

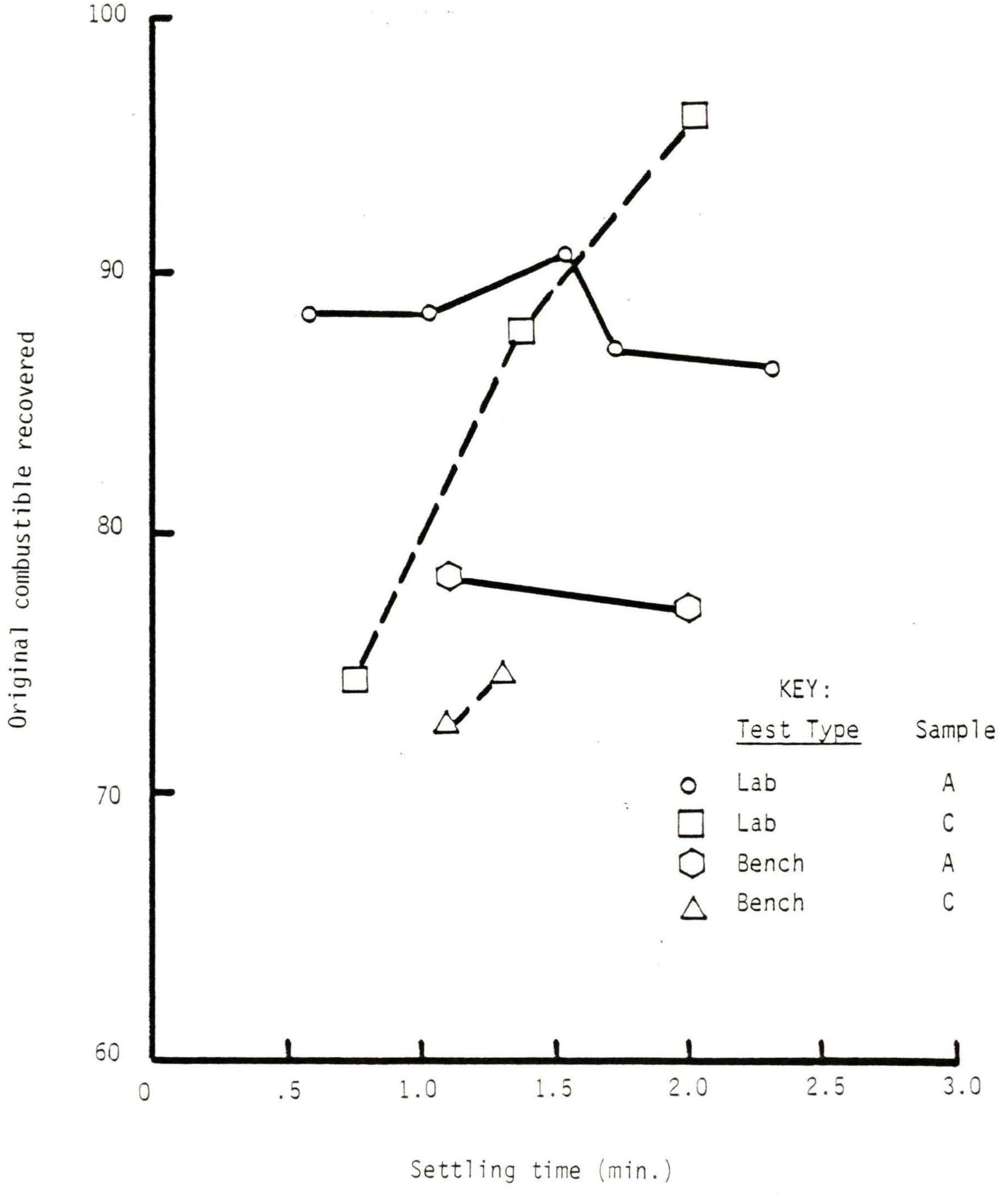


Figure 10. Comparison of mechanical cleaning data from laboratory and bench-scale tests. Effect of settling time on % original combustibles recovered.

Table 2

Effects of High Shear Agitation Followed by Gravity Settling

Randolph County, Illinois No. 6

	HHV (Btu/lb)	Ash (%)	Total Sulfur (%)	Recovery (%)
Original	8,971	25.8	3.12	
Product*	10,671	16.2	3.05	47.0
Oversize**	11,362	10.0	2.99	10.2
URF 1.80				
Original	8,719	28.6	3.53	
Product	11,738	14.5	3.21	47.0
Oversize	9,419	27.7	3.26	22.0
URF 2.37				
Original	9,031	30.7	3.58	
Product	10,190	21.6	4.47	42.8
Oversize	9,104	30.3	3.52	17.9
URF 1.61				
Original	8,915	29.3	3.21	
Product	10,776	19.5	4.06	49.8
Oversize	8,469	33.2	3.70	16.7
URF 1.71				
Original	9,100	26.3	3.27	
Product	10,607	18.1	3.59	58.6
Oversize	8,093	34.8	2.78	7.0
URF 1.61				

*underflow in separation process; $\% \text{ Recovery} = \frac{\text{Washed Product (100)}}{\text{Original - oversize}}$

**+14 mesh material; $\% \text{ Recovery} = \frac{\text{oversize}}{\text{original}} (100)$

Table 3

Effects of High Shear Agitation Followed by Screening at 50 Mesh

Randolph County, Illinois No. 6

		HHV (Btu/lb)	Ash (%)	Total Sulfur (%)	Recovery (%)
Original		9,016	28.8	3.28	
Product		11,456	12.0	3.04	50.7
Oversize		6,963	41.8	3.12	12.9
URF	2.93				
Original		9,258	24.8	3.22	
Product		11,596	10.9	2.93	47.8
Oversize		8,592	29.0	2.49	9.2
URF	2.69				
		Jackson County, Illinois No. 6			
Original		4,674	55.8	1.98	
Product		8,858	30.3	1.79	39.5
Oversize		7,202	41.8	1.87	20.2
URF	2.90				
Original		4,533	58.4	---	
Product		8,178	34.7	---	30.9
Oversize		6,984	43.2	---	13.2
URF	2.64				

Table 4

Effects of High Shear Agitation Followed by Screening at 70 Mesh

Jackson County, Illinois No. 6

		HHV (Btu/lb)	Ash (%)	Total Sulfur (%)	Recovery (%)
Original		4,469	60.1	1.52	
Product		6,699	45.8	1.33	45.9
Oversize		3,768	64.3	1.27	25.0
URF	1.79				
Original		5,292	51.8	---	
Product		8,702	32.2	---	41.7
Oversize		5,700	51.4	---	25.4
URF	2.26				
Original		11,269	15.5	1.23	
Product		12,120	9.0	1.18	50.8
Oversize		11,966	12.7	1.27	58.1
URF	1.84				
Original		11,527	14.6	1.24	
Product		12,618	6.7	1.13	32.9
Oversize		12,614	9.0	1.26	39.0
URF	2.38				
Original		11,072	15.8	1.22	
Product		12,321	7.9	1.14	34.4
Oversize		11,991	12.5	1.26	50.5
URF	2.19				
Original		10,818	14.5	1.17	
Product		11,614	7.2	1.12	52.6
Oversize		11,654	9.2	1.25	36.4
URF	2.17				

Table 4 (Continued)

Randolph County, Illinois No. 6

	HHV (Btu/lb)	Ash (%)	Total Sulfur (%)	Recovery (%)
Original	8,219	31.4	4.12	
Product	10,080	17.3	3.42	45.7
Oversize	9,416	21.5	3.28	23.0
URF 2.18				
Original	7,850	33.4	4.35	
Product	10,050	18.8	4.00	55.3
Oversize	8,145	30.8	4.42	19.8
URF 2.17				
Original	8,307	33.2	4.53	
Product	10,292	18.1	4.03	54.5
Oversize	8,615	30.0	3.72	17.5
URF 2.25				
Original	8,363	31.9	3.88	
Product	10,684	15.5	3.56	62.0
Oversize	9,021	26.9	3.71	12.8
URF 2.55				
Original	8,130	34.5	4.28	
Product	10,618	16.1	3.41	61.0
Oversize	7,793	37.0	3.76	15.0
URF 2.75				
Original	8,440	33.8	3.89	
Product	10,521	16.4	3.48	58.4
Oversize	8,217	33.8	3.49	12.0
URF 2.59				

Table 5
Effects of Screening at 14 Mesh Followed by 70 Mesh
Randolph County, Illinois No. 6

	HHV (Btu/lb)	Ash (%)	Total Sulfur (%)	Recovery (%)
Original	8,295	33.9	4.37	
Product	10,495	20.1	3.81	55.0
Oversize	9,573	26.8	4.03	16.1
URF 2.04				
Original	8,340	33.6	4.29	
Product	10,610	18.8	3.84	57.1
Oversize	8,549	31.7	3.91	14.7
URF 2.30				

Table 6
Sulfate Levels in Wastewater

	Water:coal	Sulfate (mg/l)
With High Shear Washing	10.5	1580
	11.4	1733
	14.9	1167
	16.1	1153
	20.0	1027
Without High Shear Washing	13.7	973
	21.6	753

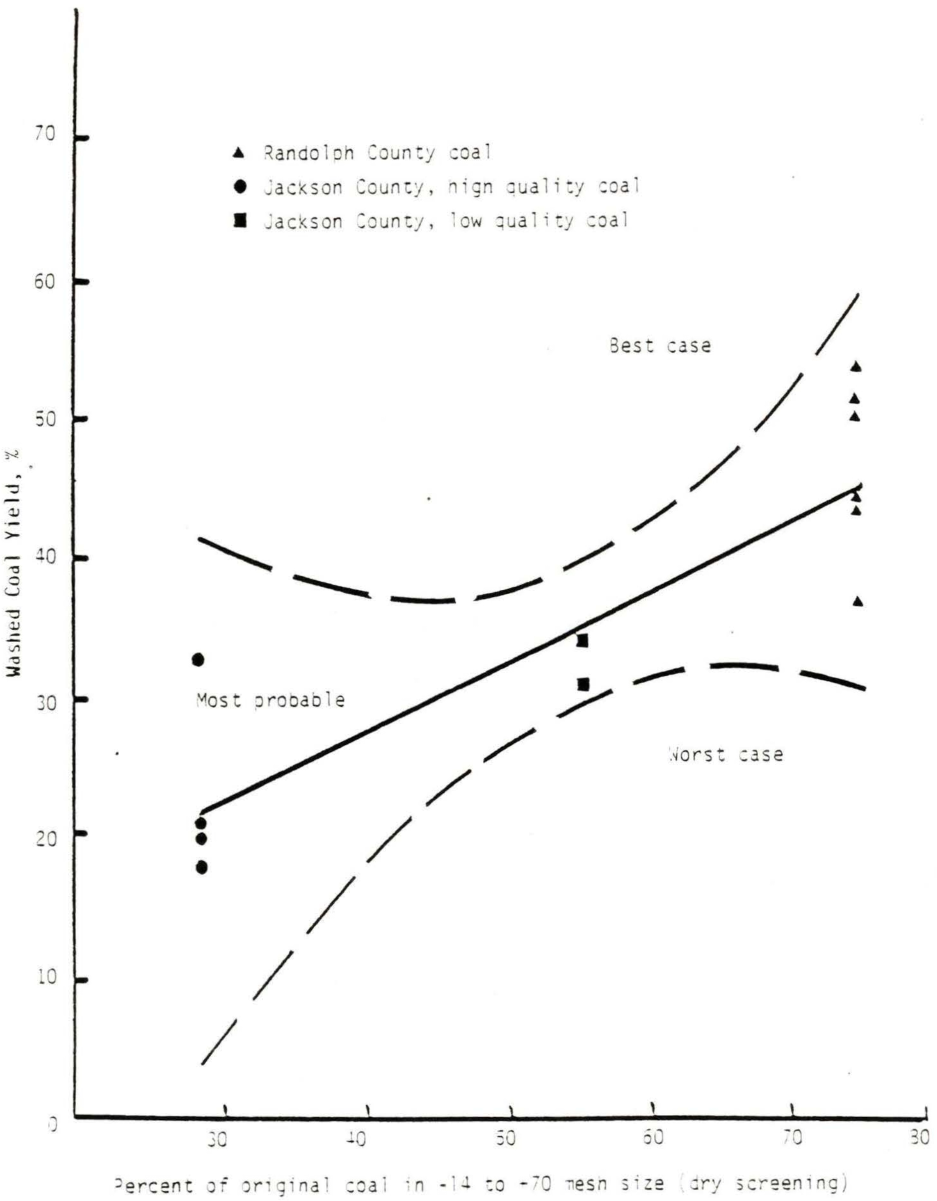


Figure 11. Correlation of dry screen size distribution with washed coal yield.

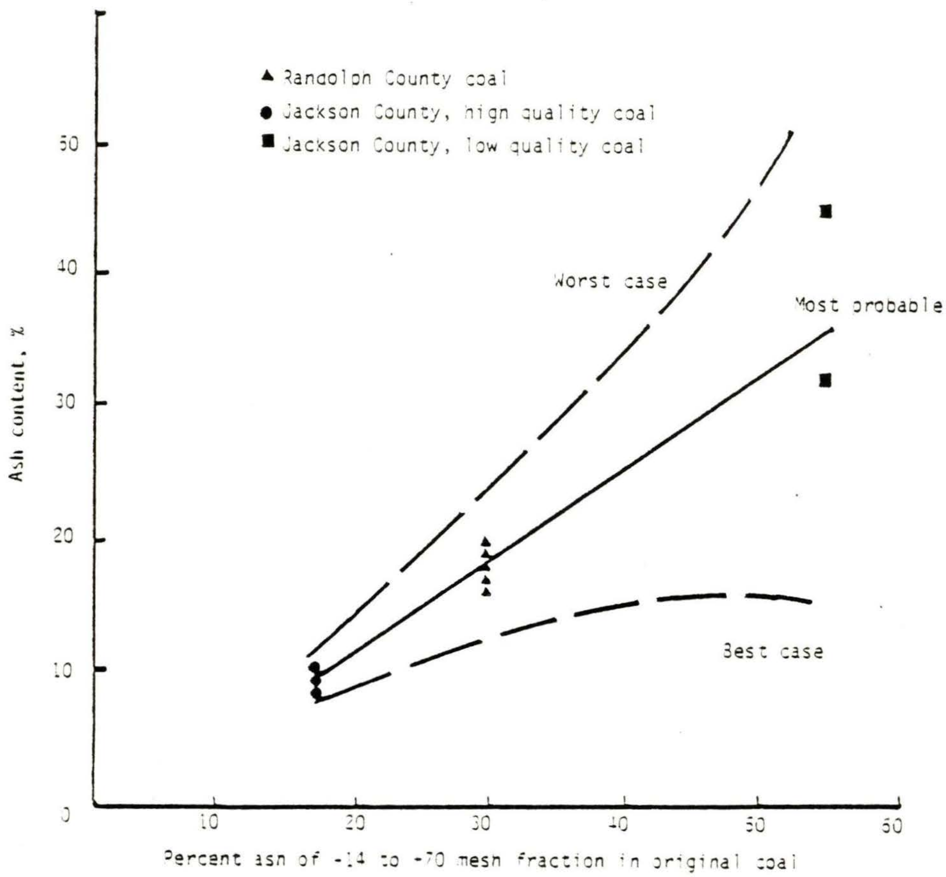


Figure 12. Correlation of dry screened sample ash content with washed coal ash content.

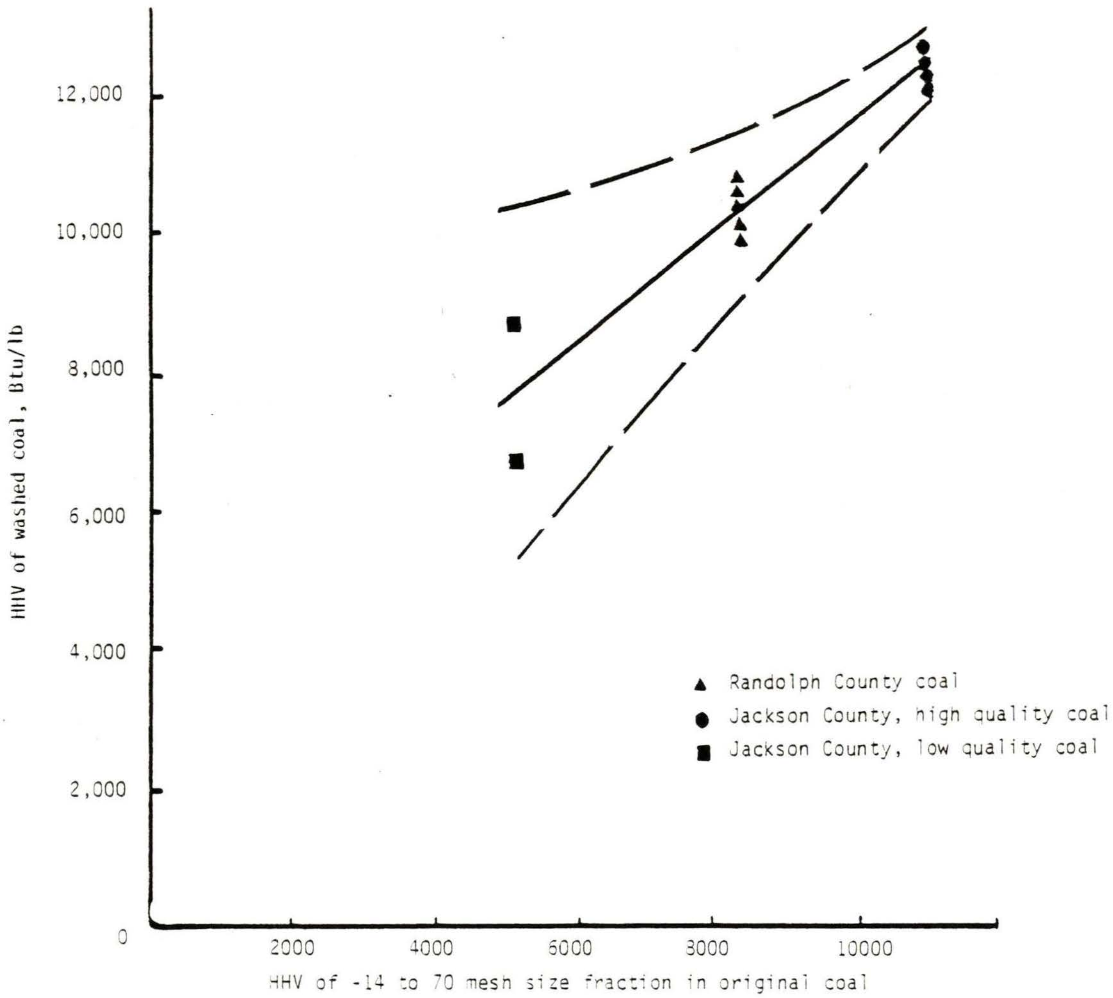


Figure 13. Effect of HHV of Original Feed on Washed Coal HHV. [Improvement in HHV of Screened Coal Through High Shear Washing.]

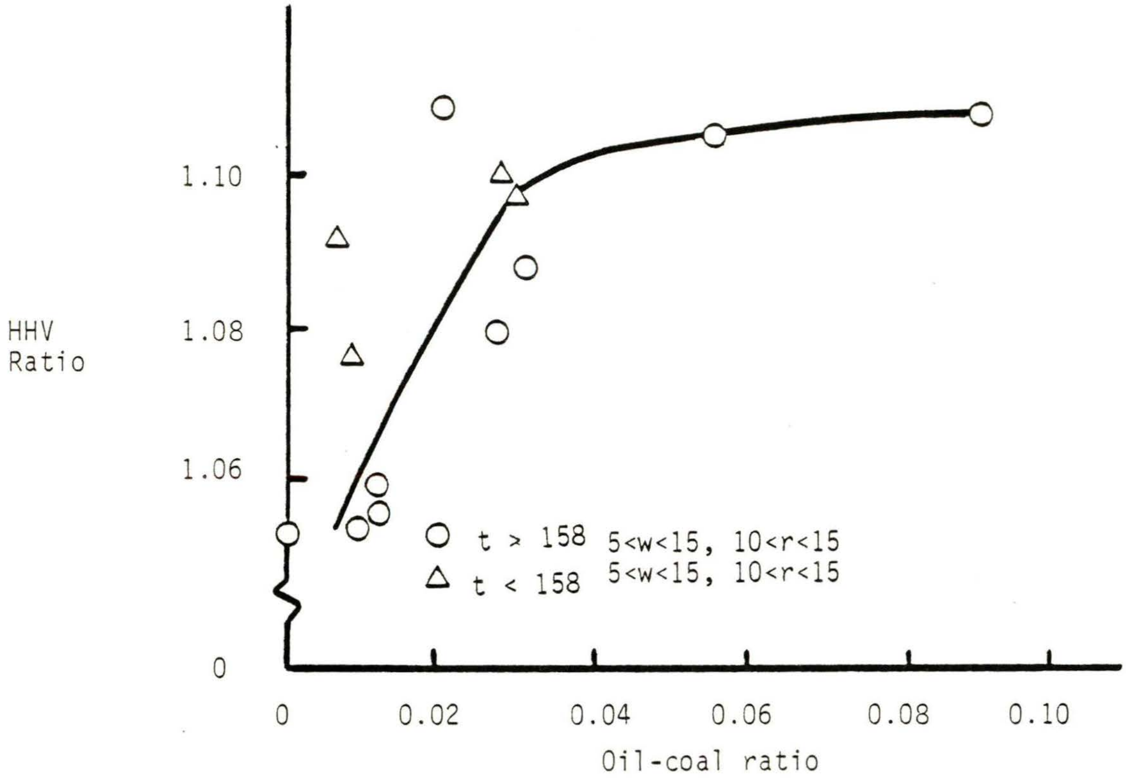


Figure 14. Effect of oil addition on heating value enhancement: Randolph County coal.

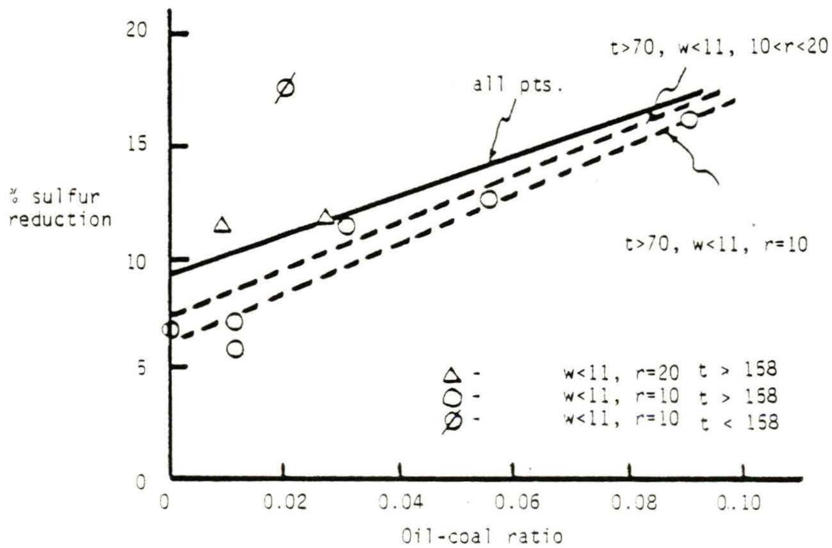


Figure 15. Effect of oil addition on sulfur removal: Randolph County coal: + = temperature, F; r = retention time, min.; w = water/coal ratio.

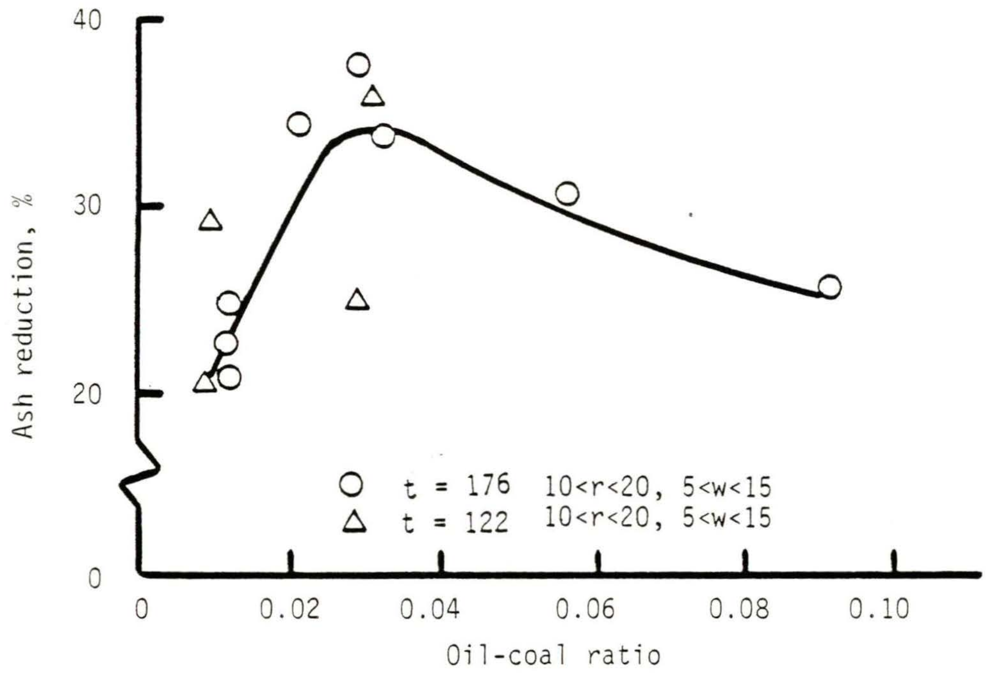


Figure 16. Effect of oil addition on ash removal: Randolph County coal.

