# AN EVALUATION OF SEPARATION METHODS FOR THE SELECTIVE COAGULATION OF ULTRAFINE COAL

by

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## (ABSTRACT)

A novel technique for selectively coagulating and separating coal from dispersed mineral matter has been developed at Virginia Tech. The process, which is known as *Selective Hydrophobic Coagulation* (SHC), differs from oil agglomeration, shear or polymer flocculation, and electrolytic coagulation processes in that it does not require reagents or additives to induce the formation of coagula. In most cases, simple pH control is all that is required to (i) induce the coagulation of coal particles and (ii) effectively disperse particles of mineral matter. If the coal is oxidized, a small dosage of reagents may be used to enhance the coagulation process.

During the SHC development, it was discovered that the hydrophobic coagula were very difficult to separate from dispersed mineral matter due to their very small size and their susceptibility to breakage. Using the SHC technique, an evaluation of new methods for coagula recovery was conducted. In this effort, several methods for improving the separation of the coal coagula from dispersed mineral matter were examined. These included lamella thickening, centrifugal sedimentation, vacuum filtration, drum screening, and froth flotation. Each separation method was optimized using statistically-designed test matrices to determined the best separation method based on overall process performance. The thickener was found to be the best method for separating hydrophobic coagula from dispersed mineral matter based on overall process performance (e.g., recovery and grade), unit capacity, and engineering feasibility. Further testing of the thickener separation unit was conducted in an attempt to improve the process performance and the unit throughput.

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# Chapter 1 Introduction

## 1.1 Ultrafine Coal Processing

The need for suitable ultrafine coal cleaning methods has arisen from the need to meet environmental regulations and the feasibility of superclean (< 2% ash) coal as an alternative liquid-fuel source. The fine grinding of run-of-mine coal increases the liberation of impurities, increasing the potential for ash and sulphur rejection. While the liberation size of the impurities is a characteristic of the coal seam, most U.S. coals require grinding to an ultrafine (< 10 microns) particle size to achieve pyrite liberation (Kneller and Maxwell, 1985; Attia, 1985). If processed effectively, superclean and ultraclean (< 0.8% ash) coal could be formulated into high-quality fuels suitable as replacements for oil and gas applications. The effective processing of ultrafine coal would also reduce the need for scrubbers while improving power plant performance.

The difficulties in treating ultrafine particles are due mainly to their small mass, their increased specific surface area, and their high surface energy (Fuerstenau, 1980). Normal coal cleaning methods fail when treating ultrafine particles by producing low separation efficiencies and/or low throughput. When processed, the small mass of the ultrafine particles causes them to become entrained in the liquid medium of the process. For flotation methods, this causes low bubble-particle collision frequency (reduced recovery) and high hydraulic entrainment (reduced ash rejection). The increase in specific surface area of the ultrafine particles increases the required reagent consumption for processing. The high surface energies of the ultrafine particles causes the preferential adsorption of the reagents onto them, while the coarser particles may not be adequately reagentized. This causes a decrease in the recovery of coarser particles. The high surface energies associated with the ultrafine particles also cause difficulty in the selectivity between the coal and the mineral matter. As the particle size is reduced the differences between the coal and mineral matter surface properties decrease, reducing the selectivity of a surface-chemical separation process.

The ultrafine particle processing methods developed over the last few decades have focused on particle surface-chemical properties and their differences. The processes increase the apparent size of the valuable particles through agglomeration, flocculation, or coagulation. The processes also attempt to minimize mineral matter entrapment while creating sufficient aggregate strength to permit the use of separation techniques such as flotation, sedimentation, or screen separation. The surface chemistry of fine coal is advantageous for these aggregate-forming type processes, in that the coal macerals are typically hydrophobic while the mineral matter is hydrophilic.

### *a) Oil Agglomeration*

Oil agglomeration preferentially wets hydrophobic coal particles in an aqueous suspension with a collecting liquid (typically an oil or a low molecular weight hydrocarbon), forming aggregates of coal particles. The collecting liquid is the bridging mechanism between the coal particles while the hydrophilic mineral matter remains dispersed in the aqueous suspension. The main factors behind the oil agglomeration process are i) the free energy relationships at the liquid-liquid-solid interface, ii) the amount of collecting liquid used in relation to the solids content, and iii) the type and intensity of mixing employed.

Higher rank coals are more hydrophobic than lower rank or oxidized coals, which have more hydrophilic surfaces. Surface conditioning agents such as long-chain surfactants may be used to improve the hydrophobicity of these coals (Venkatadri and Wheelock, 1988). The use of heavier oils as collecting liquid has also been shown to increase the wettability of these coals, increasing the effectiveness of the oil agglomeration process (Robbins et al., 1992).

The aggregate structures formed using the oil agglomeration process depend on the amount of collecting liquid used. The use of coal particles less than 0.5 mm and intense agitation produces the following aggregate structures. Low collecting liquid dosages of 1/2-5% by weight of the coal (low oil agglomeration) form unconsolidated flocs with pendular bridges between the coal particles. These flocs are two-dimensional, loosely packed, less than 1 mm in diameter, and tend to trap hydrophilic mineral matter and water. With larger dosages of collecting liquid, 5-15% by weight of the coal, the number of collecting liquid junctions increases. Funicular to capillary bridges are formed, creating three-dimensional flocs from 1 to several mm in diameter. Finally, in the capillary wetting region, 15-20% collecting liquid by weight of the coal, compact spherical pellets are formed with the voids being filled with collecting liquid. The entrapment of mineral matter and water is minimal at the higher collecting liquid dosages, providing the best ash rejection and dewatering characteristics (Capes and Germain, 1982).

Intense initial mixing in the oil agglomeration process disperses the emulsified collecting liquid and the ultrafine particles. After dispersion, the mixing intensity is reduced to allow agglomeration. Slow speed mixing produces larger, weaker agglomerates while higher speed mixing allows the formation of smaller, stronger agglomerates (Rao, 1988). The agglomerate size depends on the separation method employed, be it flotation, sedimentation, or screen separation.

The oil agglomeration process is able to produce ultraclean coal using staged agglomeration. The main drawback of the process is the high collecting liquid consumption. To decrease the high cost of the collecting liquid several processes have been developed which recycle the collecting liquid, such as the Otisca T-process. While these recovery processes work well, there are still high capital and operational costs. Another method to reduce the collecting liquid consumption has been to focus on processing techniques in the low oil agglomeration range (< 5% collecting liquid by weight of coal), in which pyrite rejection is favored. Unfortunately, the low oil agglomeration method does not handle well on screens and additional drying is required to decrease the moisture levels of the aggregates (Capes et al., 1988).