Oil Agglomeration

Detailed elevated temperature oil agglomeration test results are included in Appendix D. From these data several distinct results and trends emerge through statistical analysis. The HHV ratio (heating value of agglomerate/heating value of feed) decreases with increasing temperature and increases with increasing oil, above the effect of added oil for oil/coal ratios of 0.06 or less. Ash reduction decreases with increased temperature and decreases with oil addition, but not linearly. Energy yield (product mass x HHV/feed mass x HHV) decreases with increasing temperature and increases with oil addition. There were no significant effects of temperature, retention time or oil content upon changes in sulfur reduction.

More detailed analysis of the Randolph County coal produced the results of Figures 14-16. Oil addition up to .03 oil/coal by mass markedly increased the HHV ratio and reduced ash content and sulfur content. Above .03, ash reduction decreased slightly, HHV ratio increased slightly and sulfur reduction increased as before.

Processing of the Jackson County high HHV coal waste resulted in an average increase of the heating value from 12,170 Btu/lb. to 13,000 Btu/lb. and decrease in ash from 8 to 6%. A coal waste from the same site which had an initial HHV of 4,500 Btu/lb. and 56% ash was upgraded to 10,000 Btu/lb. and 24% ash with only .01 oil/coal during agglomeration.

Statistical tests were performed to find significant (95%) correlations between yield, HHV and ash as functions of process variables (water/coal, oil/coal, mixing time, and temperature) using all of the data as a set. Yield as a function of mixing time was the only correlation at this level; the resulting equation was used in the process simulation model.

Analysis of the volatile matter content in the feed material and corresponding agglomerate was used to determine the oil content in the pellets as a function of oil introduced to the coal in the agglomeration, Figure 17.

Trace metals content of the coal fines waste tested were measured to assess potential problems with process waste material storage and

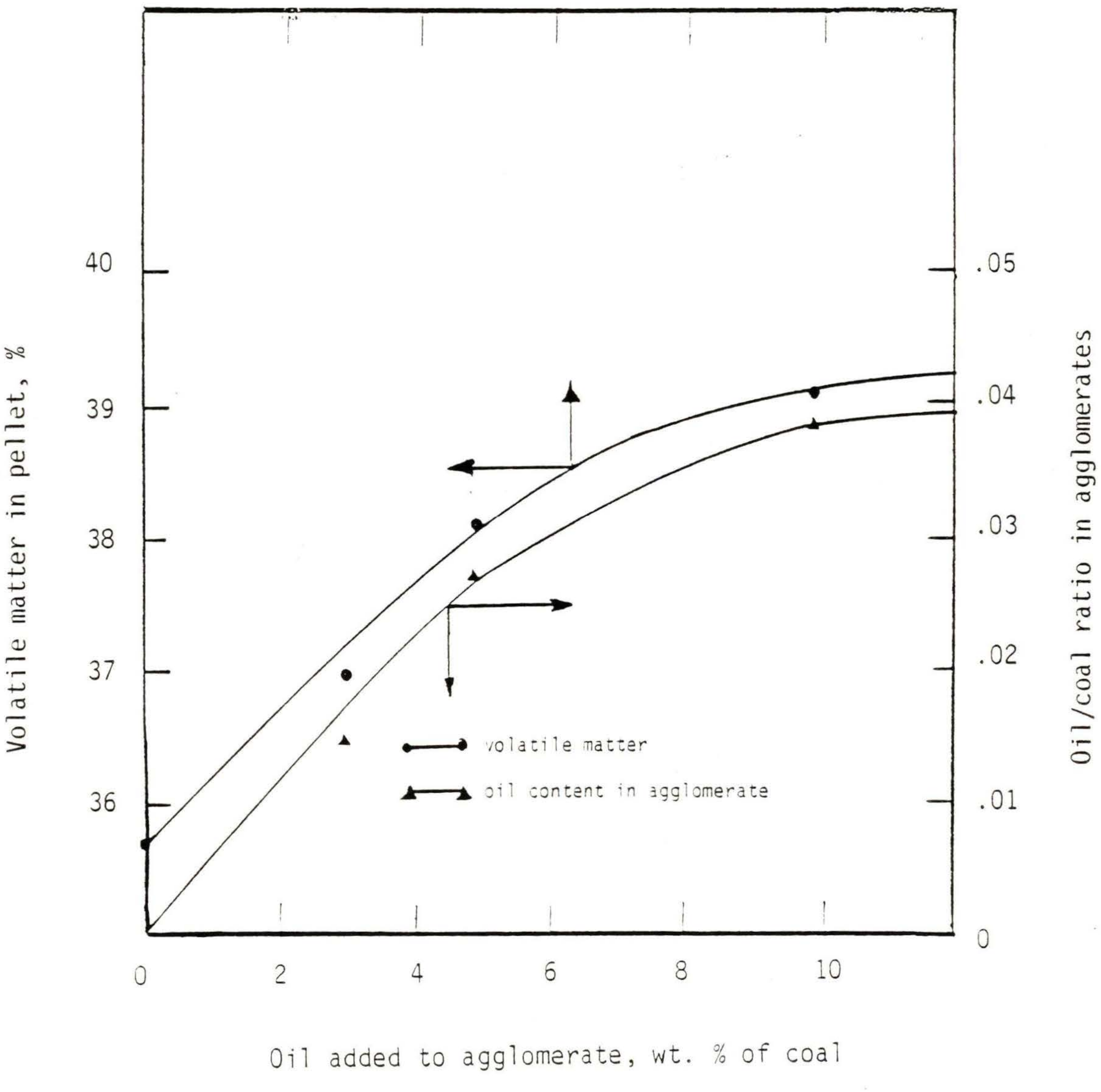


Figure 17. Effect of oil addition on volatile matter and oil content in agglomerate.

treatment, and also to evaluate its potential as a mineral source. The results, Table 7, show only iron and magnesium in significant amounts.

Pelletization

Batch pelletization studies on agglomerate as feed and asphalt as binder produced the results in Figures 18 to 20. Pellet strength increased from 4,000 to 7,500 lb/ft^2 in 30 days, Figure 18, even as the moisture content increased. The effect of binder and pellet moisture on the initial pellet strength is shown in Figure 19. Lower moisture in the pellet increases pellet strength, as does the amount of asphalt binder. Weathering increases pellet hardness rapidly, Figure 20, and achieves similar values after 10 days for initial moisture contents of 5 to 15% at 5% asphalt binder concentration in the feed.

The yield of over ¼" size pellets and concentration of binder in the pellets during a single pass through the pelletizer are shown as functions of holdup in Figures 21 and 22. The holdup is determined from pelletizer axis slope, speed of rotation and end geometry (47).

Agglomerate Evaluation

Physical properties refer to the drainability, the integrity and the dustiness of the agglomerate product and are primarily a function of the amount of oil used during processing. At oil-coal ratios below about 0.03 by weight, the agglomerate still had moisture levels above 25% after 3-4 days of air drying and had a powdery texture in appearance and to the touch. At oil ratios of 0.05, 2-3 cm. in diameter loosely-formed pellets took shape on the dewatering screen but fell apart, if not when they dropped into the collection bin, then after several days of air drying. The air-dried .05 oil/coal ratio agglomerate was granular in appearance, tacky to the touch, and formed into loosely packed spheres (.1 to .2 inch in diameter). 75% of these deformed during storage and settled into a loosely-packed solid, contiguous clump in the shape of the storage bin after four days of air drying. The four-day air dried clump had a moisture content of about 15%.

Grindability study results, Figure 23, show that oil/coal ratios of 0.04 or less at 5% moisture, 0.034 at 10% moisture and 0.01 at 15% moisture produce a grindable coal.

Table 7
Trace metals content of solids -- selected experiments.

Experiment Number	Sample Point	Metal content, dry wt. %						
		Fe	Mg	Mn	Zn	Cd	Pb	Co
1	Coal Feed	1.89	--	*	--	*	--	0.06
	Agglomerate	0.80	--	*	--	*	--	0.04
	Waste	2.79	0.10	*	0.09	*	--	0.06
2	Coal Feed	1.80	0.11	--	--	--	*	*
	Agglomerate	0.68	0.05	--	--	--	*	*
	Waste	2.78	0.19	trace	--	--	*	*
3	Coal Feed	1.64	0.13	--	--	--	*	*
	Agglomerate	1.00	0.05	--	--	--	*	*
	Waste	2.68	0.23	trace	--	--	*	*
4	Coal Feed	1.32	0.05	--	--	--	*	*
	Agglomerate	0.92	0.05	--	--	--	*	*
	Waste	2.50	0.15	trace	--	--	*	*

-- Means this metal not found. Test sensitive to .1 ppm.
* Means this metal not tested for.

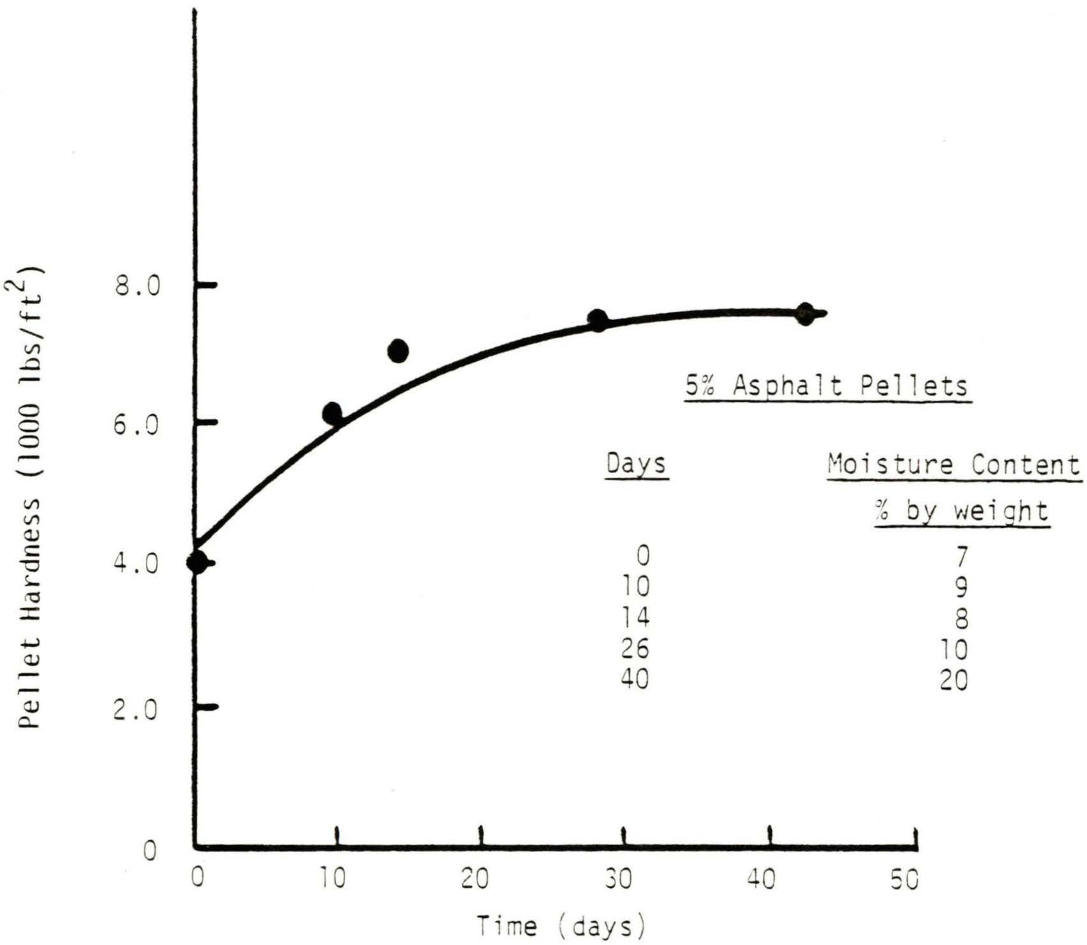


Figure 18. Effect of weathering on pellet strength moisture content.

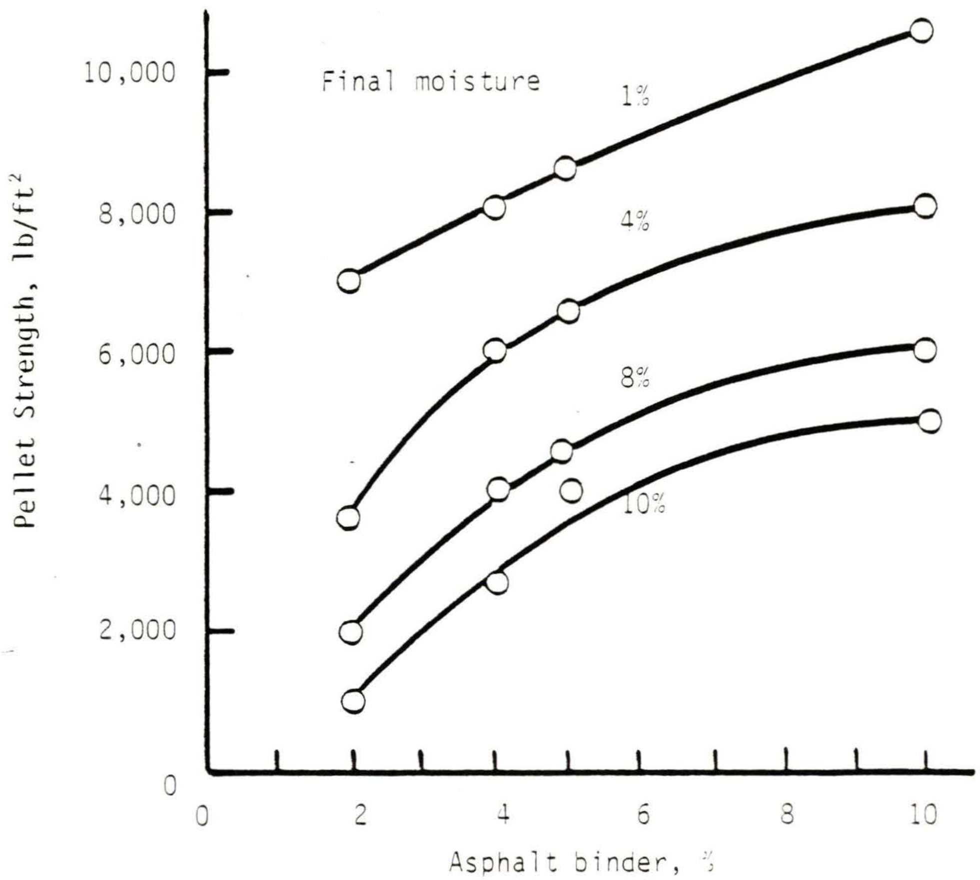


Figure 19. Effect of moisture and binder amounts on pellet strength.

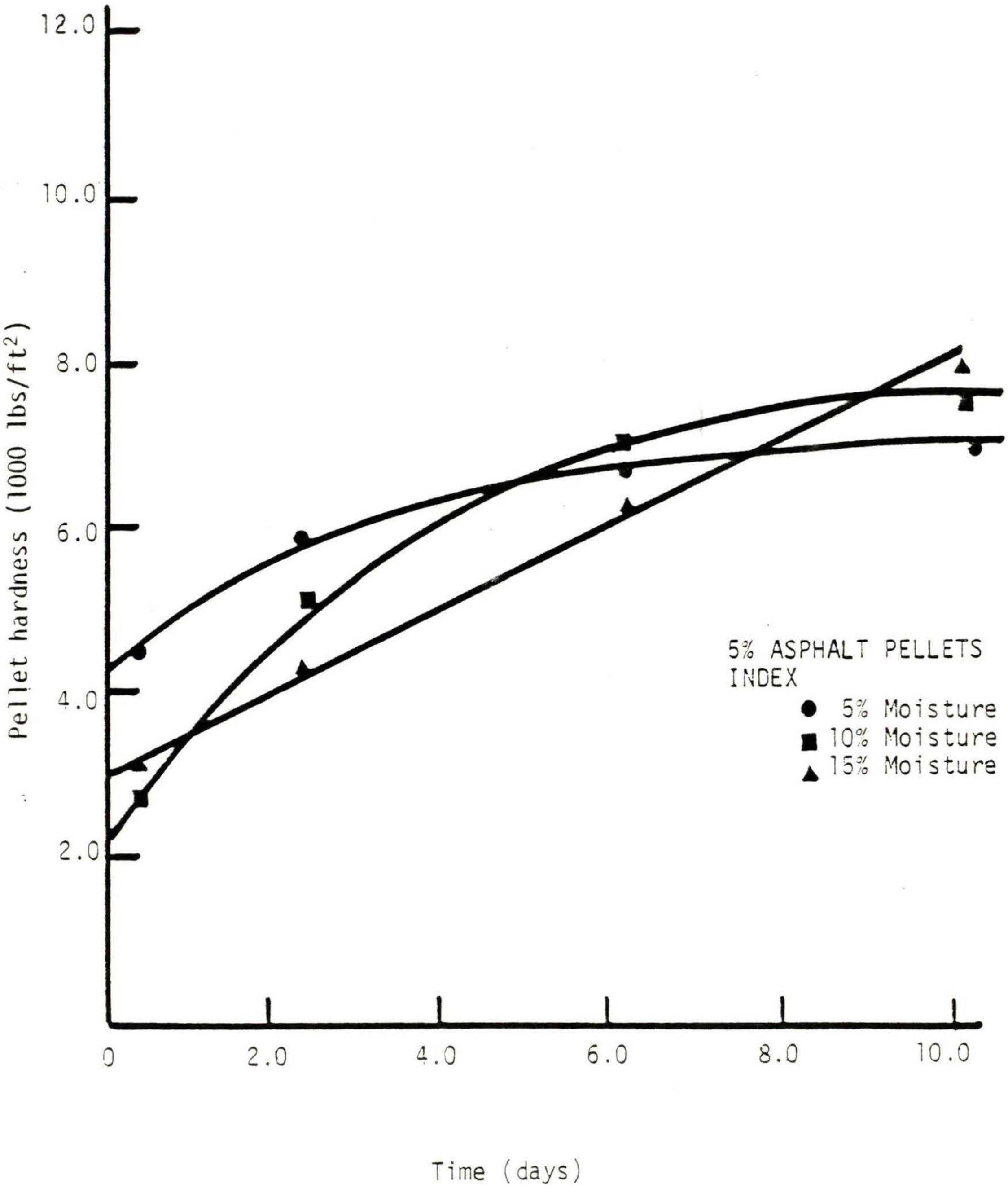


Figure 20. Effect of initial moisture content and weathering time on pellet strength.

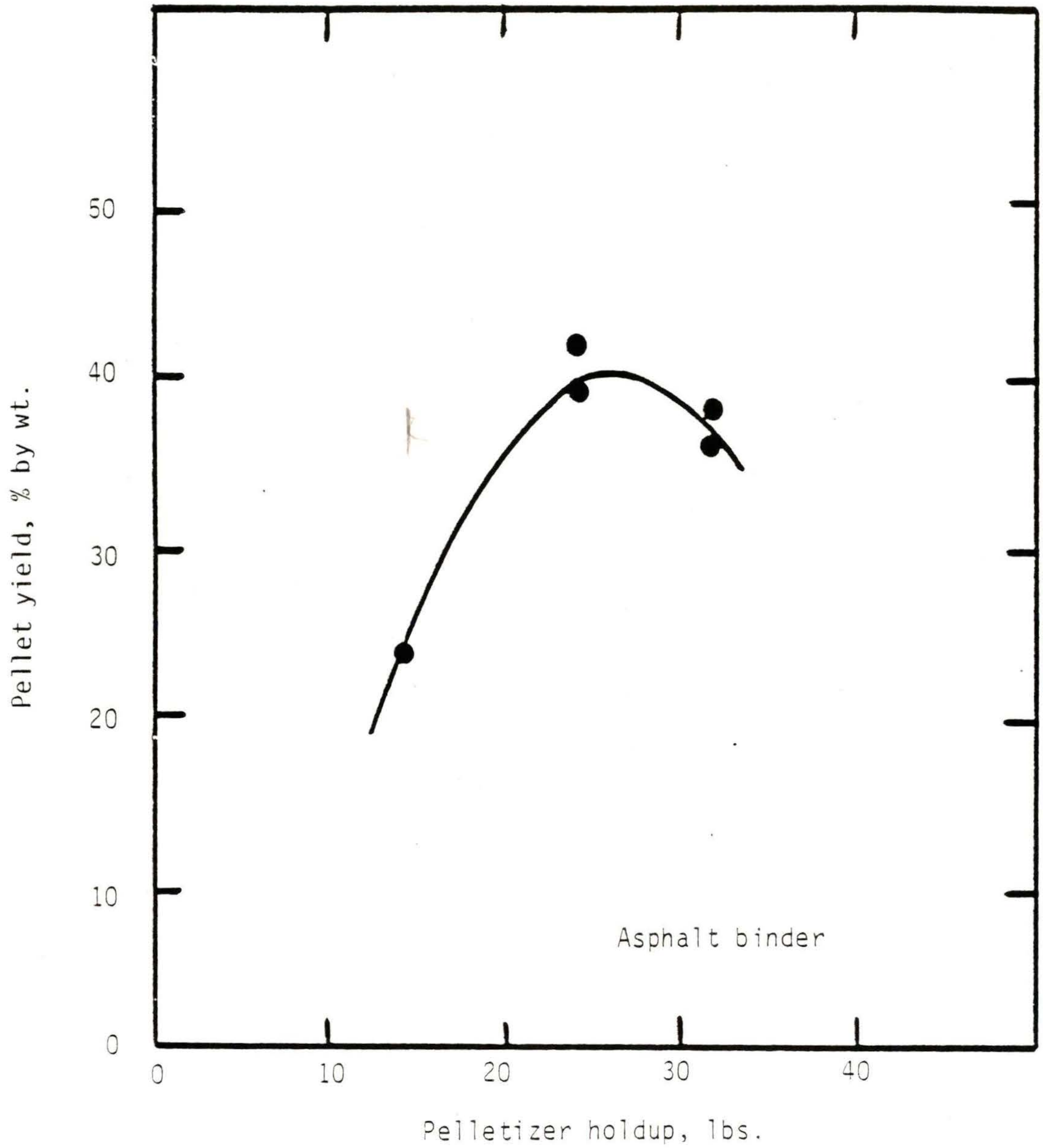


Figure 21. Effect of pelletizer holdup on yield of pellets over ½-inch diameter.

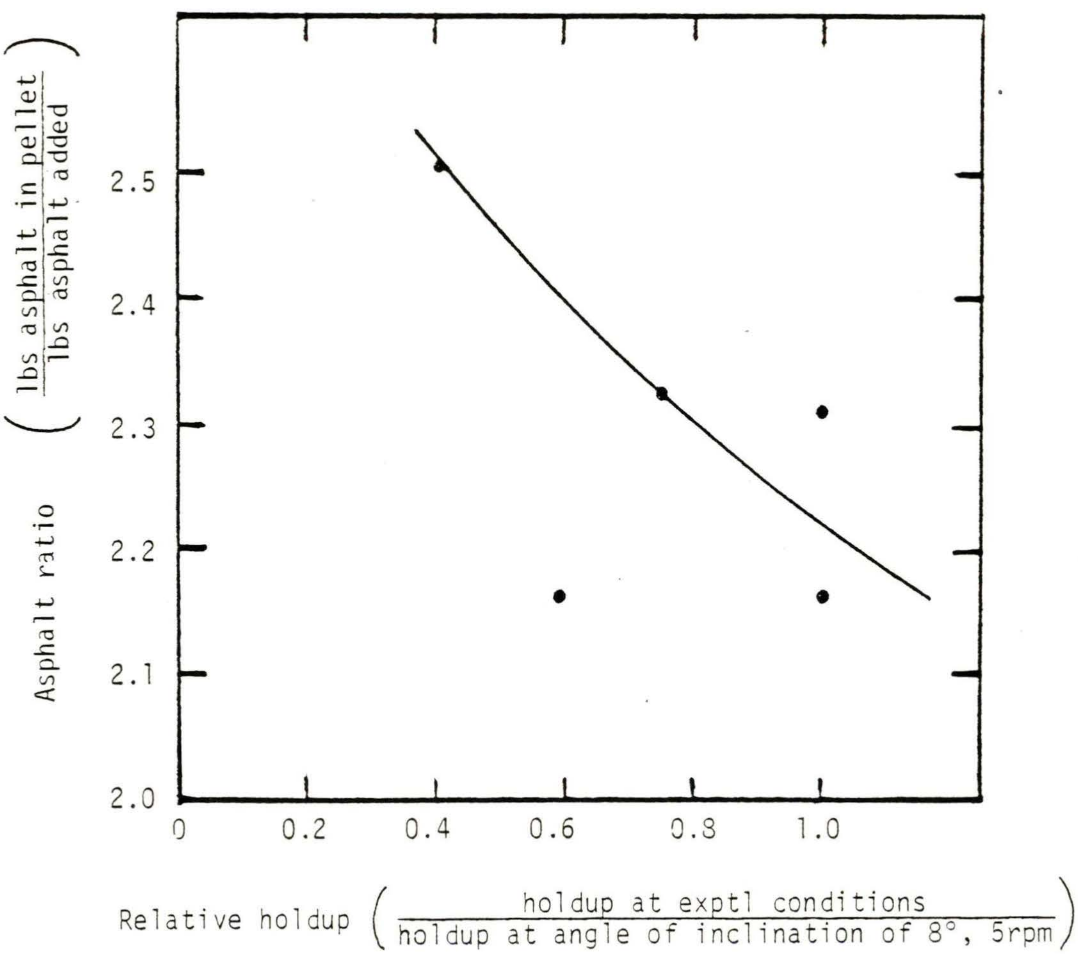


Figure 22. Effect of pelletizer holdup on asphalt ratio in pellets.