### b) Selective Flocculation

Selective flocculation bridges the desired particles together in an aqueous solution of two or more solid constituents using soluble macromolecules such as starches and polyacrylamides (flocculants). In coal slurries, the coal particles flocculate due to hydrophobic interactions between the polymeric chains and the coal surface while the hydrophilic mineral matter remains dispersed. The success of the selective flocculation process depends upon the appropriate application of surface-chemical principles. Selective xanthate-containing dispersants for coal have been developed which increase the ultrafine pyrite rejection of the flocculation process (Attia, 1985).

Flocculation produces flocs which are typically larger and contain a more loose structure than coagula, allowing hydrophilic mineral matter and water to become entrapped within the flocs. This entrapment increases both the ash and moisture contents of the flocs. While the flocs are larger than coagula, they are also significantly stronger than coagula produced using inorganic coagulants (Ray and Hogg, 1986). As the dosage of flocculant is increased, floc breakage decreases, creating stronger, more tightly packed flocs. Unfortunately these tightly packed flocs also suffer from the entrapment of mineral matter and water.

Flocculation of ultrafine particles (3-6 microns) requires increased flocculant dosages, forming flocs only 10-15 microns in size (Attia et al., 1990). This size difference between the flocs and the dispersed mineral matter makes the separation process difficult. Floc separation methods include flotation, sedimentation, and screen separation. Screening requires strong flocs, able to withstand breakup, which increases the entrapped mineral matter and water. Flotation requires an understanding of the interactions between the flocculant and the flotation reagent. While these problems must be overcome, the main drawbacks to the flocculation process are low selectivity due to the entrapment of hydrophilic mineral matter and high flocculant consumption when treating ultrafine particles. The incorporation of treating separate size fractions, precleaning steps, and multiple flocculation stages has produced results of less than 3% ash, showing that it is a feasible process for ultrafine coal cleaning (Attia et al., 1990).

### *c) Selective Coagulation*

Selective coagulation agglomerates dispersed hydrophobic coal particles without an agglomerant, while hydrophilic mineral matter remains dispersed. There are no bridging mechanisms involved in coagulation, unlike oil agglomeration or flocculation. Selective coagulation occurs because of the differences in surface potentials between the coal particles and the mineral matter particles. When the attractive force (hydrophobic interaction force) between particles is greater than the repulsive force (electrostatic force), coagulation can occur without additional external energy. With the existence of a repulsive force larger than the attractive force, external energy (in the form of mixing/kinetic energy) may be introduced to overcome the repulsive force and induce coagulation.

For selective coagulation to occur, the chemistry of the suspension must be adjusted with appropriate pH modifiers and/or electrolytes so that the component particles have the same surface-charge-sign. The selectivity of coagulation is based on the differences in the surface potentials of the component particles. In addition to pH modifiers and/or electrolytes, control of the surface potentials can be done with dispersants and chelating agents.

Several laboratory studies conducted at Virginia Tech (Honaker, 1988; Honaker 1992) have shown that selective coagulation of coal produces superclean and ultraclean coal products with high recovery values. These studies have also shown the simplicity of the selective coagulation of ultrafine coal. They reveal that high rank, unoxidized coals usually have sufficient hydrophobic force to naturally induce coagulation while oxidized coals and low rank coals may require treatment with a small amount of hydrocarbon oil (well below oil agglomeration dosages) to enhance their hydrophobicity. The studies also demonstrate the cost effectiveness of the selective coagulation process due to the reduced reagent requirements.

## 1.2 Research Objectives

One of the major advantages of selective coagulation is that it does not require the use of agglomerating agents such as hydrocarbon oils or flocculants. However, the coagula formed by selective coagulation are relatively weaker than those formed when agglomerating agents are used. As a result, attention must be given to the proper selection and design of systems to recover these coagula. In Chapter 2, five different continuous flow devices were evaluated to determine the most effective methodology for the separation of dispersed mineral matter from coagulated coal. These included (i) a lamella thickener, (ii) a centrifuge, (iii) a vacuum drum filter, (iv) a froth flotation column, and (v) a drum screen. Each unit was tested using bench-scale continuous units at throughputs up to 0.5-1.0 lb/hr. These separators were tested at the optimum reagent conditions established from batch tests carried out on (i) a high ash, low sulphur Elkhorn No. 3 seam coal sample and (ii) a high sulphur Pittsburgh No. 8 seam coal sample.

After determining the most effective method of separating the dispersed mineral matter from coagulated coal, the best possible separator was selected and tested in greater detail using the Elkhorn No. 3 seam coal sample (see Chapter 3). This selection was based on overall process performance (e.g., recovery and grade), unit capacity, and engineering feasibility. In making this selection, the results of the work conducted in the DOE project (DE-AC22-90PC90174) were also considered.

# Chapter 2 Advanced Separation Methods

## 2.1 Introduction

One of the major advantages of the SHC process is that it does not require the use of agglomerating agents such as hydrocarbon oils or flocculants. However, the coagula formed by the SHC process are relatively weaker than those formed when agglomerating agents are used. As a result, attention must be given to the proper selection and design of systems to recover these coagula. In the present work, five different continuous flow devices are being evaluated to determine the most effective methodology for the separation of dispersed mineral matter from coagulated coal. These include (i) a froth flotation column, (ii) a lamella thickener, (iii) a vacuum drum filter, (iv) a centrifuge, and (v) a rotating drum screen. Each unit was tested using bench-scale continuous units at throughputs up to 0.5-1.0 lb/hr. These separators were tested at the optimum reagent conditions established from batch tests carried out on each of the two base coals (Elkhorn No. 3 and Pittsburgh No. 8 seam coals).

## 2.2 Sample Acquisition

The process development test work was conducted using run-of-mine coal samples from the Pittsburgh No. 8 and Elkhorn No. 3 coal seams. The Pittsburgh No. 8 sample was obtained from a Consol, Inc. property in northern West Virginia (Consol Sample Designation #LL-1022-45-1). The Elkhorn No. 3 sample was obtained from United Coal Company's Wellmore No. 8 preparation plant in Buchanan County, Virginia. Approximately 225 kgs (500 lbs) of each coal was collected at the mine site and shipped to Virginia Tech in sealed 55-gallon drums. In an attempt to minimize oxidation, each drum was flushed with nitrogen prior to shipment. After delivery, each of the two coal samples were pulverized to minus 6.5 mm (1/4 inch) using a pilot-scale roll crusher. The crushed samples were split into representative lots of approximately 1 kg each and transferred to air-tight plastic containers. In order to minimize oxidation, each sample container was stored in a freezer below 20°C. Head assays for the two coal samples are provided in Table 2.1.

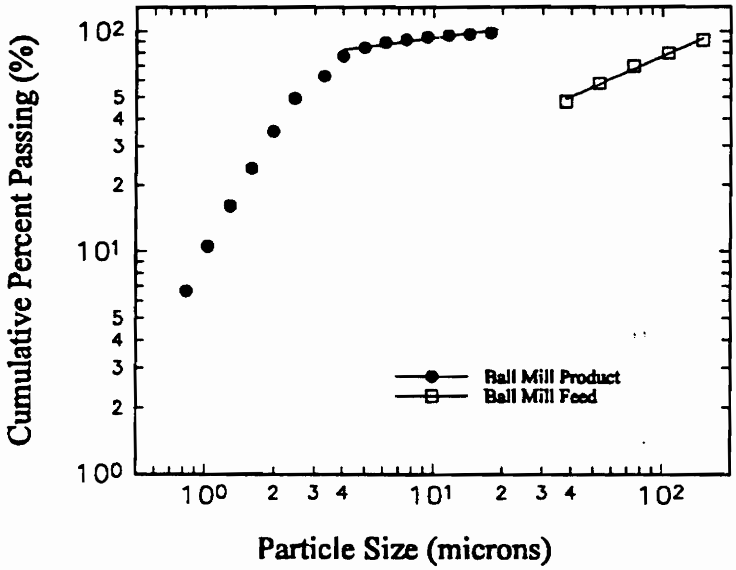
## 2.3 Sample Preparation

All of the coal samples used in the process development test work were prepared using the same procedure. In each series of experiments, a laboratory hammer mill was used to pulverize 1 kg samples of minus 6.5 mm (1/4 inch) coal to a mean size of approximately 75 microns. The sample was then split into lots of approximately 500 gm each and wet-ground for 30 minutes at 30% solids using a 13.33 cm (5-1/4 inch) diameter stirred ball mill loaded with 1.6 mm (1/16 inch) stainless steel grinding balls. This procedure resulted in a mean particle size of approximately 4 microns as measured using an Elzone 80-XY particle size analyzer. Typical size distributions of the micronized samples of the Elkhorn No. 3 and Pittsburgh No. 8 seam coals are shown in Figure 2.1 and tabulated in Appendix A.

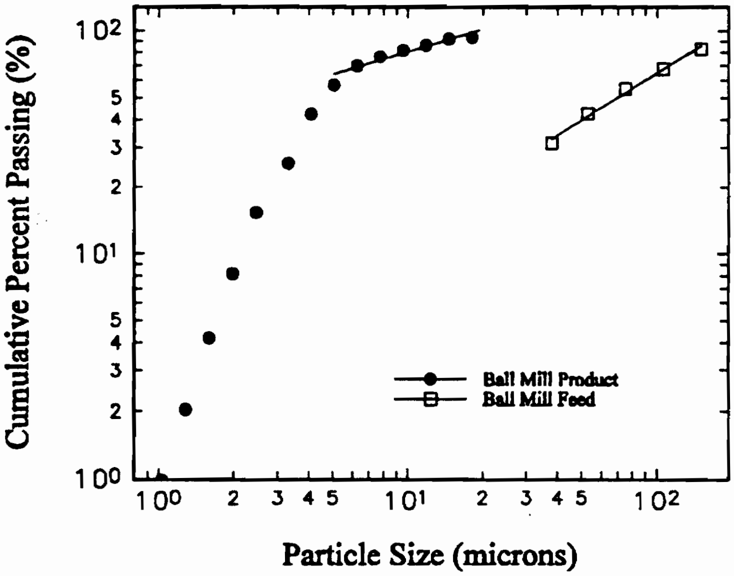
After wet-grinding, the pulverized coal samples were diluted using cold tap water to the desired solids content. Hydrochloric acid (HCl) and sodium hydroxide (NaOH) were used to adjust the pH to the desired value. When used, ethylenediaminetetraacetic acid (EDTA) was added to the sample prior to pH adjustment to tie-up free ions in solution that may be detrimental to coagulation selectivity. The pH of the suspension was allowed to stabilize prior to testing.

Table 2.1 - Head sample assays for the Pittsburgh No. 8 and Elkhorn No. 3 samples used in the process development test work.

| Sample | Type | Feed Ash % | Feed Sulfur % |
|---|---|---|---|
| Elkhorn No. 3 | ROM | 49.8 | 0.35 |
| Pittsburgh No. 8 | ROM | 15.4 | 3.6 |



Elkhorn No. 3 (50% Ash)
(30 minute grind time)



Pittsburgh No. 8
(30 minute grind time)

Figure 2.1 Typical size distributions of the micronized samples of Elkhorn No. 3 and Pittsburgh No. 8 coals.

## 2.4 Batch Testing

During many of the trial runs with the continuous test units, difficulties were experienced in obtaining good separation efficiencies. Therefore, a series of exploratory batch coagulation tests were performed to resolve these difficulties and to identify the optimal chemical conditions for treating each coal. This data would also provided a "yardstick" for evaluating the effectiveness of the continuous separators.

### *a) Experimental*

The sedimentation tests utilized a 6-inch diameter 3-liter mixing cell with baffles. One liter of the minus 20 micron coal sample at 3% solids was added to the mixing cell. The slurry was agitated with a 3-inch diameter impeller. When used, the chelating agent (EDTA) was added to the slurry in the first cleaning stage and conditioned for 15 minutes. The pH was adjusted to the desired value using hydrochloric acid (HCl) or sodium hydroxide (NaOH). After the pH had stabilized for 15 minutes at the desired value, the impeller was halted to allow coagulation and sedimentation. After 5 minutes, the supernatant of dispersed mineral matter was siphoned from the mixing cell. The remaining coagula was considered the product. Figure 2.2 provides a schematic overview of the steps used in the batch sedimentation tests.

To run multiple cleaning stages, the next stage began with the addition of cold tap water to the product of the previous stage, diluting the slurry to one liter. The slurry was then agitated to break the coagula and remove entrapped mineral matter. There was no EDTA addition in preceding cleaning stages, since the intended use of the EDTA was to tie-up the free ions acquired from the fine grinding process. The pH was adjusted and allowed to stabilize for 15 minutes. After pH stabilization, the impeller was halted and 5 minutes were given for coagulation and sedimentation. After the 5 minutes, the supernatant was siphoned from the mixing cell and the remaining sedimented coagula was taken as clean coal product. These steps were repeated for the desired number of cleaning stages.