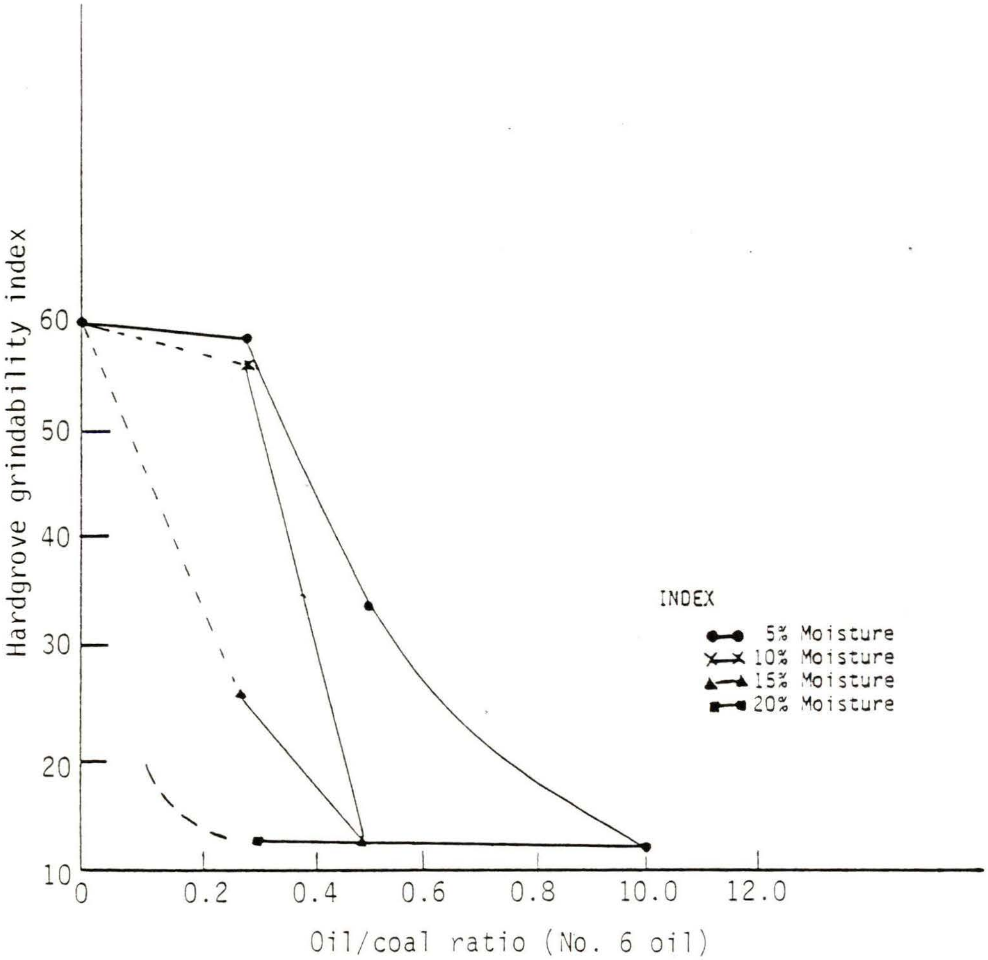


Figure 23. Effect of agglomerate moisture and oil content on grindability.

Results typical of continuous operation of the entire process are shown in Figures 24 through 28. Power measurements were also made during operation of the pilot plant. Typical measurements are shown in Table 8.

Table 8
Typical Power Requirements

Washing Step		Agglomeration Process	
Equipment	Power, watts	Equipment	Power, watts
Fresh water pump	356	Waste water pump	356
First screen	378	High speed mixer	2040
High speed mixer	2900	Growth tank mixer	580
Transfer pump	365	Star valve	388
Second screen	420	Recycle pump	186
		Oil transfer pump	373
		Dewatering screen	662

Modeling and Computer Simulation

Process Simulation and Economic Programs

The data obtained from the pilot plant operation was used to develop predictive equations for product yield and quality, based on the quality of the feed coal slurry and values of certain operating variables. The data presented in Figure 11 provided the basis for the following equations for prediction of wash yield.

Yield equations:

Most probable case:

$$\text{Product yield} = 0.535 \times (\text{Dry Screen Analysis Yield}) + 6.58 \quad (1)$$

Minimum case:

$$\text{Product yield} = 0.0165 \times (\text{Dry Screen Analysis Yield})^2 - 1.14 \times (\text{Dry Screen Analysis Yield}) + 24.5 \quad (2)$$

Maximum case:

$$\text{Product yield} = 0.0208 \times (\text{Dry Screen Analysis Yield})^2 - 1.78 \times (\text{Dry Screen Analysis Yield}) + 75.6 \quad (3)$$

In the bench scale model, agglomeration yield was found to be a function of tip speed, water/coal ratio, mixing time, and oil/coal ratio. In the pilot plant, when all data for the different coals

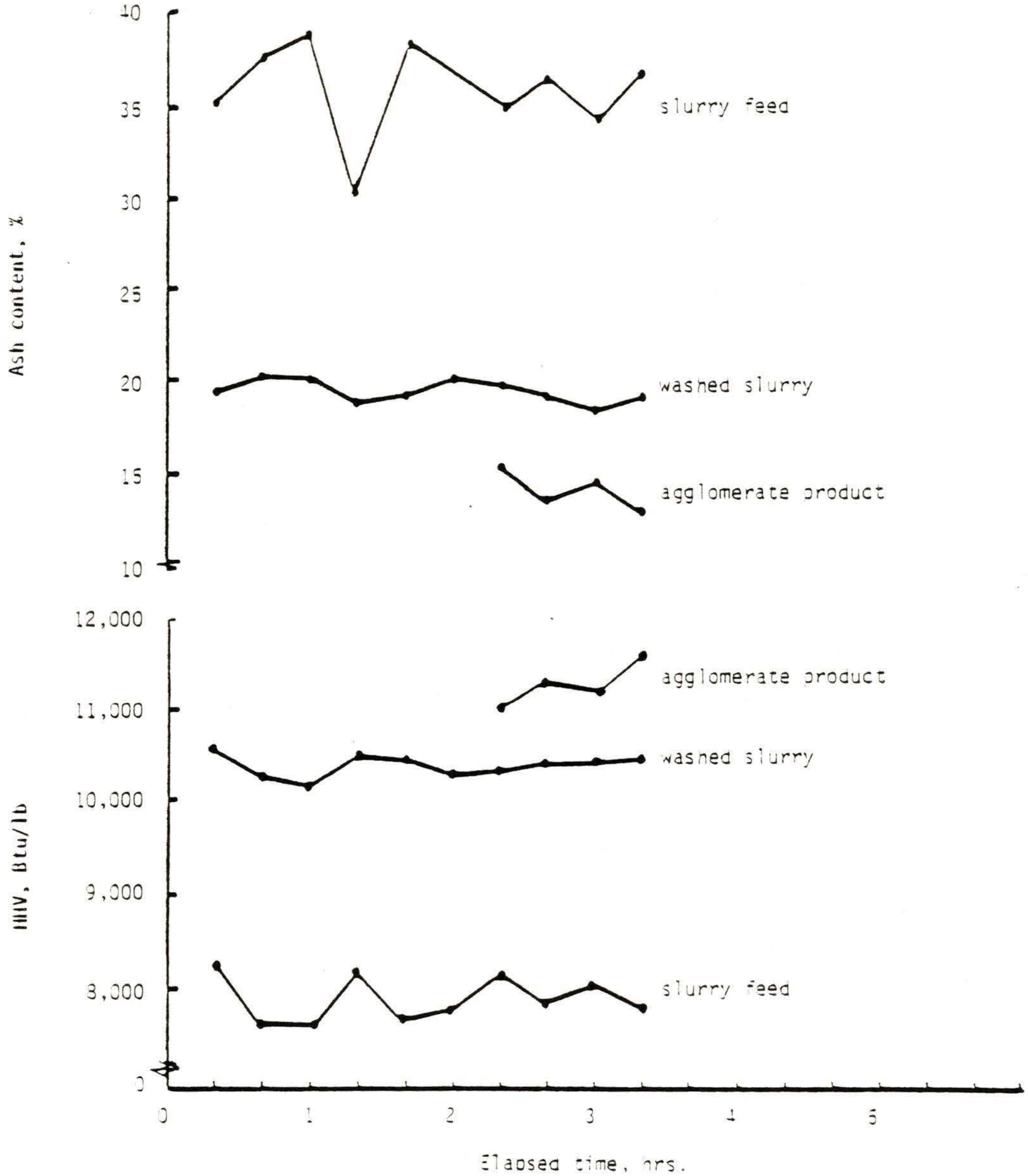
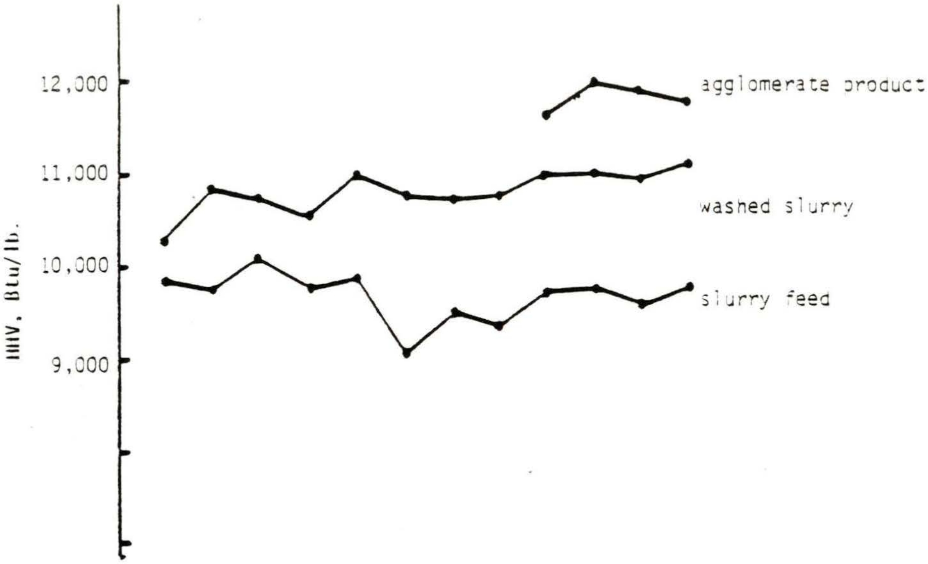


Figure 24. Improvement of ash and HHV values during continuous process operation (run 1, table E-1).

Figure 25. Improvement in sulfur content during continuous process operation (run 1, table E-1).



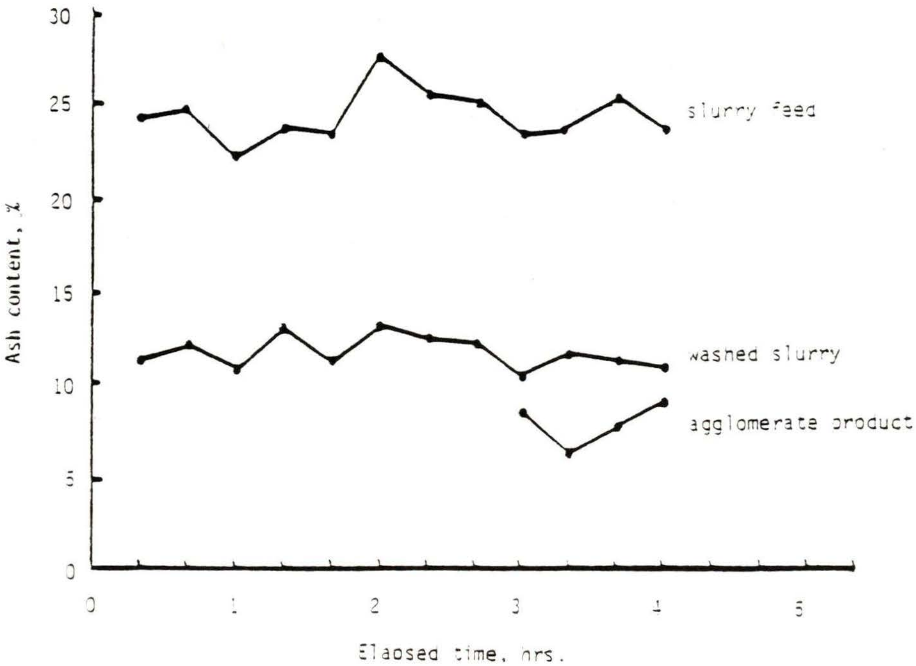


Figure 26. Improvement of ash and HHV values during continuous process operation (run 2, table E-2).

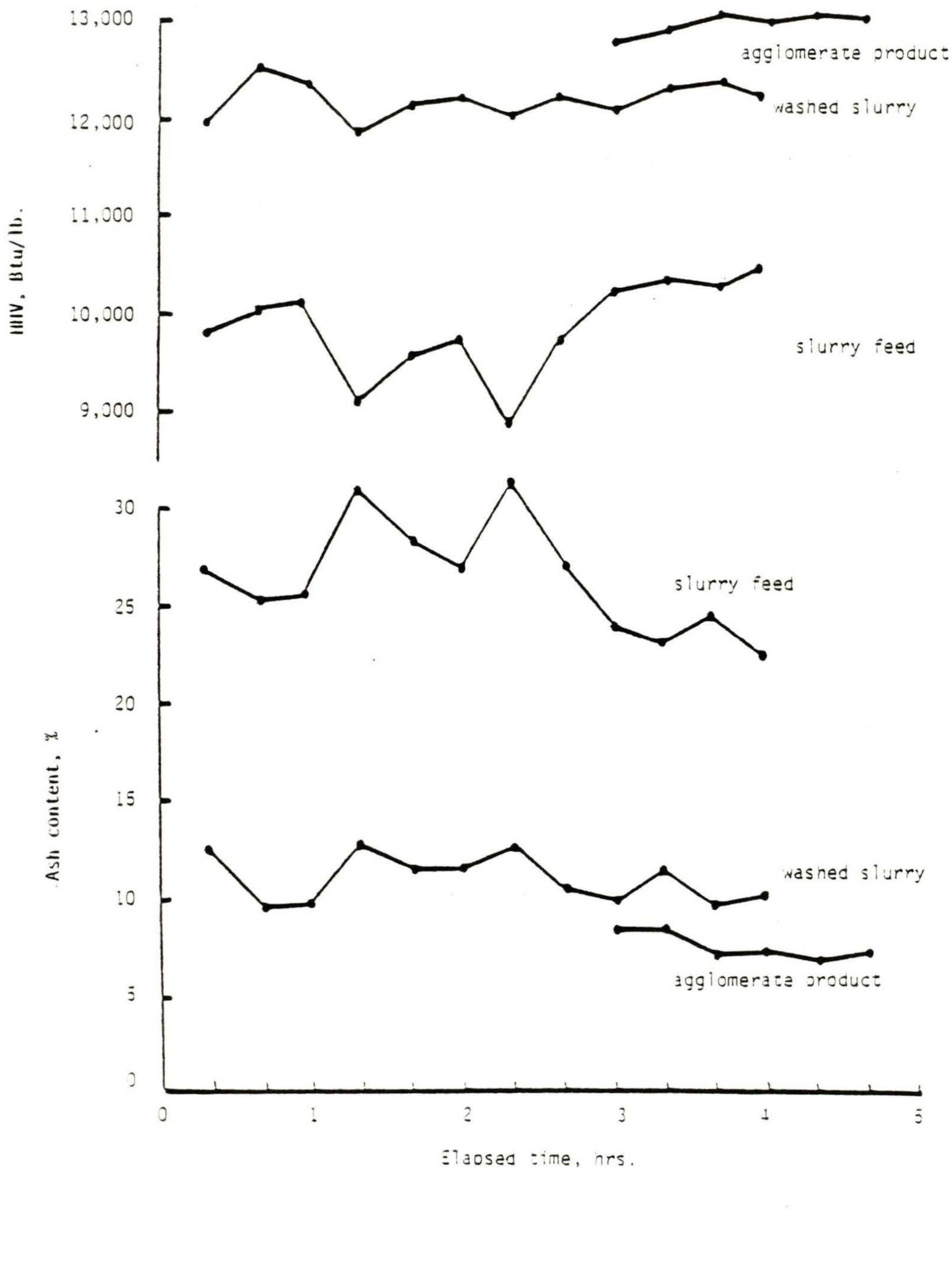


Figure 27. Improvement of ash and HHV values during continuous process operation (run 3, table E-3).

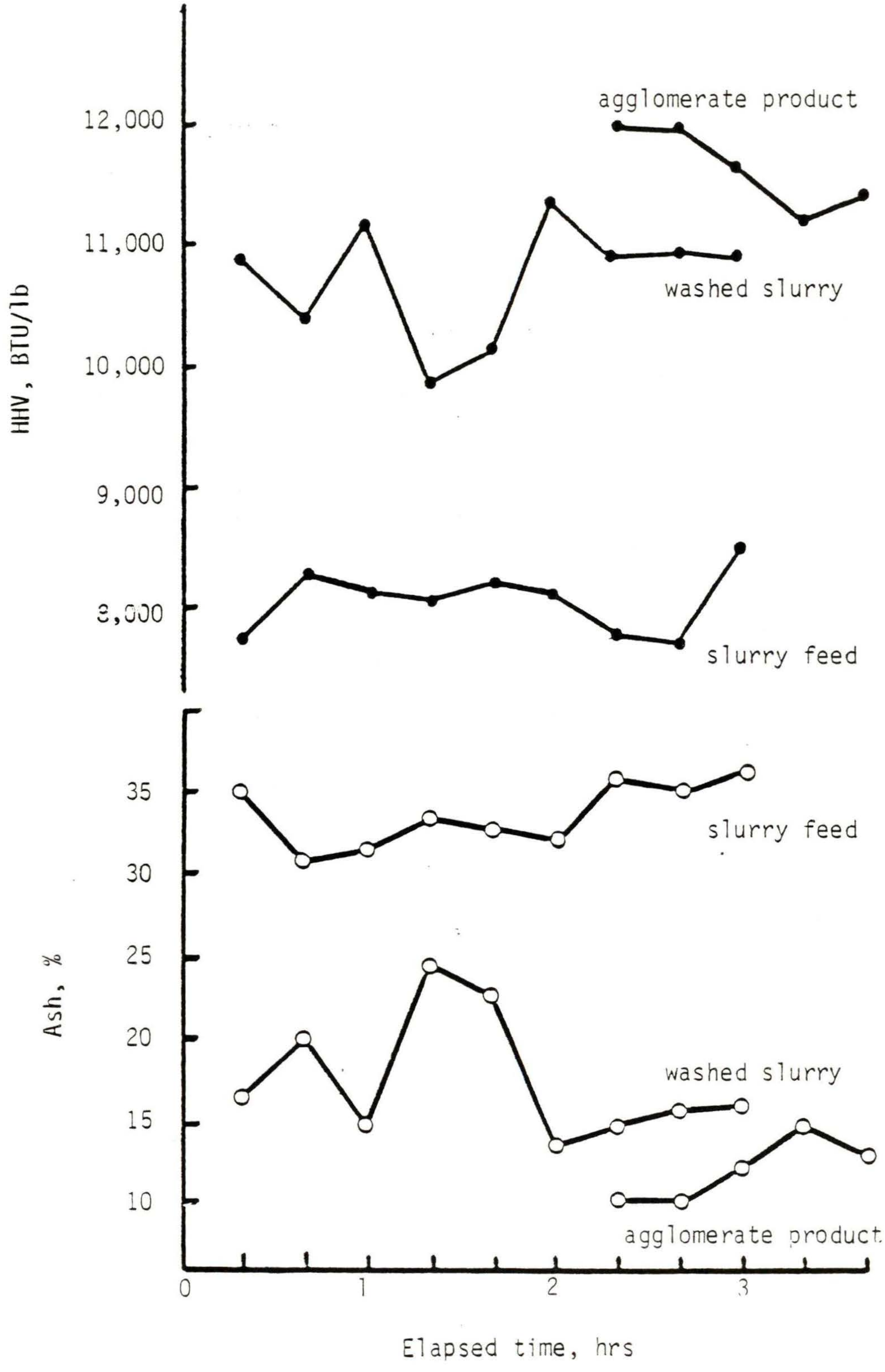


Figure 28. Improvement of ash and HHV values during continuous process operation (run 4, table E-4).

processed were analyzed together, no statistical significance was found for correlations between yield and the above given variables, with the exception of mixing time. That equation is used in the process simulation program:

$$\text{Yield} = 0.8615 - 0.00791 \times (\text{mix time}) \qquad (4)$$

Product quality equations: the pilot plant data presented in Figures 12 and 13 provided the basis for the following equations for prediction of washed coal ash and HHV, respectively.

HHV increase equations: these equations apply only over the range of 4,000 - 11,500 Btu/lb slurry quality.

(a) Most probable case:

$$\text{Btu/lb (washed slurry)} = 0.743 \times (\text{Btu/lb (input)}) + 4090 \qquad (5)$$

(b) Minimum case:

$$\text{Btu/lb (washed slurry)} = -1.38 \times 10^{-4} (\text{Btu/lb (input)})^2 + 3.28 \times (\text{Btu/lb (input)}) - 7940 \qquad (6)$$

(c) Maximum case:

$$\text{Btu/lb (washed slurry)} = 4.646 \times 10^{-5} (\text{Btu/lb (input)})^2 - 0.302 (\text{Btu/lb (input)}) + 10825 \qquad (7)$$

Ash reduction equations: these equations apply only over the range of 12 - 57% ash in the slurry material.

(a) Most probable case:

$$\text{Ash \% (washed slurry)} = 0.818 \times (\text{Ash \% (input)}) - 6.05 \qquad (8)$$

(b) Minimum case:

$$\text{Ash \% (washed slurry)} = 0.0135 (\text{Ash \% (input)})^2 + 0.278 (\text{Ash \% (input)}) + 1.93 \qquad (9)$$

(c) Maximum case:

$$\text{Ash \% (washed slurry)} = 0.0135\,(\text{Ash \% (input)})^2 + 1.42\,(\text{Ash \% (input)}) + 13.8 \qquad (10)$$

Agglomerate quality prediction: the process parameters varied in the pilot plant were oil/coal ratio, mix time, agglomeration temperature, and water to coal ratio. Other parameters, such as tip-speed, which were varied in lab-scale studies could not be investigated here due to physical and mechanical limitations of the pilot plant equipment.

The quality enhancement dependence on the parameters investigated varied depending on the coals used. The statistical significance between many factors such as the effect of oil/coal ratio on ash reduction and HHV increase, that were found in the bench scale studies, were not observed in the pilot plant studies when the total performance data observed for all coals processed was analyzed. However, performance data for individual coals did provide some significant relations. Since process responses varied with quality of the input coal, the predicted HHV increase, ash reduction and sulfur reduction are based on quality enhancement factors which depend on the quality of coal processed. These are listed in Table 9.

Table 9

Quality Enhancement Factors for Agglomeration Process.