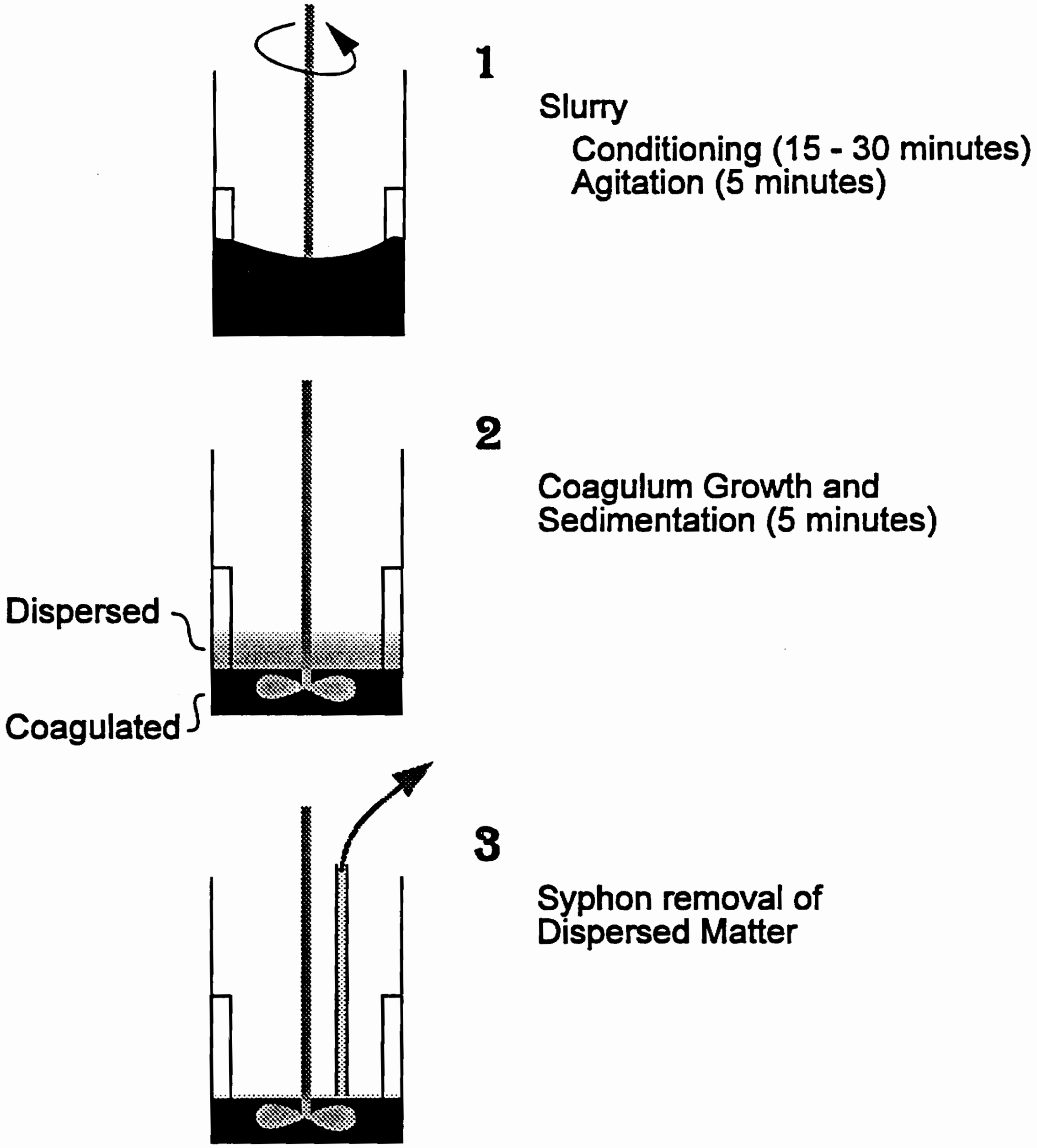


Figure 2.2 Schematic representation of the SHC batch testing procedure.

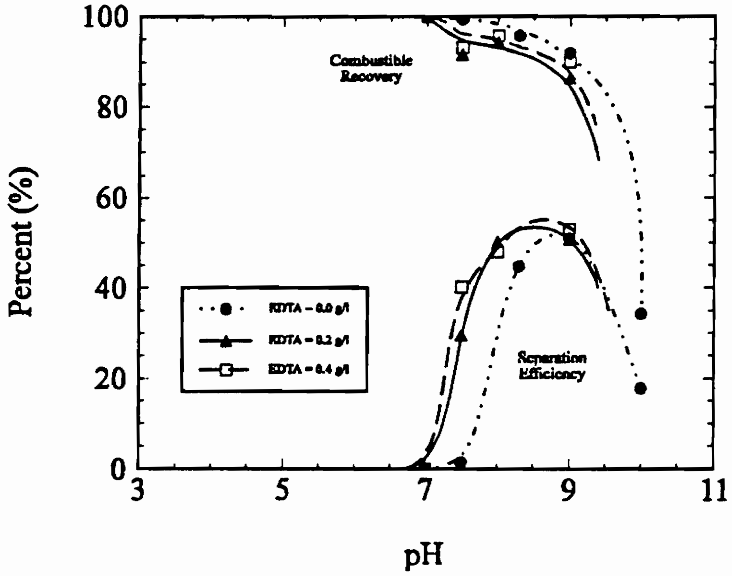
### *b) Results and Discussion*

The test results and specific operating conditions for the batch SHC tests conducted using the Elkhorn No. 3 seam coal are provided in Appendix B. The test data are summarized in Figure 2.3. As shown, both single- and three-stage tests were conducted as a function of pH and EDTA (ethylenediaminetetraacetic acid) addition. In all tests, the maximum separation efficiency for this particular coal occurred at pH 8.8. The addition of EDTA slightly widened the pH window over which effective separations could be achieved. However, it is unlikely that the small improvement would justify the additional cost of adding EDTA. An increase in the number of cleaning stages also improved the separation efficiency.

The results of batch SHC tests conducted using the Pittsburgh No. 8 seam coal are also provided in Appendix B and are summarized in Figure 2.4. As shown, this coal responded less favorably to upgrading by the SHC process as indicated by the very low separation efficiencies. Even after adding EDTA and three stages of cleaning, a maximum separation efficiency of only 26% was achieved. Recent work has shown that this coal is difficult to treat by the SHC process due to the specific adsorption of multivalent cations from solution. Thus, the testing of additional chelating agents should be considered to improve the cleanability of this particular coal.

Test results obtained with the Elkhorn No. 3 and Pittsburgh No. 8 coals indicated that multiple cleaning stages improved the performance of the batch SHC tests. In order to investigate this capability in greater detail, each coal was tested under optimal reagent conditions as a function of cleaning stage number. As shown in Figure 2.5, the Elkhorn No. 3 coal has a final percent ash of 16.5% after 5 stages of cleaning. The increase in separation efficiency with multiple cleaning stages decreased to less than 5% after 3 stages of cleaning with only a slight decrease (< 1%) in recovery. Minimal improvements in cleaning performance were also noted after three stages of cleaning with the Pittsburgh No. 8 coal (Figure 2.5).

Single-stage cleaning



Three-stage cleaning

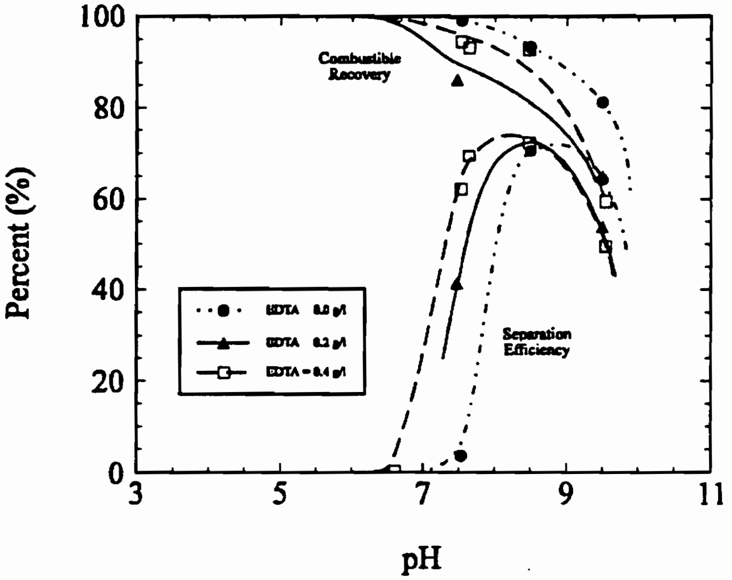
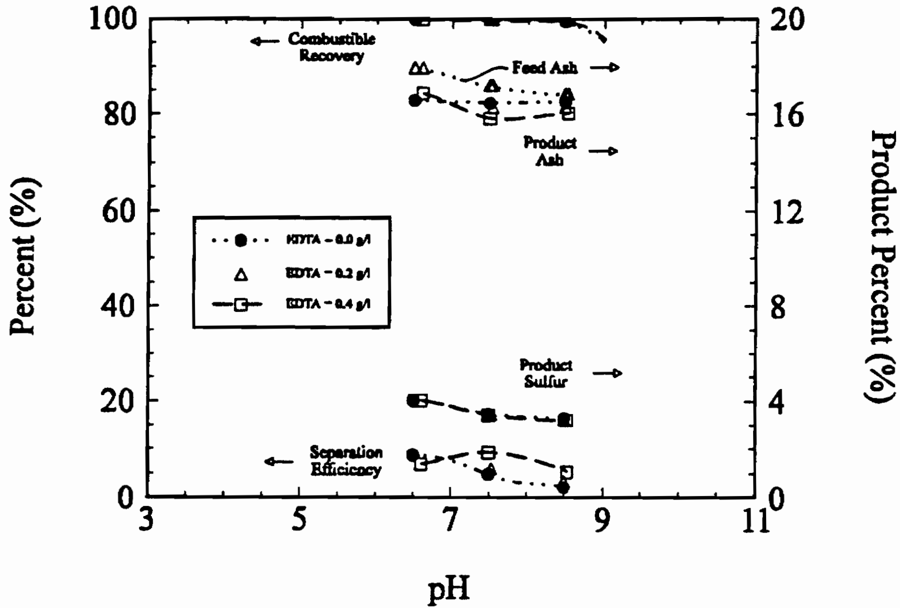


Figure 2.3 Responses versus pH for single- and three-stage batch SHC tests conducted using the Elkhorn No. 3 coal.

Single-stage cleaning



Three-stage cleaning

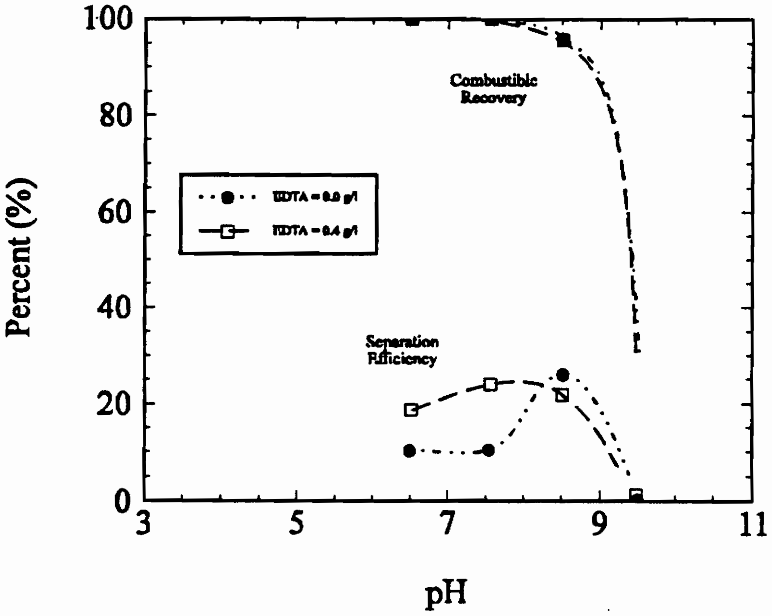


Figure 2.4 Responses versus pH for single- and three-stage batch SHC tests conducted using the Pittsburgh No. 8 coal.