Btu/lb of washed coal	Factor used for HHV increase	Factor used for ash reduction	Factor used for sulfur reduction
≤ 8500	1.33	0.60	0.90
≤ 10500	1.20	0.75	0.90
> 10500	1.05	0.93	0.90

Pelletization: the pelletization improves transportability of the product, but does not play a major role in quality enhancement with respect to the three factors: HHV increase, ash reduction and sulfur reduction. The equations reflect only the binder quality and binder/coal ratio:

$$ASHP = (ASHB \times BCR/2000 + ASHA)/(BCR/2000 + 1)$$

$$SULP = (SULB \times BCR/2000 + SULA)/(BCR/2000 + 1)$$

$$BTUP = (BTUB \times BCR/2000 + BTUA)/(BCR/2000 + 1)$$

ASHP, SULP, BTUP → Quality of pelletization product

ASHA, SULA, BTUA → Quality of agglomeration product

ASHB, SULB, BTUB → Quality of binder

BCR → Binder to coal ratio

Process energy requirements: Two classifications of energy are recognized in the process simulation model; the sensible heat required to attain optimum agglomeration temperature, and the electrical energy demands of the various processing units. Of the power measurements performed during the pilot plant operation (Table 8), the major power consuming units were the high-shear wash mix tank and the high-shear agglomeration mix tank. The scale-up parameter, N, was determined from the bench and pilot plant scale data according to the procedure of Rushton (46). For the agglomeration high-shear mix tank a value of N = 3.04 was determined; very close to the value of 3.00 that suggests power/unit volume as an appropriate scale-up factor. An unrealistically large value of N was obtained for the high-shear washing mix tank; a measurement error on the bench scale unit is suspected. A value of 3.00 is also used in the model for the washing step. Equations used to predict mixing costs for the washing and agglomeration high-shear mixers are:

$$\text{Wash mix tank energy cost (\$/ton)} = 1.119\ (SWM \times \frac{1000}{30})\ N/3\ (\frac{WTS}{30})^3)(\frac{0.04}{OWS})$$

0.04 → electricity cost, ¢/KWH

1.119 → power required in bench scale model

SWM → wash mix tank size in thousands of gallons

OWS → output of wet screen T/hr.

WTS → wash mix tank tip speed, ft/sec.

Agglomeration mix tank energy cost (\$/ton) =

$$4.97\ (\frac{ATS}{57.36})^3\ (SAM \times \frac{1000}{634})^{N/3} \times \frac{0.04}{OW2}$$

4.97 → power required in the bench scale model

ATS → agglomeration mix tank tip speed, ft/sec

SAM → size of mix tank in thousands of gallons

N → scale-up factor, found to be three in pilot plant

OW2 → output from wash, tons

0.04 → electricity cost, ¢/KWH

A typical output of the process simulation and economic program is given in Table 10. The process response to chosen values of the input variables is calculated, and the effects on product yield, product quality, and various cost components are given as the program output. The values of the input variables used for the output in Table 10 are given in Appendix A.

The process response to any selected change in the input variables is readily obtained. To illustrate the effect of key input variables, the results of several computer runs are plotted in Figures 29-33, where processing cost, in dollars per million Btu, is chosen as the dependent variable. Product quality predictions are given in Table 11. Table 12 summarizes the input variables changed to generate the output values; all other input variables were assigned values as given in Appendix A.

Reclamation Analysis Program

A typical output from the modified CLAIM© program is given in Table 13 for the cropland land use option. Portions of an input/output of a typical run for the modified CLAIM© interactive program are given in Appendix B. Table 14 presents a summary of major cost components for various land use options.

Decision Making Program

The output from the process simulation program and the modified CLAIM© program provide input to the decision-making program. Table 15 presents a cost summary for three coals of varying quality; the quality factors used were the same as given in Table 12. Most probable values are presented. A typical input/output run for the decision-making program is given in Appendix C.

Table 10

Typical Output of Process Simulation Program

COAL FINES RECOVERY ANALYSIS
****

INPUT
*****

TYPE OF COAL	SEAM 6
FINES INPUT RATE	100.0TONS/HR
WASH ****	
RATIO OF LIME TO COAL	19.9LB/TON
RATIO OF FLOCCULENT TO COAL	10.0LB/TON
AGGLOMERATION *************	
RATIO OF OIL TO COAL	7.5GAL/TON
RATIO OF WATER TO COAL	10.0TON/TON
TEMPERATURE	148.0DEG. F
TIP VELOCITY	25.0FT/SEC
MIX TIME	10.0MIN.
MIXING EXPONENT	3.0
PELLITIZE *********	
TYPE OF BINDER	ASPHALT
RATIO OF BINDER TO COAL	80.00LB/TON

ANNUALIZED COST (DOLLARS)
****

PROCEDURES

	DRY SCREEN	WET SCREEN	WASH	AGGLO-MERATION	PELLETIZE	TOTAL
CAPITAL	5,875	86,975	15,620	20,368	26,331	155,170
MATERIAL	480,000		63,359	245,442	409,725	1,198,527
ENERGY	4,479	4,435	10,101	125,618	51	144,686
LABOR & OVERHEAD	28,799	28,799	28,799	28,799	28,799	143,999
TOTAL	519,155	120,210	117,882	420,229	464,907	1,642,383

SUMMARY
****

$/TON PRODUCTION	4.11	.95	.93	3.33	3.68	13.02
YIELD(FRACT)	0.990	0.540	0.765	0.782	1.040	0.788

PRICE OF FINAL PRODUCT , CENTS/MILLION BTU = 53.8
PRODUCT OUTPUT , TONS/HOUR= 79
PRODUCT BTU=12083
PRODUCT ASH= 7.6
PRODUCT SULFUR=1.14

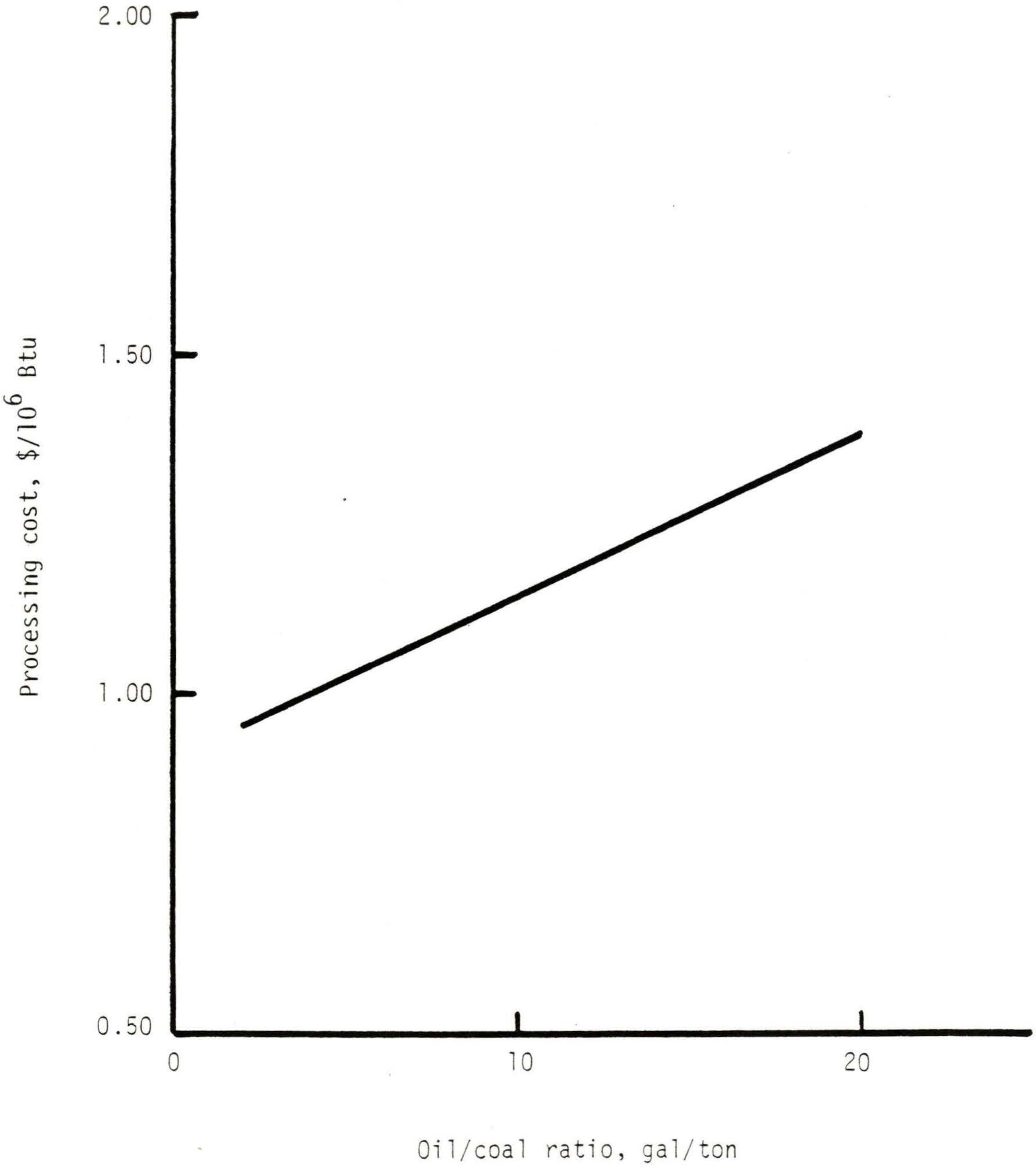


Figure 29. Effect of oil/coal ratio on processing cost.

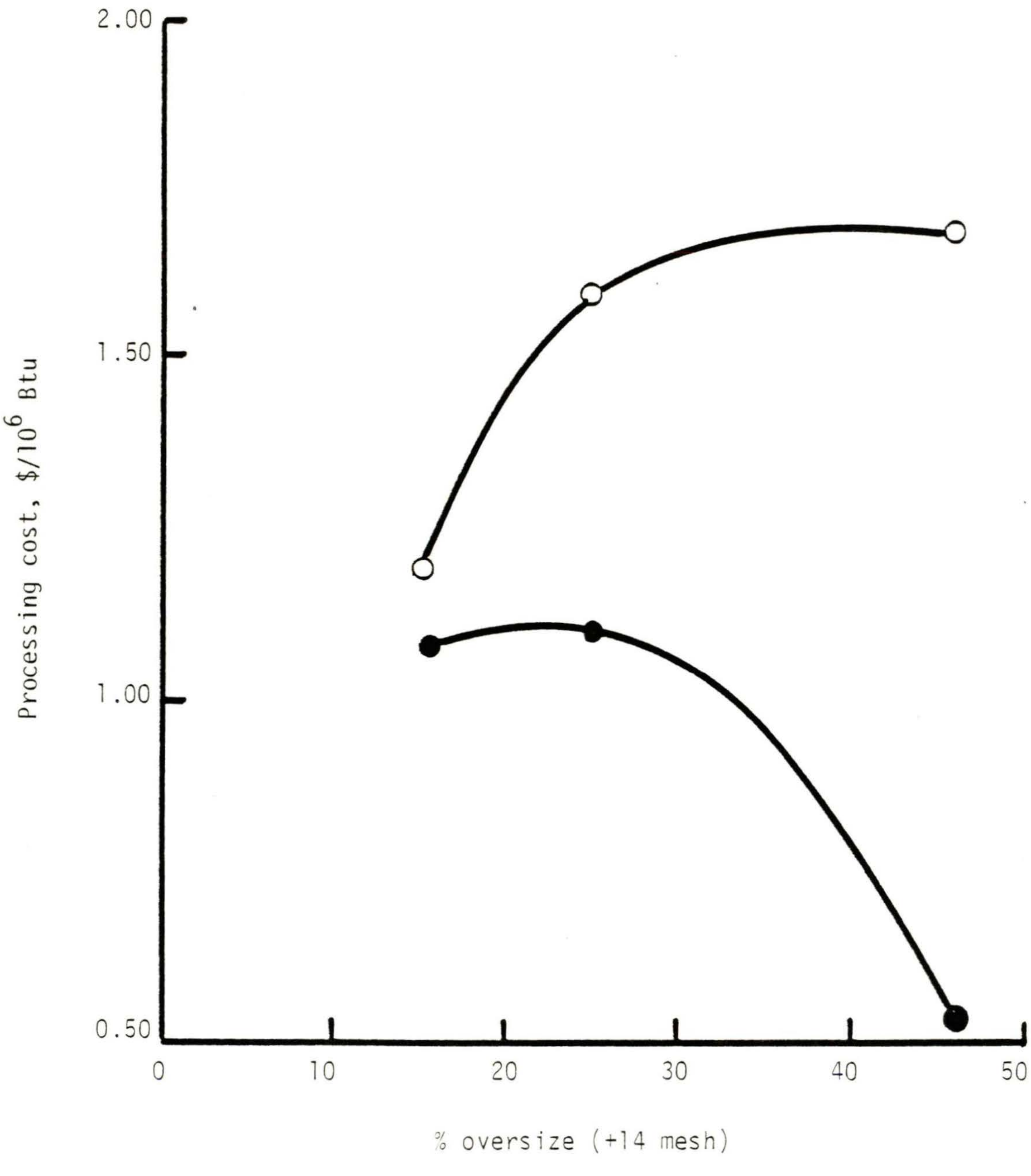


Figure 30. Effect of inclusion (•) or exclusion (o) of oversize product on processing cost, at constant value of raw material slurry.

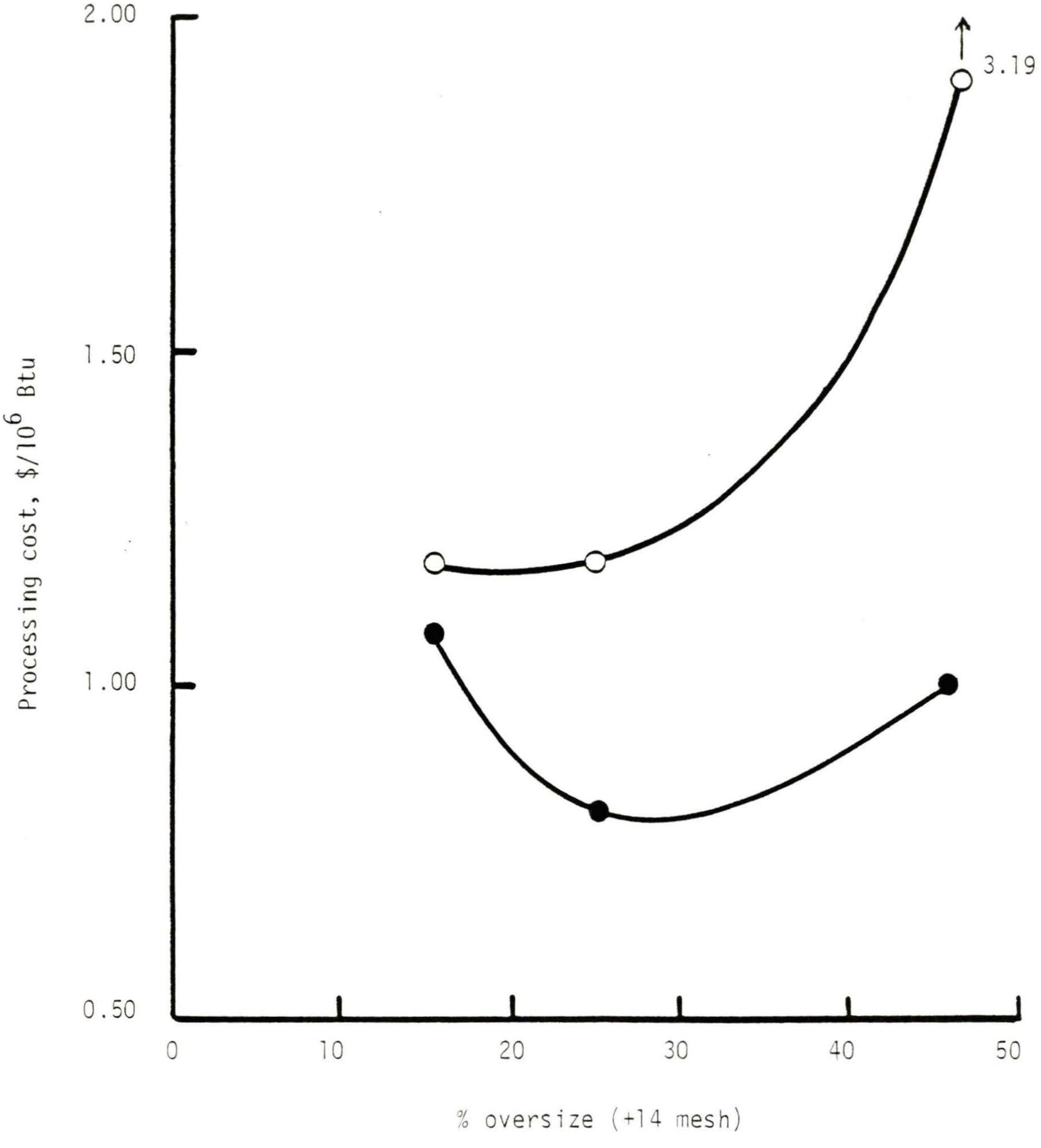


Figure 31. Effect of inclusion (•) or exclusion (o) of oversize product on processing, at actual values of raw material slurry.

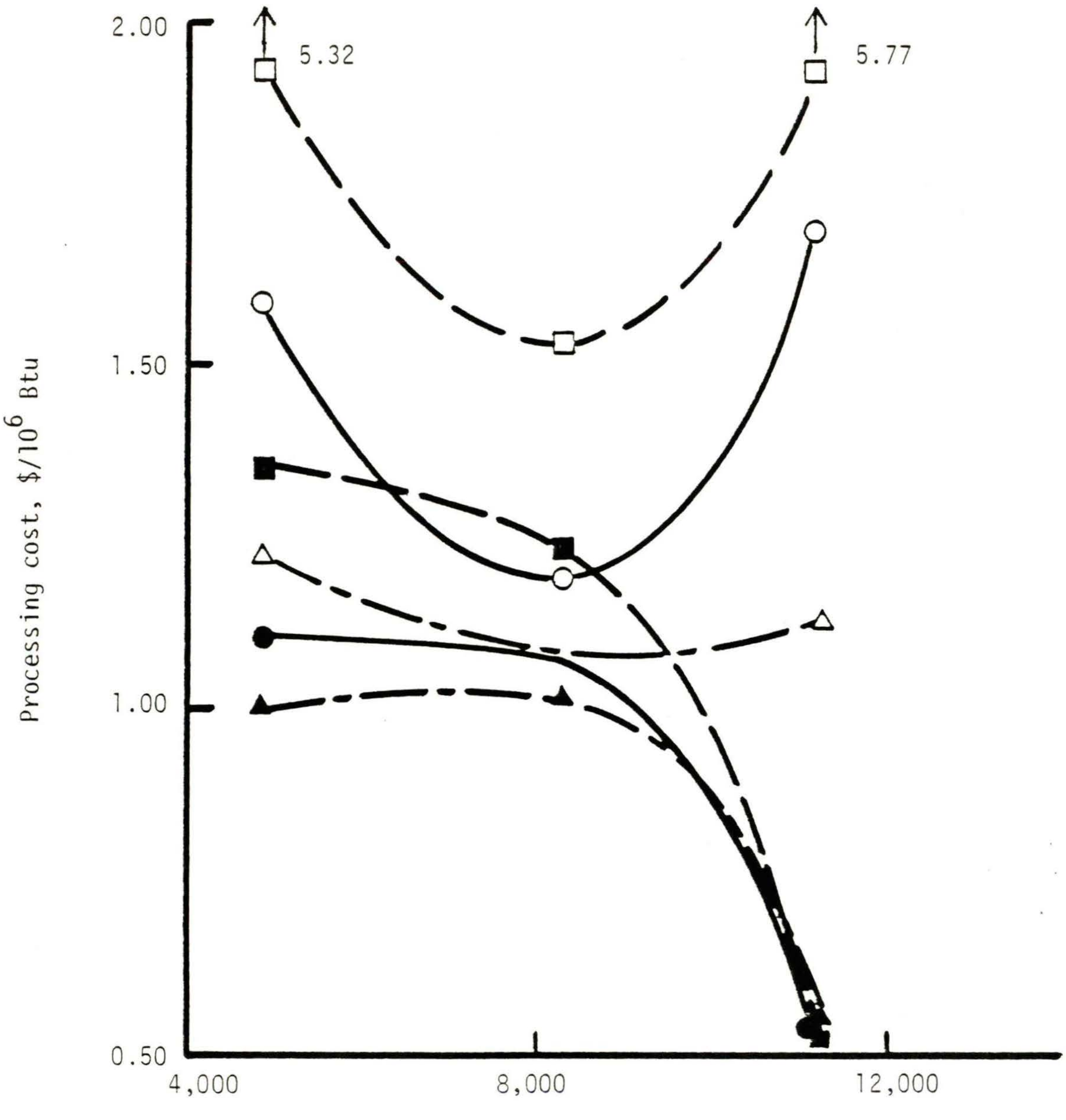


Figure 32. Effect of higher heating value of the raw material slurry on processing cost, for most probable (---●---, ---o---), worst case (---■---, ---□---), and best case (-.-▲-.-, -.-Δ-.-) predictions; oversize product included and excluded, respectively. Constant cost of raw material slurry.

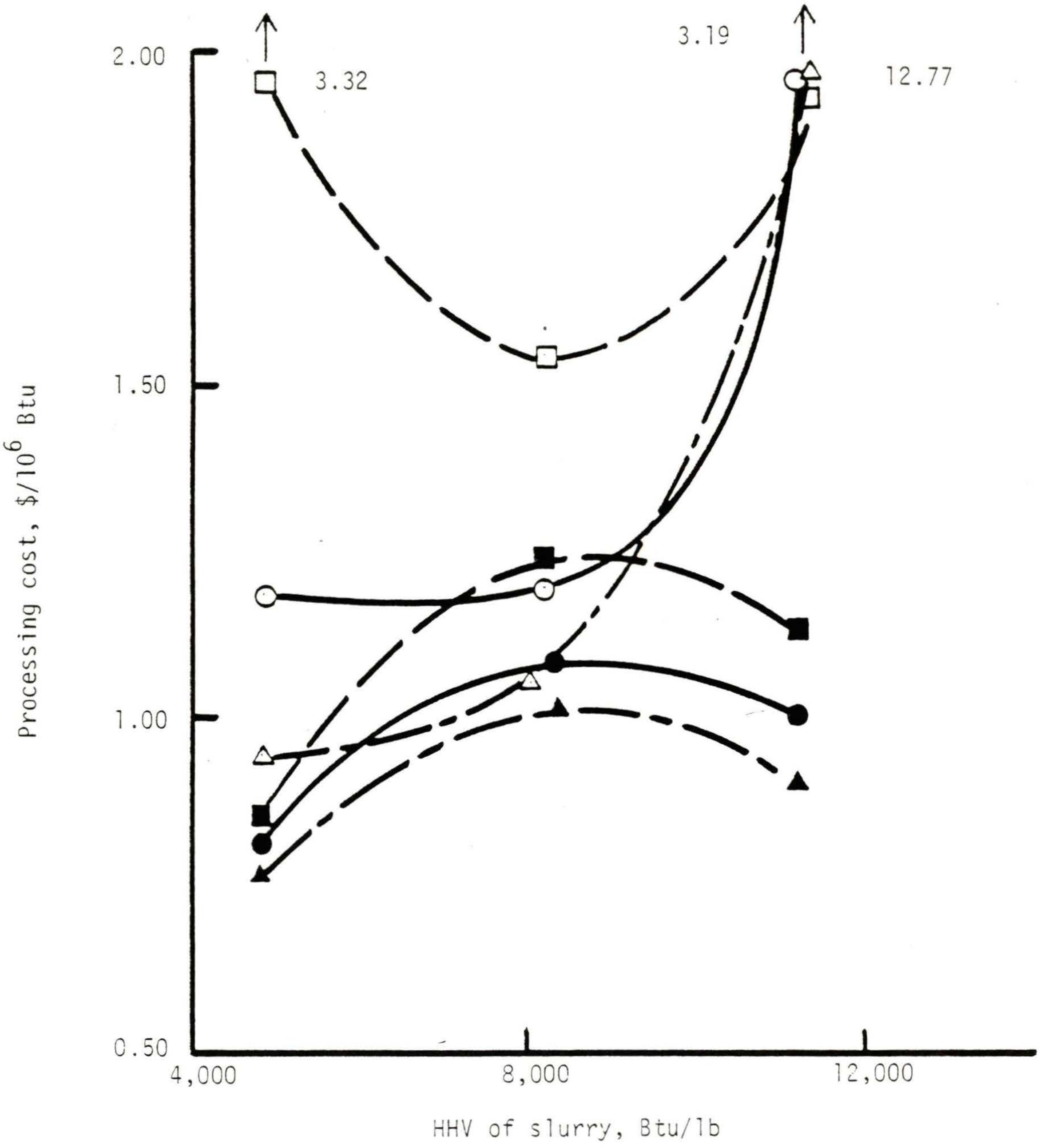


Figure 33. Effect of higher heating value of the raw material slurry on processing cost, for most probable (---●---, ---○---), worst case (---■---, ---□---), and best case (-.-▲-.-, -.-△-.-) predictions; oversize product included and excluded, respectively. Actual values of raw material slurry.