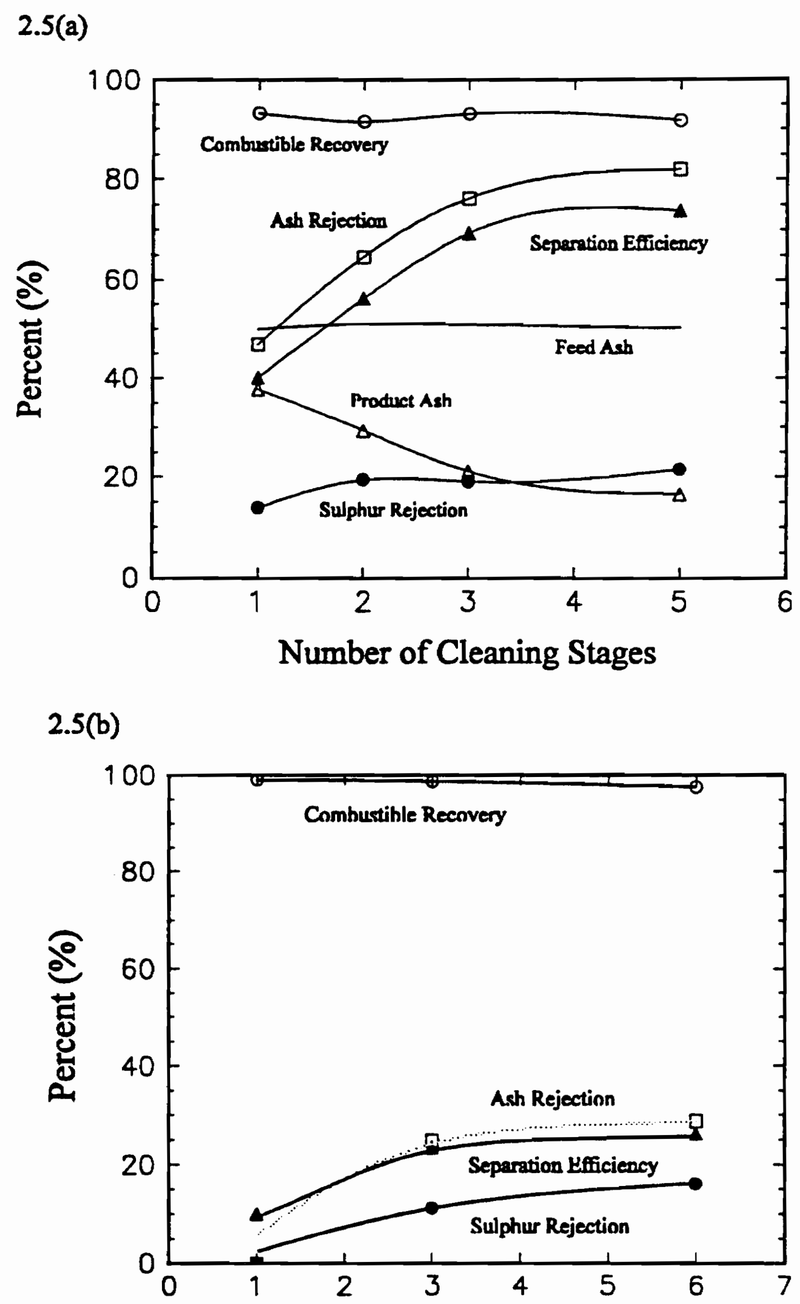


Figure 2.5 Responses versus cleaning stages for (a) Elkhorn No. 3 and (b) Pittsburgh No. 8 coals at pH 7.5 with EDTA dosages of 0.4 grams/liter of slurry.

## 2.5 Lamella Thickener

A series of tests were conducted to determine the effectiveness of a lamella-type thickener in separating clean coal coagula from dispersed mineral matter. In principle, this technique is similar to the sedimentation/elutriation technique employed in the DOE Contract No. DE-AC22-90PC90174 project (Yoon, R.H. and Luttrell, G.H., 1992). However, the lamella design should offer significant improvements in throughput compared to conventional open-tank settling vessels.

### *a) Experimental*

A prototype lamella thickener constructed of Plexiglas was used for this task (Figure 2.6). Design information for this unit is given in Appendix C. The unit included provisions for introducing countercurrent wash water to the lower section of the separator as a means of minimizing the entrainment of fine mineral matter. In each test, the unit was filled with de-ionized water and adjusted to pH 7.5 with HCl and NaOH. Cold tap water in a sump was adjusted to pH 7.5 and pumped with a peristaltic pump to the wash water tube. The conditioned feed slurry was pumped from a mixing sump with a peristaltic pump through ten feet of tubing to a four-way splitter. The feed slurry then entered the middle of each plate in the thickener. The mudline was allowed to build to a fixed level, then the underflow peristaltic pump was started, removing the product slurry. The underflow pump was adjusted as needed to maintain the fixed mudline level. After the underflow rate became constant, the test was run for a minimum of one retention time to ensure test reliability. Table 2.2 shows the standard operating parameters used for the lamella thickener experiments.

Both coals were evaluated in 8-run factorial designs which examined the effects of wash water, feed rate, and feed solids content. The test levels examined for each parameter are given in Table 2.3. The evaluation tests for both the Elkhorn No. 3 and Pittsburgh No. 8 seam coals were performed in random order to minimize experimental bias. In addition, several replicate tests were conducted throughout the test program