Table 11
Product Quality Predictions for Different Coals, With and Without Blending of Oversize

Coal Source	HHV Btu/lb	Ash Content %	Sulfur Content %
Oversize Included			
Randolph County			
most probable	9479	28.0	3.41
worst case	9028	30.3	3.43
best case	9627	27.0	3.40
Jackson County, low quality			
most probable	8099	36.5	1.67
worst case	7135	41.0	1.79
best case	8853	33.2	1.66
Jackson County, high quality			
most probable	11656	8.9	1.19
worst case	11264	9.9	1.24
best case	12083	7.6	1.14
Oversize Excluded			
Randolph County			
most probable	12277	15.1	3.25
worst case	11695	18.7	3.25
best case	12097	15.1	3.25
Jackson County, low quality			
most probable	10379	22.9	1.18
worst case	6622	34.5	1.18
best case	12576	13.9	1.18
Jackson County, high quality			
most probable	13021	5.6	0.95
worst case	12097	8.2	0.95
best case	13500	3.8b	0.95

Table 12

Input Variables Changed to Predict
Effects on Processing Costs and Product Yields and Quality

	Randolph County Coal	Jackson County High Quality Coal	Jackson County Low Quality Coal
Slurry Fines Quality (a) % ash	33.0	15.1	57.1
HHV, Btu/lb	8219	11171	4603
%S	4.17	1.22	1.98
% oversize (+14 mesh)	16.0	45	25.2
(-14 +70) fraction	74.0	29.2	55.4
Oversize (+14 mesh) (b) Quality			
% ash	33.8	12.7	41.8
HHV, Btu/lb	8217	11900	7201
%S	3.49	1.27	1.87
Process Condition			
Oil/coal ratio gal/ton and (mass ratio)	7.4 (0.04)	7.5 (0.04)	7.5 (0.04)

(a) most probable, worst, and best, predicted yields, % ash, HHV

(b) include or exclude oversize

Table 13

Typical Output of Modified CLAIM© Reclamation Program -- Crop Land Option

```
==========================================================================

               *****************************
               *                           *
               *          CLAIM            *
               *                           *
               *  COMPUTERIZED RECLAMATION *
               *     PLANNING SYSTEM       *
               *                           *
               *****************************
---------------
 DATA ANALYSIS
---------------

0 -> EXIT FROM DATA ANALYSIS OPTION

1 -> ENVIRONMENTAL FEASIBILITY RANKINGS

2 -> TECHNIQUES AND ECONOMICS ANALYSIS

3 -> OPTIMUM USE FACTORS

ENTER YOUR SELECTION -> -
? 00505
.?
          *** CROPLAND ALTERNATIVE ***

               TECHNIQUE                        COST/ACRE
               ---------                        ---------
 1)REHANDLE 2 FT. OF SEEDBED SUITABLE SPOIL $   274.27
 2)GRADE SPOIL                              $  2988.90
 3)CHISEL PLOW                              $     1.00
 4)DISC AND HARROW                          $     0.0
 5)BUY SEED                                 $    91.65
 6)DRILL SEED                               $     3.75
 7)BUY FERTILIZER : NITROGEN                $     1.00
 8)BUY FERTILIZER : PHOSPHATE               $     0.75
 9)DRILL FERTILIZER                         $     3.75
10)BUY HAY MULCH                            $     4.00
11)BUY,APPLY HERBICIDE                      $     2.75
12)STABILIZE TOPSOIL STORAGE PILE           $    11.26
13)ADMIN. OF OPERATIONS AND NECESSARY TESTS $   507.46

                                                =========
                                     TOTAL  $  3890.54

GRAND TOTAL COST FOR    23.3 ACRES IS        0.09 MILLION DOLLARS
```

Table 14

Output Summary of Major Cost Components for Various Land Uses, ($/acre)

Land Use	Strip 2 ft.; respread or rehandle	Grade Spoil	Total Cost
Cropland (6% slope)	2420	3524	7111
Native Vegetation or Wildlife (19% slope)	2097	2513	6238
Water Recreation	2097	0	3351

Table 15

Cost Summary for a 23.3 Acre Slurry Pond of 100 ft. Depth for Three Coals of Varying Quality (million dollars)

Quality of Coal Slurry	Total Revenue	Processing Cost	Reclamation Cost	Total Cost	Product Sale Price $/T	Profit (Loss)
Medium, oversize[a] excluded	31.30	29.26	0.14	29.40	31.25	1.90
Low, oversize excluded	17.03	26.26	0.14	26.40	21.54	(9.34)
High, oversize excluded	15.53	21.00	0.14	21.14	32.74	(5.61)
High, oversize included in product	50.63	21.00	0.14	21.14	30.01	29.51

[a]oversize = +14 mesh

DISCUSSION

Process Performance

Scale-up of the Washing Process

The quality improvement and combustible recovery by high shear washing followed by gravity separation in a settling tank, as given in Figures 9 and 10 for the laboratory and bench scale experiments, were sufficient to justify inclusion of these operations in the pilot plant design. Although comparable values of underflow recovery factors were obtained in the pilot plant by gravity separation of the washed coal (Table 2), mechanical problems associated with removal of solids from the tank bottom at a constant rate led to abandonment of gravity separation with replacement by a second screen, 50 or 70 mesh.

As presented in Table 3, the 50 mesh screen resulted in a more consistent quality product, generally lower in ash and with a greater HHV, than that of the gravity separation process; yields were comparable. The 70 mesh screen resulted in greater recovery, but a slightly lower quality product for comparable coals, as indicated by a comparison of the data in Tables 3 and 4. When the high-shear mixing tank was by-passed, sending the undersized material from the 14 mesh screen directly to the 70 mesh screen, comparable recoveries were observed with a slight, but not statistically significant, decrease in quality. The comparison of sulfate concentrations in the wash water for runs with and without high shear washing indicates a slightly higher sulfate concentration where the high shear washing was employed (Table 6), suggesting slightly better sulfur removal.

The relationship between dry screen size distribution and yield of the washed coal observed in the pilot plant has been utilized in the process simulation model to permit prediction of process yields based on analyses of samples from a potential recovery site. The lower yields observed in the pilot plant compared to the percent of the original coal represented in the -14 to +70 dry screen fraction, as indicated in Figure 11, results from the break-up of coal and impurities that occurs during the washing process. The enhanced quality of the washed product compared to that of the -14 to +70 mesh fraction of the sample dry screen analyses is evident in Figures 12 and 13. The lesser predictability of ash and HHV for lower quality slurry material is evident in these figures.

Oil Agglomeration

Since the cost of the oil used for agglomeration is a major component of the total processing cost, the experimental plan included determination of the minimum oil requirement. The data presented in Figures 14-16 indicate an optimum oil/coal ratio in the 0.03-0.04 range, considerably lower than values commonly reported by other investigators using -200 mesh coal. The data presented in Figure 17 indicate that in the oil/coal ratio range of 0.03-0.06 less that half the oil is retained in the agglomerate, suggesting that recycle of the unused oil could substantially reduce the material cost.

Pelletization

An asphalt binder at 5% concentration in the feed was found to produce pellets of reasonable integrity, especially after a weathering period, as shown in Figures 18-22.

Agglomerate Evaluation

The physical characteristics of the agglomerate would permit transport of the material without the dusting problem inherent with the parent coal fines. In addition, evaluation of the Hardgrove grindability index suggests the product would be suitable for fueling a pulverized coal fired boiler.

Continuous Process Runs

The results of the continuous process tests, given in Figures 24-28 and Appendix E, produced results very close to those expected from tests in the separate washing and agglomerate runs. Although the feed coal varied considerably in quality during a test, the product was of a more consistent quality. Coal of 8000 Btu/lb, 35% ash, 4.6% sulfur was enhanced to 11,500 Btu, 14% ash, 3.5% sulfur. A high quality feed of about 10,000 Btu, 25% ash was beneficiated to 12,700 Btu, 8% ash. Other runs gave similar results. These runs establish the merits of the process.

Modeling and Computer Simulation

The equations describing the response of product yield and quality to changes in coal slurry quality and other operating variables, combined with economic factors, constitute the model of the coal fines recovery process. The model output, a sample of which is given in Table 10, summarizes the values of the major input operating variables used for that run, along with calculated values of product yield and quality. For the example given, values are calculated for a plant size of 100 T/hr of coal fines input. Annualized costs are presented by cost category and for each processing step.

Components of Processing Cost

Inspection of Table 10 provides some insight into potential areas for cost reduction in further development of the process.

Operations prior to agglomeration: The major cost factor in the initial, dry screen operation is the material cost, which represents the purchase price of the raw material slurry. For the wet screening operation the capital investment is the major cost factor. Areas of potential cost reduction for the washing step include reduced chemical usage (lime and flocculant), which could be realized if low acidity coal slurry were being processed, and reduced capital and energy costs if the slurry characteristics would permit elimination of the high shear wash tank.

Agglomeration: The major cost component in the agglomeration process is the oil, in spite of the low oil/coal ratios used in the process (Figure 29). Recycle of unused oil in the agglomeraiton step offers potential savings, as would use of used motor oil, especially if the recovery site were near a recycling center. The cost of energy for this processing step includes, in addition to the power requirements of the high shear mixer and growth tank, the sensible heat requirement for the high temperature agglomeration. Recovery and combustion of the low quality waste stream from the agglomeration step could supply this energy need, thus reducing energy costs.

Pelletization: The binder cost is the major cost component. If the agglomerate product could be utilized without pelletization, processing cost savings of about \$2/T could be realized.

Effect of Coal Slurry Characteristics on Processing Costs

Percent oversize: Figures 29 and 30 illustrate the importance of the quality of oversize (+14 mesh) product in determining unit processing cost, for the cases of uniform (\$3/T) value of the input slurry and actual values (based on the coals studied), respectively. As the percent oversize increases above 15%, the processing cost penalty for discarding this oversize material becomes severe. A process option to be considered when oversize product quality does not permit direct combination with agglomerate product would be a grinding of the oversize material and recycle to the washing step of the process.

HHV of slurry: As would be expected, a better quality input slurry material, in terms of greater HHV (and lower ash) significantly reduces processing costs. Figures 31 and 32 illustrate this effect for cases of including or excluding oversize material in the product and for constant (\$3/T) and actual costs of the input slurry. The most probable, worst case and best case predictions presented in these figures suggest the degree of risk associated with projecting costs based only on dry screen analyses of the input slurry; pilot plant evaluation of slurry from a potential recovery site is essential for accurate cost predictions.

Table 11 projects the quality of product that would be obtained at three slurry sites of varying quality. The effect of including or excluding the oversize material, as well as the range of quality parameters that might result due to process variations, is evident from examination of the table. Input variables changed to predict effects on processing costs, product yields and quality are given in Table 12.

Reclamation Costs and Overall Cost Summary

The output summary of the major cost components of grading and rehandling of the surface material for various land use options is given in Table 14. The decision-making program was applied using coal quality characteristics of the three coals studied (Table 15). A hypothetical 23.3-acre slurry pont of 100 ft. depth was assumed for all cases; most probable values were used in the cost projections. Oversize (+14 mesh) material was included in the product only for the high quality coal slurry. The overall economic analysis indicated a range from about a 9 million dollars loss to a profit of nearly 30 million dollars. Clearly, the quality characteristics of the input slurry impact significantly on the overall recovery operation economics.

A significant consideration when weighing the cost of reclamation at a potential slurry recovery site, together with processing costs and projected revenues from product sales, is the fact that reclamation costs impact very slightly on the overall recovery economics. This results from the fact that the energy per acre in a typical slurry pond site, where coal depths may exceed 100 ft., is many times that of a typical strip mine where the coal seam may be only a few feet in depth.

CONCLUSIONS

1. From laboratory and pilot plant experimental data, the process is capable of producing a quality product from coal fine waste with some reduction of sulfur, in an environmentally acceptable manner. Depending on the usage, the final product can be either oil agglomerates or coal pellets.
2. By knowing the coal fines quality characteristics of size fraction, HHV, ash, and sulfur, the process performance in terms of product yield, product quality and processing costs may be predicted by the process simulation program.
3. The overall economics of a proposed recovery site, including reclamation costs, is highly dependent on site specific factors, inlcuding quality of the coal fines material. If the coal fines wastes are below a HHV of 6,000 Btu/lb and/or ash content over 35%, a high quality product (over 10,000Btu/lb) is unattainable without additional process steps; a profit will not be recognized in this operation.

RECOMMENDATIONS

The experience and results gained in this study suggest the following recommendations for further development of the coal fines recovery process:

1. Incorporation of grinding the +14 material to permit its inclusion in the washing step of the process, and its effect upon the product output and quality, needs to be studied.
2. The addition of chemical treatment of washed coal fines waste should increase sulfur removal during elevated temperature oil agglomeration. A study of this effect, applied to this process, should be undertaken.
3. Further product evaluation of pellets and agglomerates should be carried out.
4. The computer model is site-specific. Pre-law coal fines waste sites in a region can be prioritized for recovery by using the decision model developed in this project. The most promising sites indicated by the model need to be fully evaluated for all options of process operation and site reclamation.

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APPENDIX A

PROCESS SIMULATION PROGRAM

```
COLFA:PROCEDURE OPTIONS(MAIN);
ON ENDFILE GO TO DEN;
ON ZERODIVIDE PUT DATA;
DEFAULT RANGE (A:X) FLOAT VALUE(DECIMAL FLOAT (6));
DCL(ZDSAC,ZCWAC,ZWSCAC,ZAAC,ZPEC,ZCC,ZDSCM,ZCWM,ZCWSM,ZAM,ZPM,
ZMC,ZDSE,ZCWE,ZCWSE,ZAEC,ZPECE,ZEC,ZDSLO,ZCWLO,ZCWSLO,ZALO
,ZPLO,ZLC,ZDSC,ZCW,ZCWS,ZCA,ZCP,ZAPC)PIC'ZZ,ZZZ,ZZZ';
DCL YCEPMBTU PIC'ZZZZV.Z';
DCL(ZINP,ZTLPTC,ZPP,ZOCR,ZWCR,ZT,ZBCR)PIC'ZZZV.Z';
DCL YOOCPO PIC'ZZZZ';
DCL (CTYPE,BTYPE) CHAR(20);
DCL(YDS$PT,YW$PT,YWS$PT,YA$PT,YP$PT,YGT$PT)PIC'ZZZV.ZZ';
BIG:GET DATA(INP,DSY,W1Y,W2Y,WSY,PY,HRD,DYR,URDS,URWM,URWS,URWC,
URWSD,WSE,DSD,WMD,WSD,WCD,WSDD,OCR,URWSC,IPD,URAS,URP,WTS,
PEEC,CRF,DSMC,DSEC,PLA,NE,POV,ATC,ARCC,AOC,ARLC,PLM,PO,PP,PB,
FNDS,FNW,FNWS,FNA,FNP,PD,WSCD,HFC,HHVO,HHVC,TLPTC,LEPTC,CPC,
CPO,DT,CPW,TDROP,BCR,CTYPE,BTYPE,WCR,AMIX,ATS,
ASHDS,BTUDS,SULDS,ASHO,BTUO,SULO,ASHB,BTUB,SULB,N,
 NE1,NPROB);
/* OUTPUTS */
AWA=WCR;
OILM=OCR*8/2000;
  AY = 0.8615 - 0.0079 * AMIX;
ODS=INP*DSY;
OWS=ODS*WSY;
ASHWS=ASHDS;
BTUWS=BTUDS;
SULWS=SULDS;
OW1=OWS*W1Y;
SULW1=SULWS*0.9;
     SELECT (NPROB);

         WHEN(1)  DO;
                       ASHW1=0.818*ASHWS-6.05;
                       BTUW1=0.743*BTUWS+4090;
                  END;
         WHEN(2)  DO;
                       ASHW1=-0.0135*ASHWS*ASHWS+2.183*ASHWS-21.8;
                       BTUW1=-0.000138*BTUWS*BTUWS+3.2799*BTUWS-
                              7943;
                  END;
         OTHERWISE  DO;
                         ASHW1=-0.01476*ASHWS*ASHWS+1.056*ASHWS+5.73;
                         BTUW1=4.636E-5*(BTUWS**2)-0.3019*BTUWS+10825;
                    END;
       END;
OW2=OW1*W2Y;
ASHW2=ASHW1;
BTUW2=BTUW1;
SULW2=SULW1;
```

```
PY=1+BCR/2000;
OA=OW2*AY;
     SELECT;

          WHEN(BTUW2<=8500) DO;
                               ASHA=ASHW2*0.60;
                               BTUA=BTUW2*1.33;
                            END;
          WHEN(BTUW2<=10500) DO;
                               ASHA=ASHW2*0.75;
                               BTUA=BTUW2*1.2;
                            END;
          OTHERWISE         DO;
                               ASHA=ASHW2*0.93;
                               BTUA=BTUW2*1.05;
                            END;
       END;
     SULA=SULW2*0.90;
OP=OA*PY;
ASHP=(ASHB*BCR/2000+ASHA)/(BCR/2000+1);
BTUP=(BTUB*BCR/2000+BTUA)/(BCR/2000+1);
SULP=(SULB*BCR/2000+SULA)/(BCR/2000+1);
  IF BTUP > 13500.
   THEN BTUP = 13500.0;
OOC=OP+(1-WSY)*ODS;
O=INP-ODS;
ASHOC=(O*ASHO+OP*ASHP)/(O+OP);
BTUOC=(O*BTUO+OP*BTUP)/(O+OP);
SULOC=(O*SULO+OP*SULP)/(O+OP);
WASY=W1Y*W2Y;
OVY=OOC/INP;
OOCPO=OOC + OW2*OCR*3.6E-3;
/* EQUIPMENT SIZE EQUATIONS */
URAM=0.2502E3/(AWA*AMIX);
SDS=INP/URDS;
SWM=OWS/URWM;
SWS=OWS/URWS;
SWC=OWS/URWC;
SWSD=OWS/URWSD;
SWETS=ODS/URWSC;
SAM=OW2/URAM;
SAS=OW2/URAS;
SP=OA/URP;
/* EQUIPMENT COST EQUATIONS */
CEDS=SDS**0.56*DSD;
CEWM=SWM*WMD;
CEWS=SWS*WSD;
CEWC=SWC**WCD;
CEWSD=(SWSD**WSDD)*3000;
CEW=CEWM+CEWS+CEWC+CEWSD;
```

```
CEWSC=SWETS*WSCD;
CEA1=14000*(SAM*3.785)**0.52;
CEA2=1500*(SAS*3.785)**0.3;
CEP=SP*PD;
CET=CEW+CEWSC+CEA1+CEA2+CEP+CEDS;
CIP=CET*IPD;
/* DRY SCREENING WORKING EQUATIONS */
DSAC=CEDS*CRF;
DSCM=DSMC*INP*HRD*DYR;
DSE=DSEC*INP*HRD*DYR;
DSLO=(PLA*N*FNDS)*HRD*DYR*POV;
DSC=DSAC+DSCM+DSE+DSLO;
/* WASHING WORKING EQUATIONS */
WEC=1.119*((SWM*1E3/30.00)**(NE1/3))*((WTS/30)**3)*(.04/OWS);
CWAC=CEWM*CRF;
CWM=ODS*(PLM*TLPTC+PP*LEPTC)*HRD*DYR;
CWE=WEC*OWS*HRD*DYR;
CWLO=(PLA*N*FNW)*HRD*DYR*POV;
CW=CWAC+CWM+CWE+CWLO;
/* WET SCREENING WORKING EQUATIONS */
WSCAC=CEWSC*CRF;
CWSE=ODS*WSE*HRD*DYR;
CWSLO=(PLA*N*FNWS)*HRD*DYR*POV;
CWS=WSCAC+CWSE+CWSLO;
CWSM=0;
/* AGGLOMERATION WORKING EQUATIONS */
ACEC=4.97*(ATS/57.36)**3*(SAM*1E3/6.34)**(NE/3)*.04/OW2;
AAC=(CEA1+CEA2)*CRF;
AM=OW2*OCR*PO*HRD*DYR;
HCPTA=((CPC+OCR*CPO*3.6E-3)*DT+WCR*CPW*TDROP)*HFC;
AEC=OW2*(ACEC+HCPTA)*HRD*DYR;
ALO=(PLA*N*FNA)*HRD*DYR*POV;
CA=AAC+AM+AEC+ALO;
AC=CA/(OA*HRD*DYR);
/* PELLETIZATION WORKING EQUATIONS */
PEC=CEP*CRF;
PM=OA*BCR*PB*HRD*DYR;
PECE=OA*PEEC*HRD*DYR;
PLO=(PLA*N*FNP)*HRD*DYR*POV;
CP=PEC+PM+PECE+PLO;
/* HAPPY TOTALS */
APC=CP+CA+CWS+CW+DSC;
AOC=APC+ATC+ARCC;
TAOC=AOC+ARLC;
CC=DSAC+CWAC+WSCAC+AAC+PEC;
MC=DSCM+CWM+AM+PM;
EC=DSE+CWE+CWSE+AEC+PECE;
LC=DSLO+CWLO+CWSLO+ALO+PLO;
/*  COST PER TON  */
DS$PT=DSC/(OOC*HRD*DYR);
```

```
W$PT=CW/(OOC*HRD*DYR);
WS$PT=CWS/(OOC*HRD*DYR);
A$PT=CA/(OOC*HRD*DYR);
P$PT=CP/(OOC*HRD*DYR);
GT$PT=APC/(OOC*HRD*DYR);
CEPMBTU=GT$PT*1.00E8/(BTUOC*2000);
/* OUTPUT FORMATING   */
ZDSAC=ROUND(DSAC,-2);
ZCWAC=ROUND(CWAC,-2);
ZWSCAC=ROUND(WSCAC,-2);
ZAAC=ROUND(AAC,-2);
ZPEC=ROUND(PEC,-2);
ZCC=ROUND(CC,-2);
ZDSCM=ROUND(DSCM,-2);
ZCWM=ROUND(CWM,-2);
ZCWSM=ROUND(CWSM,-2);
ZAM=ROUND(AM,-2);
ZPM=ROUND(PM,-2);
ZMC=ROUND(MC,-2);
ZDSE=ROUND(DSE,-2);
ZCWE=ROUND(CWE,-2);
ZCWSE=ROUND(CWSE,-2);
ZAEC=ROUND(AEC,-2);
ZPECE=ROUND(PECE,-2);
ZEC=ROUND(EC,-2);
ZDSLO=ROUND(DSLO,-2);
ZCWLO=ROUND(CWLO,-2);
ZCWSLO=ROUND(CWSLO,-2);
ZALO=ROUND(ALO,-2);
ZPLO=ROUND(PLO,-2);
ZLC=ROUND(LC,-2);
ZDSC=ROUND(DSC,-2);
ZCW=ROUND(CW,-2);
ZCWS=ROUND(CWS,-2);
ZCA=ROUND(CA,-2);
ZCP=ROUND(CP,-2);
ZAPC=ROUND(APC,-2);
YDS$PT=DS$PT;
YW$PT=W$PT;
YWS$PT=WS$PT;
YA$PT=A$PT;
YP$PT=P$PT;
YGT$PT=GT$PT;
YCEPMBTU=CEPMBTU;
YOOCPO=OOCPO;
ZINP=INP;   ZTLPTC=2000*TLPTC ;  ZPP=PP;  ZOCR= OCR;  ZWCR=WCR;
ZBCR=BCR;  ZT=36+DT;
PUT EDIT('COAL FINES RECOVERY COSTS'
,'*************************')(SKIP(4),COLUMN(15),A(25),COLUMN(15)
,A(25));
```

```
PUT EDIT('      INPUT')(SKIP(2),R(TITLE));
PUT EDIT('      *****')(SKIP(0),R(TITLE));
TITLE:FORMAT(SKIP,X(5),A(16));
PUT EDIT('TYPE OF COAL',CTYPE)(SKIP(1),A(31),A(20));
HEAD:FORMAT(SKIP(1),A(31),A(5),A(8));
PUT EDIT('FINES INPUT RATE',ZINP,'TONS/HR')(R(HEAD));
PUT EDIT('     WASH')(R(TITLE));
PUT EDIT('     ****')(SKIP(0),R(TITLE));
PUT EDIT('RATIO OF LIME TO COAL',ZTLPTC,'LB/TON')(R(HEAD));
PUT EDIT('RATIO OF FLOCCULENT TO COAL',ZPP,'LB/TON')(R(HEAD));
PUT EDIT(' AGGLOMERATION')(R(TITLE));
PUT EDIT(' *************')(SKIP(0),R(TITLE));
PUT EDIT('RATIO OF OIL TO COAL',ZOCR,'GAL/TON')(R(HEAD));
PUT EDIT('RATIO OF WATER TO COAL',ZWCR,'TON/TON')(R(HEAD));
PUT EDIT('TEMPERATURE',ZT,'DEG. F')(R(HEAD));
PUT EDIT('TIP VELOCITY',ATS,'FT/SEC')
(COLUMN(1),A,X(20),F(5,1),A);
PUT EDIT('MIX TIME',AMIX,'MIN.')
(COLUMN(1),A,X(26),F(4,1),A);
PUT EDIT('MIXING EXPONENT',NE)
(COLUMN(1),A,X(19),F(3,1));
PUT EDIT('   PELLITIZE')(R(TITLE));
PUT EDIT('   *********')(SKIP(0),R(TITLE));
PUT EDIT('TYPE OF BINDER',BTYPE)(SKIP,A(31),A(20));
PUT EDIT('RATIO OF BINDER TO COAL',BCR,'LB/TON')
(SKIP(1),A,X(8),F(6,2),A);
PUT EDIT('COST ANALYSIS')(SKIP(3),X(5),A(13));
PUT EDIT('*************')(SKIP(0),R(TITLE));
PUT EDIT('PROCEDURES')(COLUMN(40),A);
PUT EDIT
('ANNUAL COSTS    DRY        WET        WASH       AGGLO-    PELLETIZE
  TOTAL')(SKIP(2),COLUMN(1),A(76));
PUT EDIT
('                SCREEN     SCREEN                MERATION
')(SKIP(1),COLUMN(1),A(68));
PUT EDIT('ANNUALIZED   ',ZDSAC,ZWSCAC,ZCWAC,ZAAC,ZPEC,ZCC)
(R(RFMT));
RFMT: FORMAT(SKIP(2),COLUMN(1),A(13),6 (A(10),X(1)));
PUT SKIP EDIT('CAPITAL')(A(7));
PUT EDIT('MATERIAL     ',ZDSCM,ZCWSM,ZCWM,ZAM,ZPM,ZMC)
(R(RFMT));
PUT EDIT('ENERGY       ',ZDSE,ZCWSE,ZCWE,ZAEC,ZPECE,ZEC)
(SKIP(1),R(RFMT));
PUT EDIT('LABOR &      ',ZDSLO,ZCWSLO,ZCWLO,ZALO,ZPLO,ZLC)
(SKIP(1),R(RFMT));
PUT EDIT('OVERHEAD')(COLUMN(1),A(8),SKIP(2));
PUT EDIT('TOTAL        ',ZDSC,ZCWS,ZCW,ZCA,ZCP,ZAPC)
(R(RFMT));
PUT EDIT('$/TON        ',YDS$PT,YWS$PT,YW$PT,YA$PT,YP$PT,YGT$PT)
(SKIP(3),COLUMN(1),A(13),6(X(1),A(6),X(4)));
```

```
 PUT EDIT('PRODUCTION')(COLUMN(1),A(10));
 PUT SKIP EDIT(' YIELD(FRACT)',DSY,WSY,WASY,AY,PY,OVY)(SKIP,COLUMN(1),A(
 13),6 (X(3),F(5,3),X(3)));
 PUT EDIT('PRICE OF FINAL PRODUCT , CENTS/MILLION BTU =',YCEPMBTU)
 (SKIP(2),COLUMN(1),A(44),A(6));
 PUT EDIT( 'PRODUCT OUTPUT , TONS/HOUR=',YOOCPO)
 (COLUMN(1),A(27),A(5));
 PUT EDIT('PRODUCT BTU=',BTUOC,'PRODUCT ASH=',ASHOC
 ,'PRODUCT SULFUR=',SULOC)(COLUMN(1),A,F(5,0),COLUMN(1),A,F(4,1),
 COLUMN(1),A,F(4,2));
 GO TO BIG;
 DEN:END;
EOF:
.
```

List of Variables

Input Variables

NAME	VALUE	UNITS	DESCRIPTION
INP		Ton/hr	Fines input rate
DSY		---	Dry screen yield
W2Y		---	Wash #2 yield
WSY		---	Wet screen, yield
PY		---	Pelletization yield
COR		Gal/ton	Oil to coal ratio
DT		°F	Temperature over ambient of agglomeration
TDROP		°F	Temperature drop of water recyle
WRC		---	Water to coal ratio
BCR		Lb/ton	Binder to coal
TLPTC		---	Lime to coal ratio
LEPTC		Lb/ton	Flocculant to coal ratio
ASHDS		%	Ash in fines -14
BTUDS		Btu/lb	Btu in fines -14
SULDS		%	Sulfur in fines +14
ASHO		%	Ash in fines +14
BTUO		Btu/lb	Btu in fines +14
SULO		%	Sul in fines +14
AMIX		min	Agglomeration mix time
ATS		ft/sec	Agglomeration mix speed
AWA		---	Agglomeration water to coal

Input Variables (Cont.)

NAME	VALUE	UNITS	DESCRIPTION
WTS		ft/sec	Wash tip speed
URDS	0.20	Ton/ft^2-hr	Unit process rate, dry screen
URWM	3.21	Ton/10^3 gal hr	Unit process rate, wash mix tank
URWS		"	Unit process rate, second wet screen
URWC	45.0	"	Unit process rate, wash coagulation
URWSD	0.749	"	Unit process rate, wash sedimentation
URWSC	0.10	Ton/ft^2-hr	Unit process rate, wet screen
URAM	25.1	Ton/10^3 gal hr	Unit process rate, agglomeration mix
URAS	125.5	"	Unit process rate, agglomeration settle
URP	0.10	Ton/ft^2-hr	Unit process rate, pelletizer
WSE	0.028	$/ton	Energy cost, wet screen
PEEC	0.001	"	Energy cost, pelletization
DSEC	0.028	"	Energy cost, dry screen
DSD	1,100	$/ft^2	Dry screen unit cost (exp)
WMD	5,200	$/10^3 gal	Wash mix tank unit cost
WSD	11,400	"	Wash settler unit cost
PD	500	$/ft^2	Pelletizer unit cost

Input Variables (Cont.)

NAME	VALUE	UNITS	DESCRIPTION
WSCD	534	$\$/ft^2$	Wet screen unit cost
WSDD	0.65	---	Exponent, wash sedimentation tank
WCD	0.50	---	Exponent, wash coagulation tank
PP	10	$/lb	Price, coagulant
PO	0.50	$/gal	Price, oil
PB	0.10	$/lb	Price, binder
PLM	30.0	$/ton	Price, lime
FNDS	0.20	---	Fraction of men on, dry screen
FNW	0.20	---	Fraction of men on, wash
FNWS	0.20	---	Fraction of men, wet screen
FNA	0.20	---	Fraction of men on, agglomeration
FNP	0.20	---	Fraction of men on, pelletization
HHVC	36	10^{-6}Btu/ton	Higher heating value, coal
HHVO	24	"	Higher heating value, oil
CPC	600	Btu/ton°F	Specific heat of coal
CPO	900	"	Specific heat of oil
CPW	2000	"	Specific heat of water
ATC	0.0	$/yr	Annual transportation cost
ARCC	0.0	"	Annual reclamation cost

Input Variables (Cont.)

NAME	VALUE	UNITS	DESCRIPTION
ARLC	0.0	"	Annual lost coal cost
DSMC	0.0	$/ton	
IPD	0.2	---	Piping at 20% of capital
CRF	0.16452	---	Capital recovery factor each year, 10%
PLA	12.0	$/hr	Labor + supervision costs
N	5	men	Men per shift
POV	1.5	---	$\frac{\text{\% overhead}}{100} + 1$
HRD	8	hr/day	Work shift hours
DVR	200	day/year	Work days per year
NE	2.5	---	Experimental scale-up constant
INOVS		---	Flag to include or exclude oversize 1 → Include 0 → Exclude
NPROB		---	Flag to specify most probable case, least or maximum quality enhancement 1 → most probable 2 → least probable 3 → maximum
DRYF		%	+14-70 size fraction of input coal determined by dry screen analysis

Calculated Values

NAME	VALUE	UNITS	DESCRIPTION
ODS		Ton/hr	Output of dry screen
OWS		"	Output of wet screen
OW1		"	Output of wash #1
OW2		"	Output of wash #2
OA		"	Output of agglomeration
OP		"	Output of pelletization
OOC		"	Output of washed plus oversize
WASY		---	Overall yield of both washes
OVY		---	OOC/INP
OOCPO		Ton/hr	Coal + oil output
SDS		Ft^2	Size of dry screen
SWM		10^3 gal	Size of wash mix tank
SWC		"	Size of wash coagulation tank
SWSD		"	Size of wash sedimentation tank
SWETS		Ft^2	Size of wet screen
SAM		10^3 gal	Size of agglomeration mix tank
SAS		"	Size of agglomeration settler tank
SP		Ft^2	Size of pelletizer
CEDS		$	Cost of dry screen
CEWM		$	Cost of wash mix tank
CEWS		$	Cost of wash second screen

Calculated Values (Cont.)

NAME	VALUE	UNITS	DESCRIPTION
CEWC		$	Cost of wash coagulation tank
CEWSD		$	Cost of wash sedimentation tank
CEW		$	Cost of total wash
CEWSC		$	Cost of wet screen
CEAI		$	Cost of agglomeration mix tank
CEA2		$	Cost of agglomeration settle tank
CEP		$	Cost of pelletizer
SWS		Ft^2	Size of second screen
CET		$	Cost of total equipment
CIP		$	Cost of piping
DSAC		$/yr	Dry screening annualized capital
DSCM		"	Dry screening, material cost
DSE		"	Dry screening, energy cost
DSLO		"	Dry screening, labor and overhead
DSC		"	Dry screening, total
CWAC		"	Washing, annualized capital
CWM		"	Washing, material cost
CWE		"	Washing, energy cost
CWLO		"	Washing, labor and overhead
CW		"	Washing, total

Calculated Values (Cont.)

NAME	VALUE	UNITS	DESCRIPTION
WSCAC		"	Wet screen, annualized capital
CWSE		"	Wet screen, energy cost
CWSLO		"	Wet screen, labor and overhead
CWS		"	Wet screen, total
CWSM	0.0	"	Wet screen, material cost
AAC		$/yr	Agglomeration, annualized capital
AM		"	Agglomeration, material cost
HCPTA		$/ton	Agglomeration, heating cost
AEC		$/yr	Agglomeration, energy cost
ALO		"	Agglomeration, labor and overhead
CA		"	Agglomeration, total cost
AC		$/ton	Agglomeration, cost per ton
PEC		$/yr	Pelletization, annualized capital
PM		"	Pelletization, materials costs
PECE		"	Pelletization, costs
PLO		"	Pelletization, labor and overhead
CP		"	Pelletization, total
APC		"	Total process costs

Calculated Values (Cont.)

NAME	VALUE	UNITS	DESCRIPTION
ADC		"	Total process and transportation costs
TAOC		"	Total above plus lost coal
CC		"	Total annualized capital
MC		"	Total materials costs
EC		"	Total energy costs
LC		"	Total labor and overhead
DS$PT		$/ton	Cost per ton, dry screen
W$PT		"	Cost per ton, wash
WS$PT		"	Cost per ton, wet screen
WEC		"	Energy cost, wash
A$PT		"	Cost per ton, agglomeration
P$PT		"	Cost per ton, pelletization
GT$PT		"	Cost per ton, total
CEPMBTU		"	Cost per 10^6 Btu coal + oil
ASHWS		"	Ash in wet screen output
ASHW1		"	Ash in wash 1 output
ASHW2		"	Ash in wash 2 output
ASHA		"	Ash in agglomeration output

Calculated Values (Cont.)

NAME	VALUE	UNITS	DESCRIPTION
ASHP		"	Ash in pelletization output
ASHOC		"	Ash in product output
ACEC		"	Energy cost, agglomeration
BTUWS		"	Btu in wet screen output
BTUW1		"	Btu in wash 1 output
BTUW2		"	Btu in wash 2 output
BTUA		"	Btu in agglomeration output
BTUP		"	Btu in pelletization output
BTUOC		"	Btu in product output

```
CTYPE='SEAM 6 '
BTYPE='ASPHALT',
INP=100,
DSY=0.99,
W1Y=0.58,
W2Y=1.00,
WSY=0.75,
HRD=8,
DYR=200,
URDS=0.2,
URWM=3.21,
URWS=0.08,
URWC=45,
URWSD=0.749,
WSE=0.028,
DSD=1100,
WMD=5700,
WSD=534,
WCD=0.5,
WSDD=0.65,
OCR=7.5,
URWSC=.1,
IPD=0.2,
URAS=5.0,
URP=0.1,
PEEC=0.001,
CRF=0.16452,
DSMC=0.5,
DSEC=0.028,
PLA=12,
N=5,
POV=1.5,
ATC=0,
ARCC=0,
AOC=0,
ARLC=0,
PLM=30.00,
PP=10,
ASHDS=55.95,
BTUDS=4880.8,
SULDS=1.5160,
ASHO=38,
BTUO=8600,
SULO=2.42,
WCR=10,
AMIX=10,
ATS=25.0,
WTS=19,
ASHB=0,
BTUB=13289,
.
```

```
SULB=0,
NE=3.,
PO=0.5,
PB=.10,
FNDS=0.2,
FNW=0.2,
FNWS=0.2,
FNA=0.2,
FNP=0.2,
WSCD=534,
HHVC=24,
HHVO=36,
CPC=600,
DT=112,
TDROP=45,
BCR=80,
CPO=900,
CPW=2000,
TLPTC=.01,
LEPTC=.01,
PD=500.0,
HFC=9.09E-7,NE1=3,NPROB=1;
 NPROB=2;NPROB=3;
 W1Y=0.42,WSY=0.8332,ASHDS=57.13,BTUDS=4603.5,SULDS=1.976,
 NPROB=1;NPROB=2;NPROB=3;
  W1Y=0.69,WSY=0.55,DSMC=10,ASHDS=15.09,BTUDS=11171.5,SULDS=1.215,
 NPROB=1;NPROB=2;NPROB=3;
 W1Y=0.55,WSY=0.89,DSMC=3,ASHDS=26.79,BTUDS=9136,SULDS=3.248,
 NPROB=1,NPROB=2;NPROB=3;
 W1Y=0.67,WSY=0.84,ASHDS=33.05,BTUDS=8219.2,SULDS=4.173,NPROB=1;
 NPROB=2;NPROB=3;
EOF:
.
```

APPENDIX B

Sample Run of Portions of Modified CLAIM© Program

```
 CRUN
COPY CLAIM1 TEXT B = = A ( UNPACK
COPY CLAIM1 DATA B = = A ( UNPACK
COPY CLAIM DATA B = = A ( UNPACK
COPY SRILIB TXTLIB B = = A ( UNPACK
COPY SHRILIB TXTLIB B = = A ( UNPACK
FI 08 DISK CLAIM1 DATA A
FI 09 DISK CLAIM DATA A
GLOBAL TXTLIB FORTLIB SRILIB SHRILIB SUBLIB
FI 05 TERM
FI 06 TERM
LOAD CLAIM1 ( START
EXECUTION BEGINS...


    HELLO. ILL NEED A FEW SECONDS TO GET ORGANIZED..
              *****************************
              *                           *
              *           CLAIM           *
              *                           *
              *  COMPUTERIZED RECLAMATION *
              *      PLANNING SYSTEM      *
              *                           *
              *****************************
---------
 OPTIONS
---------
0 -> TERMINATE CLAIM

1 -> DATA INPUT

2 -> DATA EDIT

3 -> CURRENT DATA REVIEW

4 -> DATA ANALYISIS

5 -> GRADE SPOILS WITHOUT CURRENT
     LAND USE OPTION RESTRICTIONS


ENTER OPTION SELECTION -> -
? 03000
.1
              *****************************
              *                           *
              *           CLAIM           *
              *                           *
              *  COMPUTERIZED RECLAMATION *
              *      PLANNING SYSTEM      *
              *                           *
              *****************************
------------
 DATA INPUT
------------

0 -> EXIT FROM DATA INPUT OPTION

1 -> MANUAL INPUT OF THE GENERAL MINE DESCRIPTION

2 -> MANUAL INPUT OF ENVIRONMENTAL DATA

3 -> MANUAL INPUT OF NON-STANDARD EXPECTATION VALUES

4 -> INPUT TITLE TO APPEAR ON ALL OUTPUTS


ENTER YOUR SELECTION HERE -> -
? 00105
.1
```

INPUT RESPONSES/GENERAL DESCRIPTION

```
.) GENERAL DESCRIPTION   ********************************************
                         *           STANDARD EXPECTATIONS           *
                         ********************************************
                         *CROP*  NATIVE   *WILD*  WATER    *HIGH*OTHER*
                         *LAND*VEGETATION*LIFE*RECREATION*USE *     *

**********************************************************************
                         *    *          *    *          *    *     *
A.) TYPE OF MINE :       *    *          *    *          *    *     *
 1.) DRAGLINE            *  2 *    2     *  2 *    2     * 2  *  0  *
 2.) TRUCK AND SHOVEL    *  2 *    2     *  2 *    2     * 2  *  0  *

NTER THE APPROPRIATE     ********************************************

UMBER, OR ZERO TO QUIT -> -
? 00085
.2

VERAGE COST TO EXCAVATE SPOIL (CENTS/CU.Y.)-> -
?
.17

.) GENERAL DESCRIPTION   ********************************************
                         *           STANDARD EXPECTATIONS           *
                         ********************************************
                         *CROP*  NATIVE   *WILD*  WATER    *HIGH*OTHER*
                         *LAND*VEGETATION*LIFE*RECREATION*USE *     *

**********************************************************************
                         *    *          *    *          *    *     *
B.) STAGE IN MINING      *    *          *    *          *    *     *
    SEQUENCE :           *    *          *    *          *    *     *
 1.) OPENING BOX CUT     *  1 *    1     *  2 *    1     * 1  *  0  *
 2.) MINE RUN            *  2 *    2     *  2 *    2     * 2  *  0  *
 3.) FINAL BOX CUT       *  1 *    1     *  3 *    3     * 1  *  0  *

NTER THE APPROPRIATE     ********************************************

UMBER, OR ZERO TO QUIT -> -
? 00085
.2

**********************************************************************
                         *    *          *    *          *    *     *
C.) AVERAGE SLOPE OF     *    *          *    *          *    *     *
    10 RANDOM POINTS     *    *          *    *          *    *     *
    IN THE AREA :        *    *          *    *          *    *     *
 1.)  0.00 - 3.00        *  3 *    2     *  2 *    2     * 3  *  0  *
 2.)  3.01 - 5.70        *  2 *    3     *  2 *    3     * 2  *  0  *
 3.)  5.71 - 11.50       *  0 *    2     *  3 *    2     * 1  *  0  *

NTER THE APPROPRIATE     ********************************************

UMBER, OR ZERO TO QUIT -> -
? 00085
.1

    *** TRUCK AND SHOVEL MINE ***

    ENTER COST OF GRADING SPOILS(CENTS/CU.YD) -> -
```

```
    ** TRUCK AND SHOVEL SEGMENT - CROPLAND ALTERNATIVE **

    TOTAL VOLUME OF REHANDLE (CU.YDS) -> -
?
.1000

    COST OF REHANDLE (CENTS/CU.YD.) -> -
?
.60

    ** TRUCK AND SHOVEL SEGMENT - CROPLAND ALTERNATIVE **

    INPUT WALL/BENCH INFORMATION :

    > BEGIN WITH BOTTOM HIGHWALL AND BENCH

      PROCEEDING UPWARD UNTIL DONE

    > WHEN DONE,ENTER ZERO FOR THE HEIGHT
      OF WHAT WOULD HAVE BEEN THE NEXT HIGHWALL

    > 10 HIGHWALL//BENCH PAIRS ARE ALLOWED

    > WIDTH OF TOP BENCH CAN BE NO GREATER
      THAN ONE HALF THE WIDTH OF THE HILL TOP


    NOW DESCRIBING HIGHWALL/BENCH PAIR # 1

    VERTICAL HEIGHT OF HIGHWALL(FEET) -> -
?
.100
    WIDTH OF THE BENCH(FEET) -> -
?
.250
    INITIAL SLOPE OF THE HIGHWALL(DEGREES) -> -
?
.36
    LENGTH OF BENCH ALONG OUTSIDE EDGE(FEET) -> -
?
.1000

    NOW DESCRIBING HIGHWALL/BENCH PAIR # 2

    VERTICAL HEIGHT OF HIGHWALL(FEET) -> -
?
.0

    INPUT SPOIL FILE CONFIGURATION CODE :
    1-> SEMI-CIRCULAR SPOILS
    2-> RECTANGULAR SPOILS
    ENTER CONFIGURATION BEST DESCRIBING SPOILS -> -
?
.2
              *** CURRENT HIGHWALL/BENCH DATA ***

 PAIR #  HW HEIGHT  HW SLOPE  BENCH WIDTH  BENCH LENGTH
 ------  ---------  --------  -----------  ------------

  1        100.00     36.00       250.00         1000.00

 HIGHWALL/BENCH PAIR NUMBER OF EDIT(0 TO QUIT) ->-
?
.0
```

```
    *** INPUT FINAL SLOPES ***


     * CROPLAND ALTERNATIVE  *

    DEFAULT SLOPES :
    HIGHWALL/BENCH PAIR   DEFAULT SLOPE VALUE
    -------------------   -------------------

             1                     0.0

    SELECT ONE OF THE FOLLOWING :
    1) USE THE DEFAULT VALUES
    2) I WILL USE MY OWN VALUES
    ENTER 1 OR 2 -> -
?
.2

    THE MINIMUM REQUESTABLE SLOPE FOR HIGHWALL # 1
    IS  8.91DEGREES. THIS SLOPE WILL REDUCE THE WIDTH OF
    BENCH #  1TO ABOUT ZERO.

    INPUT THE FINAL SLOPE FOR HIGHWALL #  1 -> -
?
.5.63

    ERROR -> THE CURRENT MINIMUM SLOPE REQUEST FOR
    HIGHWALL  1 IS  8.91 DEGREES. YOU CAN :
    1) RE-ENTER YOUR VALUE
    2) START OVER
    3) OBTAIN A SUGGESTION THAT WILL LET YOU USE THIS SLOPE
    4) EXIT FROM THIS ROUTINE
    ENTER YOUR CHOICE HERE -> -
?
.3

    SUGGESTION :

    IF YOU INCREASE BENCH  1 FROM  250.00 FEET,TO

     438.46 FEET,THE FINAL SLOPE VALUE OF    5.63 DEGREES

    WILL WORK.


    YOU CAN :

    1) IMPLEMENT THE ABOVE SUGGESTION

    2) USE YOUR OWN BENCH ADJUSTMENTS

    3) INPUT A DIFFERENT SLOPE VALUE

    4) RE-INPUT ALL THE FINAL SLOPES FOR THIS ALTERNATIVE

    5) EXIT FROM THIS OPTION

    ENTER YOUR CHOICE HERE -> -
?
.1
```

```
     *** EDIT OPTIONS ***

    0 -> EXIT FROM THIS LAND USE OPTION

    1 -> DISPLAY SUMMARY TABLE OF VOLUME AND COST CALCULATIONS

    2 -> EDIT REHANDLE DATA  (NOT FOR OPENING CUT )

    3 -> EDIT THE SPOIL PILE CONFIGURATION CODE

    4 -> RE - INPUT ALL INITIAL HIGHWALL / BENCH DATA

    5 -> RE - INPUT ALL FINAL SLOPE VALUES

    6 -> EDIT THE COST OF GRADING OVERBURDEN
         AND RE-COMPUTE ALL COSTS FOR ALL LAND
         USE OPTIONS CURRENTLY DESCRIBED

   ENTER YOUR SELECTION -> -
? 00510
.1

                 ***** CROPLAND ALTERNATIVE *****
TRUCK AND SHOVEL GRADING

                                                 MINE RUN OPTION
-----------------------------------------------------------------------
H/B *HW SLOPES-DEG* BENCHES  (FT) * HW HGT *BEN LEN*VOL GRADED*       *
NO. *INITIAL*FINAL*INITIAL* FINAL * (FEET) * (FEET) *  (CU YDS) * COST*
-----------------------------------------------------------------------
  1 *36.00  * 5.63*438.5  *   0.0 * 100.0  *1000.0 * 405986.1 ******** *
-----------------------------------------------------------------------

    TOTAL VOLUME GRADED            :      405986.1  CUBIC YARDS.
    COST PER CU. YD    OF GRADING:           17.0  CENTS.
    TOTAL COST OF GRADING          : $    69017.62
    AREA  COVERED BY SPOILS        :         23.3  ACRES.
    COST PER ACRE OF GRADING       : $     2963.14

    VOLUME OF REHANDLE                :        1000.0 CUBIC YARDS.
    COST PER CUBIC YARD FOR REHANDLE:           60.0 CENTS.
    TOTAL COST OF REHANDLE           : $       600.00
    COST PER ACRE FOR REHANDLE       : $        25.76

    GRAND TOTAL COST                 : $    69617.62
    GRAND TOTAL COST PER ACRE         : $     2988.90
     *** EDIT OPTIONS ***

    0 -> EXIT FROM THIS LAND USE OPTION

    1 -> DISPLAY SUMMARY TABLE OF VOLUME AND COST CALCULATIONS

    2 -> EDIT REHANDLE DATA  (NOT FOR OPENING CUT )

    3 -> EDIT THE SPOIL PILE CONFIGURATION CODE

    4 -> RE - INPUT ALL INITIAL HIGHWALL / BENCH DATA

    5 -> RE - INPUT ALL FINAL SLOPE VALUES

    6 -> EDIT THE COST OF GRADING OVERBURDEN
         AND RE-COMPUTE ALL COSTS FOR ALL LAND
         USE OPTIONS CURRENTLY DESCRIBED

   ENTER YOUR SELECTION -> -
? 00510
.0
EXIT FROM TRUCK AND SHOVEL ROUTINES ?(YES OR NO) -
.NO
```

```
=======================================================================

              *****************************
              *                           *
              *           CLAIM           *
              *                           *
              *  COMPUTERIZED RECLAMATION *
              *      PLANNING SYSTEM      *
              *                           *
              *****************************
---------------
 DATA ANALYSIS
---------------

0 -> EXIT FROM DATA ANALYSIS OPTION

1 -> ENVIRONMENTAL FEASIBILITY RANKING

2 -> TECHNIQUES AND ECONOMICS ANALYSIS

3 -> OPTIMUM USE FACTORS

ENTER YOUR SELECTION -> -
? 00505
.?
         *** CROPLAND ALTERNATIVE ***

              TECHNIQUE                          COST/ACRE
              ---------                          ---------
 1)REHANDLE 2 FT. OF SEEDBED SUITABLE SPOIL $  274.27
 2)GRADE SPOIL                              $ 2988.90
 3)CHISEL PLOW                              $    1.00
 4)DISC AND HARROW                          $    0.0
 5)BUY SEED                                 $   91.65
 6)DRILL SEED                               $    3.75
 7)BUY FERTILIZER : NITROGEN                $    1.00
 8)BUY FERTILIZER : PHOSPHATE               $    0.75
 9)DRILL FERTILIZER                         $    3.75
10)BUY HAY MULCH                            $    4.00
11)BUY,APPLY HERBICIDE                      $    2.75
12)STABILIZE TOPSOIL STORAGE PILE           $   11.26
13)ADMIN. OF OPERATIONS AND NECESSARY TESTS $  507.46

                                               =========
                                      TOTAL $  3890.54

GRAND TOTAL COST FOR    23.3 ACRES IS         0.09 MILLION DOLLARS
```