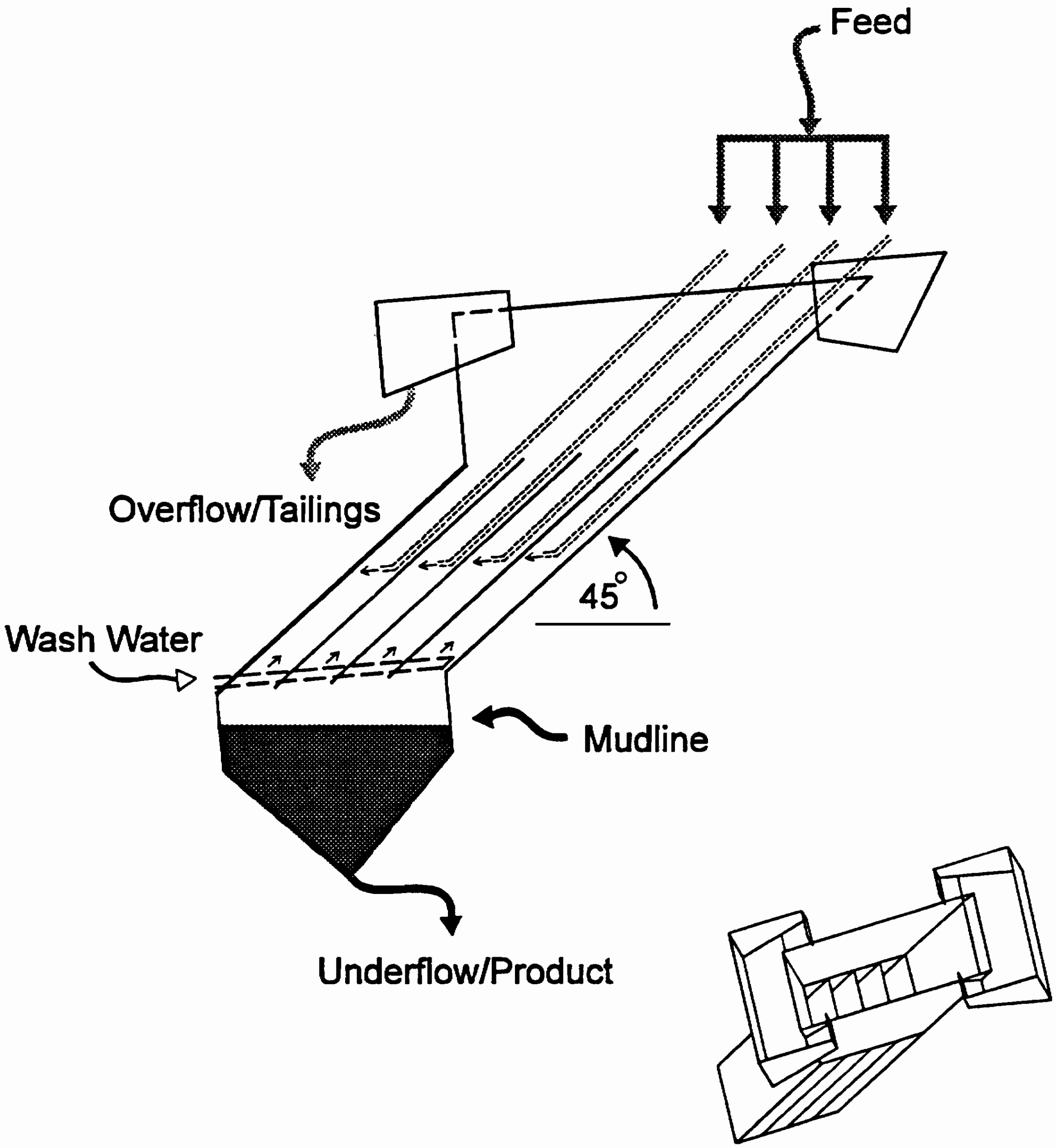


Figure 2.6 Schematic of the lamella thickener separation unit used in coagula recovery test work.

Table 2.2 - Standard operating conditions for the lamella thickener tests.

| Parameter | Value |
|---|---|
| pH | 7.5 |
| pH Condition Time | 15 minutes |
| Chelating Agent | EDTA |
| Chelate Dosage | 0.4 gm/liter |
| Chelate Condition Time | 15 minutes |
| Feed Particle Size | -20 microns |
| Mudline | constant |
| Lamella Plate Angle | 45 degrees |
| Cell Actual Area | 42 inch$^2$ |
| Cell Effective Area | 170 inch$^2$ |
| Cell Volume | 11 liters |

Table 2.3 - Experimental levels for the lamella thickener parametric tests.

| | | | Parameter Range | | |
|---|---|---|---|---|---|
| Coal Seam | Parameter | Units | Low (-1) | Normal (0) | High (1) |
| Elkhorn No. 3<br>(50% Ash) | Feed Solids | (%) | 2 | 4 | 6 |
| | Wash Water | (ml/min) | 0 | 20 | 40 |
| | Feed Rate | (ml/min) | 50 | 100 | 150 |
| Pittsburgh No. 8 | Feed Solids | (%) | 2 | 4 | 6 |
| | Wash Water | (ml/min) | 20 | 60 | 100 |
| | Feed Rate | (ml/min) | 50 | 75 | 100 |

under "normal" operating conditions in order to provide a check on the reproducibility of test procedures and assay determinations. The experimental data were adjusted using a material balance program to ensure that a consistent data set was obtained in each case.

Statistical analysis of the experimental test results was carried out using the Design-Expert software. The program was used to generate the necessary test matrix and to complete all required regression analyses. The data analysis procedure was an iterative process since, in most cases, several analyses were required in order to obtain a suitable relationship between the operating variables and lamella thickener performance. After selecting an appropriate model, a variety of statistical routines were executed to identify the goodness-of-fit. For all test runs, the values of regression coefficients, standard errors, variances, t-tests, etc., were determined as a means of quantifying the statistical significance of each of the coefficients in the model. After developing a reasonable mathematical model of the desired response, contour plots were created to demonstrate the effects of the various operating parameters on the process performance.

### *b) Results and Discussion*

Prior to conducting the parametric tests, the lamella thickener was sampled as a function of time to ensure that all data points were taken under steady-state conditions. Figure 2.7 and Appendix C show the variation between samples taken during a single continuous test run. For all practical purposes, the lamella thickener had reached steady-state operation prior to taking the first sample point (i.e., after 20 minutes of operation), although a slight downward drift in ash rejection was observed until after 90 minutes of continuous operation. Therefore, all test runs were allowed to proceed for 90 minutes prior to taking samples during the parametric test program.

The parametric test data obtained using the Elkhorn No. 3 seam coal is summarized in Appendix C. The best separation efficiency (i.e., 51.0%) was obtained at a combustible recovery of 92.4%. At this level of recovery, it was possible to achieve ash and sulfur rejections of 58.6% and 15.3%, respectively. However, the maximum