APPENDIX C

FINAL DECISION MAKING PROGRAM AND SUBROUTINES

```
      COMMON/THREE/PPRICE(6),PROPRC(6),PCOSTA(6,6),PPRFTA(6,6)
     $ ,PLOSSA(6,6),PCOSTB(6,6),PPRFTB(6,6),PLOSSB(6,6),WASTE,OPTUSE(6)
      COMMON/ONE/INUM,IRECL,IMSG,NUMPON
      COMMON/TWO/PAREA(6),PDEPTH(6),PWAST(6),CENBTU(6),COSTA(6,6)
     $ ,COSTB(6,6),DRYBTU(6),DRYASH(6),DRYSUL(6),DRYYLD(6),PROBTU(6)
     $ ,PROASH(6),PROSUL(6),PROYLD(6),IWSTAC(6),PQUANT(6)
      COMMON/FOUR/TCOSTA(6),TCOSTB(6),TLOSSA(6),TLOSSB(6),
     $TPRFTA(6),TPRFTB(6),NUMFIL
      QUAMIN=11000.
      PPRICE(1)=15.
      PPRICE(2)=14.
      PPRICE(3) = 16.
      PPRICE(4) = 17.
      PPRICE(5) = 18.
      PPRICE(6) = 19.
      WRITE(6,1)
      READ(5,*)NUMPON
      WRITE(6,800)
800   FORMAT(2X,'DO YOU WANT TO INPUT SALE PRICE?(YES OR NO)')
      READ(5,801)ICHAR
801   FORMAT(A3)
      DATA IYES/'YES'/
      IF(ICHAR.NE.IYES)GOTO 2000
      DO 900 IJK=1,NUMPON
      WRITE(6,901)IJK
901   FORMAT(2X,'POND NUM =',2X,I5,2X,'MARKET VALUE OF COAL =')
      READ(5,*)PPRICE(IJK)
900   CONTINUE
2000  IF(NUMPON-1) 10,10,20
10    INUM=1
      WRITE(6,3)
      READ(5,*)BTUPRO
      IF(BTUPRO.GE.QUAMIN) GOTO 11
      GOTO 999
 11   IRECL=1
      CALL PREAD
      CALL CALC
      CALL CLOUT
      CALL PROUT
      GOTO 1000
20    WRITE(6,3)
      READ(5,*)BTUPRO
      IF(BTUPRO.LT.QUAMIN) GOTO 999
      CALL NREAD
      CALL TOUT
      IRECL=1
      IMSG=0
      WRITE(6,30)
  30  FORMAT(10X,'PONDS HANDLED SEPERATELY',/10X,24('*'))
      DO 22 INUM = 1,NUMPON
```

```
      IRECL = 1
      CALL CALC
      CALL PROUT
22    CONTINUE
40    DO 23 INUM = 1,NUMPON
      CALL PROUT
23    CONTINUE
      GOTO 1000
999   WRITE(6,2)
1000  STOP
1     FORMAT(2X,'ENTER NUMBER OF PONDS')
2     FORMAT(2X,'IN THIS CASE THERE ARE NO MORE CALCULATIONS'/,
     $ 2X,'DONE,AS THE PROCESS IS NOT WORTH GOING THROUGH')
3     FORMAT(2X,'ENTER BTU OF PRODUCT FROM THE PROCESS')
      END
EOF:
.
```

```
      SUBROUTINE PREAD
      COMMON/THREE/PPRICE(6),PROPRC(6),PCOSTA(6,6),PPRFTA(6,6)
     $ ,PLOSSA(6,6),PCOSTB(6,6),PPRFTB(6,6),PLOSSB(6,6),WASTE,OPTUSE(6)
      COMMON/ONE/INUM,IRECL,IMSG,NUMPON
      COMMON/TWO/PAREA(6),PDEPTH(6),PWAST(6),CENBTU(6),COSTA(6,6)
     $ ,COSTB(6,6),DRYBTU(6),DRYASH(6),DRYSUL(6),DRYYLD(6),PROBTU(6)
     $ ,PROASH(6),PROSUL(6),PROYLD(6),IWSTAC(6),PQUANT(6)
      WRITE(6,1) INUM
      WRITE(6,2)
      READ(5,*) OPTUSE(INUM)
      WRITE(6,3)
      READ(5,*) (COSTA(INUM,I),I=1,6)
      WRITE(6,4)
      READ(5,*) (COSTB(INUM,I),I=1,6)
      WRITE(6,5)
      READ(5,*) CENBTU(INUM)
      WRITE(6,6)
      READ(5,*) PAREA(INUM)
      WRITE(6,7)
      READ(5,*) PDEPTH(INUM)
      WRITE(6,8)
      READ(5,*) (DRYBTU(INUM),DRYASH(INUM),DRYSUL(INUM),DRYYLD(INUM))
      WRITE(6,9)
      READ(5,*) (PROBTU(INUM),PROASH(INUM),PROSUL(INUM),PROYLD(INUM))
      WRITE(6,10)
      READ(5,11) IWSTAC(INUM)
      RETURN
1     FORMAT(2X,'INPUT FOR POND NUMBER = ',I5)
2     FORMAT(2X,'ENTER OPTIMUM LAND USE NUMBER.',
     $ /2X,'1.CROPLAND',/2X,
     $      '2.NATIVE VEGETATION.',/2X,
     $      '3.WATER RECREATION.',/2X,
     $      '4.WILD LIFE',/2X,
     $      '5.HIGH USE',/2X,
     $      '6.OTHER USE')
3     FORMAT(2X,'ENTER COSTS FOR THE SIX LAND - USES FOR ',/,
     $ 2X,'RECLAMATION(IN ORDER),FOR THE CASE WHEN THE ',/,
     $ 2X,'WASTE CAN BE PUT BACK IN THE POND')
4     FORMAT(2X,'ENTER COSTS FOR THE SIX LAND-USES FOR '/,
     $ 2X,'RECLAMATION (IN ORDER),FOR THE CASE WHEN THE',/,
     $ 2X,'WASTE CAN NOT BE PUT BACK IN THE POND')
5     FORMAT(2X,'ENTER THE COST FOR THE PROCESS IN CENTS ',
     $'PER MILLION BTU')
6     FORMAT(2X,'ENTER THE AREA OF THE POND(ACRES)')
7     FORMAT(2X,'ENTER THE AVERAGE DEPTH OF THE POND',/2X,
     $ '(IN FEET)')
8     FORMAT ( 2X,'ENTER THE DRY (INPUT) COAL PARAMETERS : -',
     $ /2X,'1.BTU IN BTU/LB',/,
     $ 2X, '2. ASH IN % ',
     $ /2X,'3.SUL IN %',
```

```
     $ /2X,'4.YLD IN %')
9     FORMAT(2X,'ENTER PRODUCT COAL PARAMETERS IN THE GIVEN ORDER:',
     $/2X,'1.BTU IN BTU/LB',
     $/2X,'2.ASH IN %',
     $/2X,'3.SUL IN %',
     $/2X,'4.YIELD IN %')
10    FORMAT(2X,'ENTER IF THE WASTE IS ACCEPTABLE OR NOT.',/,
     $2X,'ENTER YES OR NO ')
11    FORMAT(A3)
      END
EOF:
.
```

```
      SUBROUTINE NREAD
      COMMON/THREE/PPRICE(6),PROPRC(6),PCOSTA(6,6),PPRFTA(6,6)
     $ ,PLOSSA(6,6),PCOSTB(6,6),PPRFTB(6,6),PLOSSB(6,6),WASTE,OPTUSE(6)
      COMMON/ONE/INUM,IRECL,IMSG,NUMPON
      COMMON/TWO/PAREA(6),PDEPTH(6),PWAST(6),CENBTU(6),COSTA(6,6)
     $ ,COSTB(6,6),DRYBTU(6),DRYASH(6),DRYSUL(6),DRYYLD(6),PROBTU(6)
     $ ,PROASH(6),PROSUL(6),PROYLD(6),IWSTAC(6),PQUANT(6)
      COMMON/FOUR/TCOSTA(6),TCOSTB(6),TLOSSA(6),TLOSSB(6),
     $TPRFTA(6),TPRFTB(6),NUMFIL
      DIMENSION TEMPA(6,6),TEMPB(6,6)
      WRITE(6,10)
10    FORMAT(10X,'PONDS HANDLED TOGETHER'/10X,22('*'))
      TOTWST = 0
      DO 2 INUM = 1,NUMPON
      CALL PREAD
      IRECL = 1
      CALL CALC
      DO 11 I = 1,6
      TEMPA(INUM,I)=COSTA(INUM,I)
      TEMPB(INUM,I)=COSTB(INUM,I)
11    CONTINUE
      TOTWST=PWAST(INUM) + TOTWST
      CALL CLOUT
    2 CONTINUE
      WASTE = TOTWST
      NUMFIL = 0
      DO 30 INUM =1,NUMPON
      IRECL = 2
      IMSG=0
      A = WASTE/PQUANT(INUM)
      IF (A.LT.1.) GOTO 40
      CALL CALC
      NUMFIL=NUMFIL+1
      WASTE=WASTE-PQUANT(INUM)
      IF(WASTE.NE.0)IMSG=1
      CALL PROUT
      GOTO 30
   40 IRECL = 1
      IMSG=0
      CALL CALC
      CALL PROUT
   30 CONTINUE
      DO 15 I = 1,6
       TCOSTA(I) = 0.
       TCOSTB(I) = 0.
       TLOSSA(I) = 0.
       TLOSSB(I) = 0.
       TPRFTA(I) = 0.
       TPRFTB(I) = 0.
   15 CONTINUE
```

```
      DO 20 I = 1,6
      DO 20 INUM = 1,NUMPON
      TCOSTA(I) = TCOSTA(I) + PCOSTA(INUM,I)
      TCOSTB(I) = TCOSTB(I) + PCOSTB(INUM,I)
      TLOSSA(I) = TLOSSB(I) + PLOSSA(INUM,I)
      TLOSSB(I) = TLOSSB(I) + PLOSSB(INUM,I)
      TPRFTA(I) = TPRFTA(I) + PPRFTA(INUM,I)
      TPRFTB(I) = TPRFTB(I) + PPRFTB(INUM,I)
   20 CONTINUE
      DO 12 I = 1,6
      DO 12 J = 1,6
      COSTA(I,J) = TEMPA(I,J)
      COSTB(I,J) = TEMPB(I,J)
   12 CONTINUE
      RETURN
      END
EOF:
.
```

```
TOF:
      SUBROUTINE CALC
      COMMON/THREE/PPRICE(6),PROPRC(6),PCOSTA(6,6),PPRFTA(6,6)
     $ ,PLOSSA(6,6),PCOSTB(6,6),PPRFTB(6,6),PLOSSB(6,6),WASTE,OPTUSE(6)
      COMMON/ONE/INUM,IRECL,IMSG,NUMPON
      COMMON/TWO/PAREA(6),PDEPTH(6),PWAST(6),CENBTU(6),COSTA(6,6)
     $ ,COSTB(6,6),DRYBTU(6),DRYASH(6),DRYSUL(6),DRYYLD(6),PROBTU(6)
     $ ,PROASH(6),PROSUL(6),PROYLD(6),IWSTAC(6),PQUANT(6)
      DIMENSION PROQUA(6),PFEED(6)
      IF(PPRICE(INUM).EQ.0)GOTO 999
      GOTO 900
999   IF(PROBTU(INUM).LE.11400.) PPRICE(INUM)=3.+
     $ (26.5/3400.*(PROBTU(INUM)-8000.))
      IF(PROBTU(INUM).GT.11400.)PPRICE(INUM)=(PROBTU(INUM)-11400.)
     $*.002+29.5
900   IF (IRECL.NE.1) GOTO 10
      GOTO 100
  10  DO 20 I = 1,6
      COSTA(INUM,I) =0
      COSTB(INUM,I) = 0
  20  CONTINUE
 100  DO 90 I = 1,6
      PLOSSA(INUM,I) = 0.
      PPRFTA(INUM,I) = 0.
      PLOSSB(INUM,I) = 0.
      PPRFTB(INUM,I) = 0.
  90  CONTINUE
      PQUANT(INUM) = PAREA(INUM) * PDEPTH(INUM)*43560.*53./2000.
      PFEED(INUM) = PQUANT(INUM) * DRYYLD(INUM)/100.0
      PROQUA(INUM) = PFEED(INUM) * PROYLD(INUM)/100.0
      PWAST(INUM) = PFEED(INUM) - PROQUA(INUM)
      PROPRC(INUM) = PROQUA(INUM)*PPRICE(INUM)/1E6
      PCOST = PROQUA(INUM) * PROBTU(INUM) * CENBTU(INUM)*2.0E-5
      DO 30 I = 1,6
      PCOSTA(INUM,I)=(PAREA(INUM) * COSTA(INUM,I) + PCOST)/1E6
      PCOSTB(INUM,I)=(PAREA(INUM) * COSTB(INUM,I) + PCOST)/1E6
      IF(PROPRC(INUM)-PCOSTA(INUM,I)) 40,40,50
  40  PLOSSA(INUM,I) = PCOSTA(INUM,I)-PROPRC(INUM)
      GOTO 60
  50  PPRFTA(INUM,I) = (PROPRC(INUM) - PCOSTA(INUM,I))/1.
  60  IF(PROPRC(INUM)-PCOSTB(INUM,I)) 70,70,80
  70  PLOSSB(INUM,I) = (PCOSTB(INUM,I)-PROPRC(INUM))/1.
      GOTO 30
  80  PPRFTB(INUM,I) = (PROPRC(INUM) - PCOSTB(INUM,I))/1.
  30  CONTINUE
      RETURN
      END
EOF:
.
```

```
      SUBROUTINE CLOUT
      COMMON/THREE/PPRICE(6),PROPRC(6),PCOSTA(6,6),PPRFTA(6,6)
     $ ,PLOSSA(6,6),PCOSTB(6,6),PPRFTB(6,6),PLOSSB(6,6),WASTE,OPTUSE(6)
      COMMON/ONE/INUM,IRECL,IMSG,NUMPON
      COMMON/TWO/PAREA(6),PDEPTH(6),PWAST(6),CENBTU(6),COSTA(6,6)
     $ ,COSTB(6,6),DRYBTU(6),DRYASH(6),DRYSUL(6),DRYYLD(6),PROBTU(6)
     $ ,PROASH(6),PROSUL(6),PROYLD(6),IWSTAC(6),PQUANT(6)
      INTEGER LANUSE(6,5)
      DATA LANUSE/'    ',' NA',' WA','    ','    ','    ',
     $ 'CROP','TIVE','TER ','WILD',' HIG','OTHE','LAND',' VEG',
     $ 'RECR',' LIF','H US','R US','    ','ETAT','EATI','E   ',
     $ 'E   ','E   ','    ','ION ','ON  ','    ','    ','    '/
      J=OPTUSE(INUM)
      WRITE(6,1)
      WRITE(6,2) INUM
      WRITE(6,3)(LANUSE(J,IJ),IJ=1,5)
      WRITE(6,4)
      DO 5 I=1,6
      WRITE(6,6) (LANUSE(I,J),J=1,5),COSTA(INUM,I)
      WRITE(6,7) (LANUSE(I,J),J=1,5),COSTB(INUM,I)
    5 CONTINUE
      RETURN
    1 FORMAT(/10X,'RECLAMATION COSTS (CLAIM OUTPUT)',/10X,32('*'))
    2 FORMAT(/10X,'POND NUMBER CONSIDERED = ',I2)
    3 FORMAT(/10X,'OPTIMUM LAND USE =',5A4)
    4 FORMAT(/10X,'COSTS FOR THE DIFFERENT LAND USES',/10X,33('*'))
    6 FORMAT(/10X,'LANDUSE = ',5A4,/10X,'COST = ',F8.1,2X,
     $ ' DOLLARS/ACRE',2X'--> WASTE ACCEPTABLE ')
    7 FORMAT(/10X,'LANDUSE = ',5A4,/10X,'COST = ',F8.1,2X,
     $ ' DOLLARS/ACRE',2X,'--> WASTE NOT ACCEPTABLE ')
      END
EOF:
.
```

```
      SUBROUTINE PROUT
      COMMON/THREE/PPRICE(6),PROPRC(6),PCOSTA(6,6),PPRFTA(6,6)
     $ ,PLOSSA(6,6),PCOSTB(6,6),PPRFTB(6,6),PLOSSB(6,6),WASTE,OPTUSE(6)
      COMMON/ONE/INUM,IRECL,IMSG,NUMPON
      INTEGER LANUSE(6,5)
      DATA LANUSE/'    ',' NA',' WA','    ','    ','    ',
     $ 'CROP','TIVE','TER ','WILD',' HIG','OTHE','LAND',' VEG',
     $ 'RECR',' LIF','H US','R US','    ','ETAT','EATI','E   ',
     $ 'E   ','E   ','    ','ION ','ON  ','    ','    ','    '/
      WRITE(6,1)
      WRITE(6,2)INUM
      DO 3 I=1,6
      IF(IRECL.NE.1)GOTO 4
      WRITE(6,5)(LANUSE(I,J),J=1,5)
      GOTO 6
    4 WRITE(6,7)
    6 WRITE(6,8) PPRICE(INUM)
      WRITE(6,9)PROPRC(INUM)
      WRITE(6,10)PCOSTA(INUM,I)
      WRITE(6,11)PPRFTA(INUM,I)
      WRITE(6,12)PLOSSA(INUM,I)
      WRITE(6,13)PCOSTB(INUM,I)
      WRITE(6,11)PPRFTB(INUM,I)
      WRITE(6,12)PLOSSB(INUM,I)
    3 CONTINUE
      IF(IMSG.NE.1) GOTO 16
      WRITE(6,17) WASTE
   16 RETURN
    1 FORMAT(/10X,'PROFITS AND LOSSES FOR THE COMPLETE ',
     $'COAL-FINES OPERATION',/10X,56('*'))
    2 FORMAT(//10X,'OUTPUT FOR POND NUMBER = ',2X,I2)
    5 FORMAT(/10X,'LAND USE CONSIDERED = ',5A4)
    7 FORMAT(/10X,'NO RECLAMATION COSTS CONSIDERED.',/10X,31('*'))
    8 FORMAT(/10X,'PRODUCT SALE PRICE = ',2X,F6.2,'DOLLARS/TON')
    9 FORMAT(/10X,'COST FOR THE PROCESS = ',2X,F6.2,'MILL.DOLLS')
   10 FORMAT(/10X,'TOTAL COST WHEN WASTE IS ACCEPTABLE = ',2X,
     $F7.2,'MILL.DOLS.')
   11 FORMAT(/10X,'TOTAL PROFIT FOR THIS PROCESS(IF ANY) = ',2X,
     $ F7.2,' MILL.DOLS')
   12 FORMAT(/10X'TOTAL LOSS FOR THIS PROCESS (IF ANY) =',2X
     $,F7.2,' MILL.DOLS')
   13 FORMAT(/10X,'TOTAL COST WHEN WASTE IS NOT ACCEPTABLE = ',2X,
     $ F7.2,' MILL.DOLS')
   17 FORMAT(/10X'AMOUNT OF WASTE LEFT AFTER THIS POND HAS BEEN '
     $,'FILLED ',/20X,F8.2,' TONNES.')
      END
EOF:
```

```
      SUBROUTINE TOUT
      COMMON/THREE/PPRICE(6),PROPRC(6),PCOSTA(6,6),PPRFTA(6,6)
     $ ,PLOSSA(6,6),PCOSTB(6,6),PPRFTB(6,6),PLOSSB(6,6),WASTE,OPTUSE(6)
      COMMON/FOUR/TCOSTA(6),TCOSTB(6),TLOSSA(6),TLOSSB(6),
     $TPRFTA(6),TPRFTB(6),NUMFIL
      WRITE(6,1)
    1 FORMAT(10X,'PONDS HANDLED TOGETHER:TOTALS',/,10X,29('*'))
      WRITE(6,2) NUMFIL
      WRITE(6,3) WASTE
 3    FORMAT(/2X,'AMOUNT OF WASTE REMAINING = ',F8.2,'TONS')
    2 FORMAT(2X,'NUMBER OF PONDS FILLED = ',I2)
      DO 10 I = 1,6
      WRITE(6,4) I
      WRITE(6,5) TCOSTA(I)
      WRITE(6,6) TCOSTB(I)
      WRITE(6,7) TLOSSA(I)
      WRITE(6,8) TLOSSB(I)
      WRITE(6,9) TPRFTA(I)
      WRITE(6,11) TPRFTB(I)
 10   CONTINUE
      RETURN
  4   FORMAT(///2X,'LAND USE NUMBER = ',5X,I2)
  5   FORMAT(/2X,'TOTAL COST WHEN WASTE ACCEPTABLE = ',F8.2,'MILL.DOLS'
     $)
  6   FORMAT(/2X,'COST WHEN WASTE NOT ACCEPTABLE = ',F8.2,'MILL.DOLS')
  7   FORMAT(/2X,'LOSSES(IF ANY) WHEN WASTE ACCEPTABLE = ',F8.2,
     $'MILL.DOLS')
  8   FORMAT(/2X,'LOSSES(IF ANY)WHEN WASTE NOT ACCFEPTABLE = ',F8.2,
     $'MILL.DOLS')
  9   FORMAT(/2X,'PROFITS(IF ANY) WHEN WASTE ACCEPTABLE = ',F8.2,
     $ 'MILL.DOLS')
 11   FORMAT(/2X,'PROFITS(IF ANY)WHEN WASTE NOT ACCEPTABLE = ',F8.2,
     $ 'MILL.DOLS')
      END
EOF:
```

```
.FINAL
COPY FINAL TEXT B = = A ( UNPACK REPL
COPY PREAD TEXT B = = A ( UNPACK REPL
COPY NREAD TEXT B = = A ( UNPACK REPL
COPY CALC TEXT B = = A ( UNPACK REPL
COPY PROUT TEXT B = = A ( UNPACK REPL
COPY CLOUT TEXT B = = A ( UNPACK REPL
COPY TOUT TEXT B = = A ( UNPACK REPL
FI 05 TERM
FI 06 TERM
LOAD FINAL PREAD NREAD CALC PROUT CLOUT TOUT ( START
EXECUTION BEGINS...
 ENTER NUMBER OF PONDS
?
.1
 DO YOU WANT TO INPUT SALE PRICE?(YES OR NO)
.NO
 ENTER BTU OF PRODUCT FROM THE PROCESS
?
.12000
 INPUT FOR POND NUMBER =      1
 ENTER OPTIMUM LAND USE NUMBER.
 1.CROPLAND
 2.NATIVE VEGETATION.
 3.WATER RECREATION.
 4.WILD LIFE
 5.HIGH USE
 6.OTHER USE
?
.3
 ENTER COSTS FOR THE SIX LAND - USES FOR
 RECLAMATION(IN ORDER),FOR THE CASE WHEN THE
 WASTE CAN BE PUT BACK IN THE POND
?
.6000,5000,3000,5000,5900,0
 ENTER COSTS FOR THE SIX LAND-USES FOR
 RECLAMATION (IN ORDER),FOR THE CASE WHEN THE
 WASTE CAN NOT BE PUT BACK IN THE POND
?
.7000,6000,4000,6000,6900,0
 ENTER THE COST FOR THE PROCESS IN CENTS PER MILLION BTU
?
.120
 ENTER THE AREA OF THE POND(ACRES)
?
.23.3
 ENTER THE AVERAGE DEPTH OF THE POND
 (IN FEET)
?
.100
 ENTER THE DRY (INPUT) COAL PARAMETERS : -
 1.BTU IN BTU/LB
 2. ASH IN %
 3.SUL IN %
 4.YLD IN %
?
.11400,14.4,2.5,59
 ENTER PRODUCT COAL PARAMETERS IN THE GIVEN ORDER:
 1.BTU IN BTU/LB
 2.ASH IN %
 3.SUL IN %
 4.YIELD IN %
?
.13500,8.8,1.7,65
 ENTER IF THE WASTE IS ACCEPTABLE OR NOT.
 ENTER YES OR NO
.YES
```

```
RECLAMATION COSTS (CLAIM OUTPUT)
********************************

POND NUMBER CONSIDERED =  1

OPTIMUM LAND USE =  WATER RECREATION

COSTS FOR THE DIFFERENT LAND USES
*********************************

LANDUSE =      CROPLAND
COST =   6000.0   DOLLARS/ACRE  --> WASTE ACCEPTABLE

LANDUSE =      CROPLAND
COST =   7000.0   DOLLARS/ACRE  --> WASTE NOT ACCEPTABLE

LANDUSE =    NATIVE VEGETATION
COST =   5000.0   DOLLARS/ACRE  --> WASTE ACCEPTABLE

LANDUSE =    NATIVE VEGETATION
COST =   6000.0   DOLLARS/ACRE  --> WASTE NOT ACCEPTABLE

LANDUSE =    WATER RECREATION
COST =   3000.0   DOLLARS/ACRE  --> WASTE ACCEPTABLE

LANDUSE =    WATER RECREATION
COST =   4000.0   DOLLARS/ACRE  --> WASTE NOT ACCEPTABLE

LANDUSE =      WILD LIFE
COST =   5000.0   DOLLARS/ACRE  --> WASTE ACCEPTABLE

LANDUSE =      WILD LIFE
COST =   6000.0   DOLLARS/ACRE  --> WASTE NOT ACCEPTABLE

LANDUSE =       HIGH USE
COST =   5900.0   DOLLARS/ACRE  --> WASTE ACCEPTABLE

LANDUSE =       HIGH USE
COST =   6900.0   DOLLARS/ACRE  --> WASTE NOT ACCEPTABLE

LANDUSE =      OTHER USE
COST =      0.0   DOLLARS/ACRE  --> WASTE ACCEPTABLE

LANDUSE =      OTHER USE
COST =      0.0   DOLLARS/ACRE  --> WASTE NOT ACCEPTABLE
```

PROFITS AND LOSSES FOR THE COMPLETE COAL-FINES OPERATION
****

OUTPUT FOR POND NUMBER = 1

LAND USE CONSIDERED = CROPLAND

PRODUCT SALE PRICE = 33.70DOLLARS/TON

COST FOR THE PROCESS = 34.76MILL.DOLLS

TOTAL COST WHEN WASTE IS ACCEPTABLE = 33.56MILL.DOLS.

TOTAL PROFIT FOR THIS PROCESS(IF ANY) = 1.20 MILL.DOLS

TOTAL LOSS FOR THIS PROCESS (IF ANY) = 0.0 MILL.DOLS

TOTAL COST WHEN WASTE IS NOT ACCEPTABLE = 33.58 MILL.DOLS

TOTAL PROFIT FOR THIS PROCESS(IF ANY) = 1.18 MILL.DOLS

TOTAL LOSS FOR THIS PROCESS (IF ANY) = 0.0 MILL.DOLS

LAND USE CONSIDERED = NATIVE VEGETATION

PRODUCT SALE PRICE = 33.70DOLLARS/TON

COST FOR THE PROCESS = 34.76MILL.DOLLS

TOTAL COST WHEN WASTE IS ACCEPTABLE = 33.54MILL.DOLS.

TOTAL PROFIT FOR THIS PROCESS(IF ANY) = 1.22 MILL.DOLS

TOTAL LOSS FOR THIS PROCESS (IF ANY) = 0.0 MILL.DOLS

TOTAL COST WHEN WASTE IS NOT ACCEPTABLE = 33.56 MILL.DOLS

TOTAL PROFIT FOR THIS PROCESS(IF ANY) = 1.20 MILL.DOLS

TOTAL LOSS FOR THIS PROCESS (IF ANY) = 0.0 MILL.DOLS

LAND USE CONSIDERED = WATER RECREATION

PRODUCT SALE PRICE = 33.70DOLLARS/TON

COST FOR THE PROCESS = 34.76MILL.DOLLS

TOTAL COST WHEN WASTE IS ACCEPTABLE = 33.49MILL.DOLS.

TOTAL PROFIT FOR THIS PROCESS(IF ANY) = 1.27 MILL.DOLS

TOTAL LOSS FOR THIS PROCESS (IF ANY) = 0.0 MILL.DOLS

TOTAL COST WHEN WASTE IS NOT ACCEPTABLE = 33.51 MILL.DOLS

TOTAL PROFIT FOR THIS PROCESS(IF ANY) = 1.25 MILL.DOLS

TOTAL LOSS FOR THIS PROCESS (IF ANY) = 0.0 MILL.DOLS

LAND USE CONSIDERED = WILD LIFE

PRODUCT SALE PRICE = 33.70DOLLARS/TON

COST FOR THE PROCESS = 34.76MILL.DOLLS

TOTAL COST WHEN WASTE IS ACCEPTABLE = 33.54MILL.DOLS.

TOTAL PROFIT FOR THIS PROCESS(IF ANY) = 1.22 MILL.DOLS

TOTAL LOSS FOR THIS PROCESS (IF ANY) = 0.0 MILL.DOLS

TOTAL COST WHEN WASTE IS NOT ACCEPTABLE = 33.56 MILL.DOLS

TOTAL PROFIT FOR THIS PROCESS(IF ANY) = 1.20 MILL.DOLS

TOTAL LOSS FOR THIS PROCESS (IF ANY) = 0.0 MILL.DOLS

LAND USE CONSIDERED = HIGH USE

PRODUCT SALE PRICE = 33.70DOLLARS/TON

COST FOR THE PROCESS = 34.76MILL.DOLLS

TOTAL COST WHEN WASTE IS ACCEPTABLE = 33.56MILL.DOLS.

TOTAL PROFIT FOR THIS PROCESS(IF ANY) = 1.20 MILL.DOLS

TOTAL LOSS FOR THIS PROCESS (IF ANY) = 0.0 MILL.DOLS

TOTAL COST WHEN WASTE IS NOT ACCEPTABLE = 33.58 MILL.DOLS

TOTAL PROFIT FOR THIS PROCESS(IF ANY) = 1.18 MILL.DOLS

TOTAL LOSS FOR THIS PROCESS (IF ANY) = 0.0 MILL.DOLS

LAND USE CONSIDERED = OTHER USE

PRODUCT SALE PRICE = 33.70DOLLARS/TON

COST FOR THE PROCESS = 34.76MILL.DOLLS

TOTAL COST WHEN WASTE IS ACCEPTABLE = 33.42MILL.DOLS.

TOTAL PROFIT FOR THIS PROCESS(IF ANY) = 1.34 MILL.DOLS

TOTAL LOSS FOR THIS PROCESS (IF ANY) = 0.0 MILL.DOLS

TOTAL COST WHEN WASTE IS NOT ACCEPTABLE = 33.42 MILL.DOLS

TOTAL PROFIT FOR THIS PROCESS(IF ANY) = 1.34 MILL.DOLS

TOTAL LOSS FOR THIS PROCESS (IF ANY) = 0.0 MILL.DOLS

R;

APPENDIX D

TABLE 2. Experiment operating parameters; fines, agglomerate and waste quality; and fines upgrading measures.

		Experiment No.					
		5(g)	6	7	8	9	10
Mixing time, min.	High speed	10.1	10.0	9.9	10.1	20.2	19.2
	Growth	13.7	13.6	13.6	13.7	27.5	26.2
Agglomeration temp., °C		80.4	82.3	79.8	81.3	79.1	80.0
Water-coal ratio by wt.		7.9	7.5	6.9	8.1	5.5	7.2
Oil-coal ratio by wt.		0.000	0.032	0.012	0.082	0.011	0.041
Feed	HHV, Btu/lb. (a)(b)	10922	10194	10238	9457	9208	9497
	% Ash	16.20	17.71	18.32	25.69	27.58	25.53
	% Sulfur (c)	3.459	3.808	3.962	2.997	2.892	3.655
	% Moisture	20.21	19.05	19.73	21.40	20.26	23.74
Agglomerate	HHV, Btu/lb.	11485	11092	10800	11197	11045	11359
	% Ash	10.68	11.74	14.64	15.92	14.98	14.14
	% Sulfur	3.063	3.439	3.680	2.902	2.545	2.627
	% Moisture (d)	---	---	---	34.49	36.17	37.62
	% Moisture (e)	31.10	30.05	27.48	21.83	28.19	23.71
Waste	HHV, Btu/lb.	7595	8336	6477	5192	5612	5901
	% Ash	34.46	33.25	43.03	57.37	53.42	51.01
	% Sulfur	3.114	2.987	4.439	3.496	2.408	3.272
% Ash reduction		34.60	33.71	20.09	38.00	45.70	44.61
% Sulfur reduction		6.69	11.45	7.12	3.17	12.00	28.13
% Yield	by wt.	73.30	78.83	92.67	77.33	69.38	58.44
	ash balance	76.79	72.25	87.04	76.54	67.22	50.18
	Btu	80.75	74.01	89.80	77.19	78.81	55.29
HHV ratio (f)		1.052	1.088	1.055	1.184	1.200	1.196
Experiment time, hrs.		0.87	0.92	1.17	1.06	1.38	1.31

TABLE 2. (cont.)

		Experiment No.					
		11	13(g)	14	15	17	18
Mixing time, min.	High speed	9.8	5.8	10.4	11.4	9.7	18.9
	Growth	13.3	7.9	14.1	15.6	13.3	25.8
Agglomeration temp., °C		80.7	79.4	80.4	80.0	70.7	78.9
Water-coal ratio by wt.		5.8	12.0	13.1	5.5	5.6	6.1
Oil-coal ratio by wt.		0.006	0.026	0.011	0.020	0.012	0.009
Feed	HHV, Btu/lb. (a)(b)	7499	12437	12494	12635	10789	10464
	% Ash	41.31	9.38	7.61	7.90	16.24	16.09
	% Sulfur (c)	1.950	1.236	1.089	1.214	3.546	3.533
	% Moisture	17.68	22.27	22.54	17.55	20.23	22.58
Agglomerate	HHV, Btu/lb.	9979	13066	12665	13141	11423	11030
	% Ash	24.00	6.17	6.55	5.90	12.53	12.75
	% Sulfur	1.532	1.179	1.073	1.151	3.338	3.133
	% Moisture (d)	33.45	36.85	36.01	36.90	36.37	37.17
	% Moisture (e)	---	26.21	23.11	23.23	27.93	33.88
Waste	HHV, Btu/lb.	4451	10042	10695	10511	8670	8259
	% Ash	61.90	26.30	18.97	22.18	32.21	32.64
	% Sulfur	1.524	1.124	1.014	1.194	4.231	3.756
% Ash reduction		41.90	34.22	13.93	25.32	22.84	20.76
% Sulfur reduction		21.44	4.61	1.47	5.47	5.87	11.32
% Yield	by wt.	---	86.75	67.84	95.25	75.18	77.85
	ash balance	54.33	84.05	91.47	87.71	81.10	83.21
	Btu	71.19	84.71	91.16	88.45	84.05	86.24
HHV ratio		1.331	1.051	1.014	1.040	1.059	1.054
Experiment time, hrs.		1.09	0.67	0.97	0.86	0.87	1.45

TABLE 2. (cont.)

		Experiment No.					
		19	20	21	22	23	24
Mixing time, min.	High speed	9.8	18.9	18.7	9.9	18.9	10.0
	Growth	13.3	25.7	25.6	13.5	25.7	13.6
Agglomeration temp., °C		53.1	79.5	53.1	52.1	51.9	79.7
Water-coal ratio by wt.		5.9	5.9	5.6	6.5	6.0	7.3
Oil-coal ratio by wt.		0.007	0.028	0.030	0.029	0.009	0.091
Feed	HHV, Btu/lb. (a)(b)	10219	10431	10069	10186	10645	10601
	% Ash	18.67	18.31	18.88	17.51	16.24	16.37
	% Sulfur (c)	4.021	3.757	3.731	3.727	3.441	3.732
	% Moisture	19.80	22.69	13.79	18.30	20.31	17.58
Agglomerate	HHV, Btu/lb.	11156	11256	11053	11264	11469	11751
	% Ash	14.05	13.79	12.08	10.95	11.47	12.19
	% Sulfur	3.305	3.316	3.141	2.977	3.031	3.119
	% Moisture (d)	38.33	35.95	39.04	39.64	40.59	33.40
	% Moisture (e)	30.79	---	27.84	27.71	26.37	25.57
Waste	HHV, Btu/lb.	8435	8044	8165	8240	9099	8950
	% Ash	32.30	38.59	32.94	31.16	27.68	34.21
	% Sulfur	4.015	4.778	3.629	3.658	3.141	3.927
% Ash reduction		24.75	24.69	36.02	37.46	29.37	25.53
% Sulfur reduction		6.80	11.74	17.50	20.12	11.92	16.43
% Yield	by wt.	67.57	---	68.18	68.31	79.49	78.66
	ash balance	74.68	81.77	67.40	67.54	70.57	81.02
	Btu	80.49	83.76	69.80	70.67	74.74	76.61
HHV ratio		1.092	1.077	1.098	1.106	1.077	1.108
Experiment time, hrs.		0.90	1.30	1.59	0.94	1.61	0.97

TABLE 2. (cont.)

		Experiment No.	
		25	26
Mixing time, min.	High speed	10.2	8.5
	Growth	13.9	11.6
Agglomeration temp., °C		80.6	80.7
Water-coal ratio by wt.		9.9	13.9
Oil-coal ratio by wt.		0.056	0.021
Feed	HHV, Btu/lb. (a)(b)	10764	10443
	% Ash	16.34	17.11
	% Sulfur (c)	3.562	3.626
	% Moisture	18.40	18.08
Agglomerate	HHV, Btu/lb.	11908	11487
	% Ash	11.33	11.20
	% Sulfur	3.105	2.976
	% Moisture (d)	35.74	38.58
	% Moisture (e)	23.88	26.78
Waste	HHV, Btu/lb.	8632	9034
	% Ash	33.61	29.62
	% Sulfur	4.064	3.861
% Ash reduction		30.66	34.54
% Sulfur reduction		12.83	17.93
% Yield	by wt.	84.91	69.05
	ash balance	77.51	67.92
	Btu	77.70	71.75
HHV ratio		1.106	1.100
Experiment time, hrs.		1.02	0.96

a) 2.3244 Btu/lb = KJ/kg.

b) This and all other reported quality and quality improvement values are on a dry coal basis.

c) Total sulfur.

d) Sample.

e) Taken at least 24 hrs. after experiment and used for mass balance determination.

f) (HHV of agglomerates)/(HHV of feed coal).

g) Experiments 1-4, 12 and 16 deleted because they were trial experiments or system was not operating properly.

APPENDIX E

Table E-1
Continuous Run By Passing the Wash Tank
Randolph County Coal (All No. 6)

Washing Step

Coal Feed Rate (lb/hr) (dry)	335.8
Water:Coal	11.92
U.R.F.	2.35
Run Time (hrs)	3.0
Initial Screen Size (mesh)	14

Agglomeration Step

Coal Feed Rate (lb/hr) (dry)	103.9
Water:Coal	9.72
Oil:Coal	.033
Run Time (hrs)	3.0
Temperature (%)	80
Rapid Mix Tank Volume (gal)	21.4
Rapid Mix Detention Time (min)	10.6
Rapid Mix Impeller Tip Speed (ft/min)	1535
Growth Tank Volume (gal)	30.1
Growth Tank Retention Time (min)	14.9
Growth Tank Impeller Tip (ft/min)	142
Dewatering Screen Size (mesh)	50

	Original Feed			Wash Product			Agglomeration Product		
	Btu	Ash	S	Btu	Ash	S	Btu	Ash	S
1	8246.1	34.96	4.636	10,611	19.42	3.825	10,977	15.53	3.441
2	7597.4	37.65	5.506	10,276	20.34	4.027	11,348	13.69	3.402
3	7594.6	38.82	4.541	10,183	20.14	3.927	11,232	14.86	3.495
4	8175.6	30.24	4.446	10,487	18.84	3.695	11,612	12.95	3.342
5	7631.0	38.21	4.860	10,457	19.36	3.755	--	--	--
6	7780.3	36.96	4.437	10,306	20.33	3.859	--	--	--
7	8143.4	34.84	4.359	10,376	19.72	3.853	--	--	--
8	7802.8	36.43	4.747	10,435	19.21	3.847	--	--	--
9	8081.0	34.07	4.831	10,454	18.33	3.687	--	--	--
10	7783.4	36.73	--	10,487	19.08	3.896	--	--	--

$$\frac{\text{Agglomeration Product}}{\text{Slurry Pond}} \times 100 = 36.55$$

$$\frac{\text{(Agglomeration Product) + (Oversize)}}{\text{Slurry Feed}} \times 100 = 50.60$$

Table E-2

Continuous Run By Passing the Wash Tank

Jackson County Coal (Illinois No. 6)

Washing Step

Coal Feed Rate (lb/hr) (dry)	342.55
Water:Coal	11.69
U.R.F.	2.45
Run Time (hrs)	4.0
Initial Screen Size (mesh)	14
Dewatering Screen Size (mesh)	70

Agglomeration Step

Coal Feed Rate (lb/hr) (dry)	149.5
Water:Coal	6.76
Oil:Coal	.013
Run Time (hrs)	2.75
Temperature (°C)	80
Rapid Mix Tank Volume (gal)	21.4
Rapid Mix Retention Time (min)	10.6
Rapid Mix Impeller Tip Speed (ft/min)	1535
Growth Tank Volume (gal)	30.1
Growth Tank Retention Time (min)	14.9
Growth Tank Impeller Tip Speed (ft/min)	142
Dewatering Screen Size (mesh)	50

	Original			Wash Product			Agglomeration Product		
	Btu	Ash	S	Btu	Ash	S	Btu	Ash	S
1	9833.5	24.21	1.442	10,248	11.20	1.305	11,662	8.42	1.489
2	9754.0	24.71	1.348	10,812	12.07	1.353	11,974	6.04	1.342
3	10,075	22.26	1,358	10,747	10.80	1.307	11,836	7.64	1.331
4	9780.7	23.85	1.288	10,563	13.03	1.422	11,694	8.99	1.316
5	9846.4	23.38	1.466	10,964	11.09	1.342	--	--	--
6	9015.8	27.75	1.435	10,740	13.10	1.375	--	--	--
7	9517.5	25.52	1.332	10,685	12.48	1.317	--	--	--
8	9359.6	25.25	1.292	10,720	12.11	1.370	--	--	--
9	9684.6	23.43	1.393	10,944	10.27	1.482	--	--	--
10	9734.5	23.77	1.202	10,979	11.67	1.300	--	--	--
11	9357.3	25.57	1.364	10,851	11.33	1.310	--	--	--
12	9772.8	23.78	1.425	11,088	10.95	1.387	--	--	--

$$\frac{\text{Agglomeration Product}}{\text{Slurry Pond}} \times 100 = 15.93$$

$$\frac{(\text{Agglomeration Product}) + (\text{Oversize})}{\text{Slurry Feed}} \times 100 = 67.53$$

Table E-3

Continuous Run Utilizing the Wash Tank

Jackson County Coal (Illinois No. 6)

Washing Step

Coal Feed Rate (lb/hr) (dry)	271.2
Water:Coal	14.80
U.R.F.	2.91
Run Time (hrs)	4.0
Initial Screen Size (mesh)	14
Wash Tank Operating Capacity (gal)	70
Impeller Tip Speed (ft/sec)	1150
Retention Time (min)	8.73
Dewatering Screen Size (mesh)	70

Agglomeration Step

Coal Feed Rate (lb/hr) (dry)	116.6
Water:Coal	8.67
Oil:Coal	.036
Run Time (hrs)	3.0
Temperature (°C)	80
Rapid Mix Tank Volume (gal)	21.4
Rapid Mix Retention Time (min)	10.6
Rapid Mix Impeller Tip Speed (ft/min)	1535
Growth Tank Volume (gal)	30.1
Growth Tank Retention Time (min)	14.9
Growth Tank Impeller Tip Speed (ft/min)	142
Dewatering Screen Size (mesh)	50

	Original			Wash Product			Agglomeration Product		
	Btu	Ash	S	Btu	Ash	S	Btu	Ash	S
1	9814.4	26.92	1.138	11,971	12.68	1.204	12,814	8.17	1.308
2	10,052	25.16	1.251	12,534	9.75	1.253	12,935	8.47	1.231
3	10,148	25.25	1.204	12,387	9.85	1.102	13,048	7.22	1.197
4	9105.1	31.92	1.158	11,880	12.80	1.214	13,014	7.43	1.237
5	9571.8	28.53	1.216	12,171	11.62	1.131	13,068	6.94	1.285
6	9778.5	26.78	1.242	12,227	11.61	1.133	13,025	6.94	1.230
7	8903.7	32.96	1.361	12,070	12.74	1.217	--	--	--
8	9678.1	28.37	1.204	12,242	10.73	1.090	--	--	--
9	10,215	24.01	1.273	12,118	9.78	1.092	--	--	--
10	10,400	23.09	1.197	12,337	11.52	1.026	--	--	--
11	10,303	24.56	1.254	12,440	9.79	1.118	--	--	--
12	10,527	22.31	1.232	12,226	10.22	1.082	--	--	--

$$\frac{\text{Agglomeration Product}}{\text{Slurry Pond}} \times 100 = 15.31$$

$$\frac{(\text{Agglomeration Product}) + (\text{Oversize})}{\text{Slurry Feed}} \times 100 = 65.67$$

Table E-4
Continuous Run Utilizing the Wash Tank
Randolph County Coal (Illinois No. 6)

Washing Step

Coal Feed Rate (lb/hr) (dry)	251.9
Water:Coal	15.89
U.R.F.	2.31
Run Time (hrs)	3.33
Initial Screen Size (mesh)	14
Wash Tank Operating Capacity (gal)	70
Impeller Tip Speed (ft/sec)	1150
Retention Time (min)	8.75
Dewatering Screen Size (mesh)	70

Agglomeration Step

Coal Feed Rate (lb/hr)	164
Water:Coal	5.74
Oil:Coal	.021
Run Time (hrs)	2.67
Temperature (°C)	80
Rapid Mix Tank Volume (gal)	21.4
Rapid Mix Retention Time (min)	11.28
Rapid Mix Impeller Tip Speed (ft/min)	1535
Growth Tank Volume (gal)	30.1
Growth Tank Retention Time (min)	15.9
Growth Tank Impeller Tip Speed (ft/min)	142
Dewatering Screen Size (mesh)	50

	Original			Wash Product			Agglomeration Product		
	Btu	Ash	S	Btu	Ash	S	Btu	Ash	S
1	7735.6	35.09	4.736	10,895	16.51	3.363	11,984	10.67	2.424
2	8231	31.21	4.134	10,386	19.99	3.836	11,983	10.60	2.609
3	8140.8	32.16	4.146	11.102	15.07	3.122	11,545	12.69	3.028
4	8036.5	33.40	3.669	9801.2	24.25	4.254	11,106	15.46	3.526
5	8187	33.07	3.921	10,117	22.32	4.106	11,325	13.28	3.584
6	8082.8	32.72	3.665	11,331	13.96	3.247	--	--	--
7	7758.2	36.10	4.179	10,819	15.72	3.567	--	--	--
8	7671.1	35.97	4.393	10,878	16.68	3.659	--	--	--
9	8478.3	36.21	3.978	10,823	17.10	3,617	--	--	--

$$\frac{\text{Agglomeration Product}}{\text{Slurry Pond}} \times 100 = 35.73$$

$$\frac{\text{(Agglomeration Product)} + \text{(Oversize)}}{\text{Slurry Feed}} \times 100 = 48.11$$