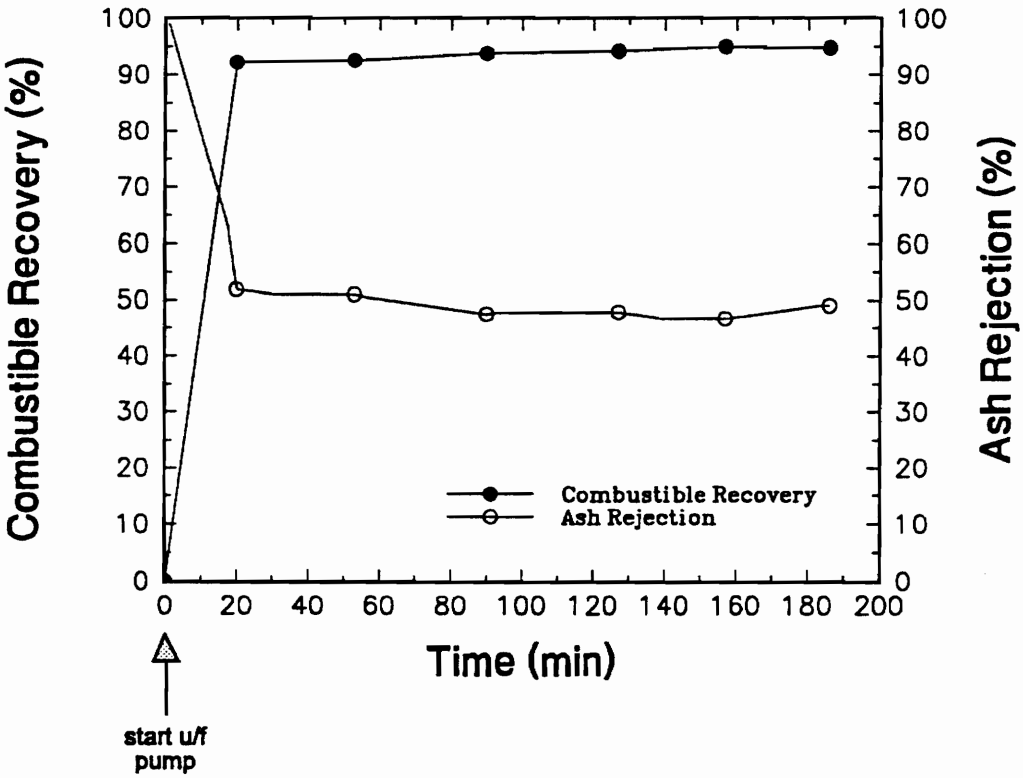


Figure 2.7 Combustible recovery and ash rejection versus retention time in the lamella thickener unit using Elkhorn No. 3 coal.

throughput of the lamella thickener was only 0.11 lb/hr for this combination of operating conditions. A significantly higher throughput of 0.33 lb/hr was obtained at a slightly lower separation efficiency of 47.5%. The penalty for operating under this set of conditions was a loss of approximately 2 percentage points in combustible recovery.

The results of the statistical computations performed using the Elkhorn No. 3 seam coal parametric test data are provided in Appendix C. In general, very good correlations were obtained between the model predictions and experimental results. The resultant response surface plots are given in Figure 2.8, while Table 2.4 shows the effect of increasing operating parameters on lamella thickener responses. According to the response surface plots, the separation efficiency was increased with decreasing feed solids content. The decrease in performance can be attributed to the increased entrapment of ash-forming minerals within the hydrophobic coagula at higher solids concentrations. The plots also indicate that an increase in wash water rate improved the separation efficiency. Higher wash water flows tended to expand the settled coagula bed and improve the removal of fine mineral matter. Finally, higher feed rates resulted in a loss of clean coal coagula to the thickener overflow, while low feed rates allowed mineral matter to settle and be recovered with the clean coal product. In summary, these analyses show that the highest overall separation efficiencies were obtained at a low feed solids content, moderate feed rate and high wash water rate.

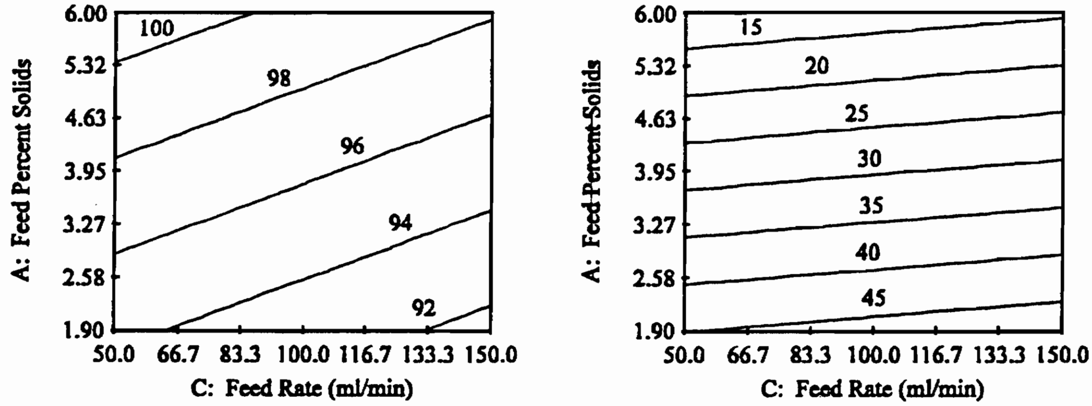
The parametric test data for the Pittsburgh No. 8 seam coal is summarized in Appendix C. Because of the difficult nature of this coal, the best separation efficiency was only 30.3%. This corresponds to a combustible recovery, ash rejection and total sulfur rejection of 93.3%, 36.9% and 23.07%, respectively. The maximum throughput of the lamella thickener for this set of operating conditions was approximately 0.23 lb/hr.

The statistical computations of the Pittsburgh No. 8 parametric test data are provided in Appendix C. The model predictions were found to be in good agreement with the experimental results. The resultant response surface plots are given in Figure 2.9. Table 2.5 shows the effect of increasing operating parameters on lamella thickener

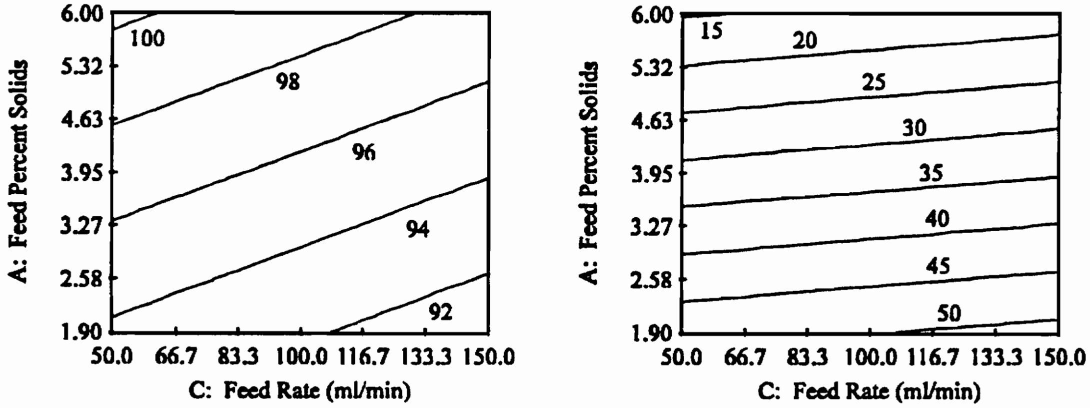
Response:
Combustible Recovery (%)

Response:
Separation Efficiency (%)

**Actual Constants: Wash Water = 0 ml/min**



**Actual Constants: Wash Water = 20 ml/min**



**Actual Constants: Wash Water = 40 ml/min**

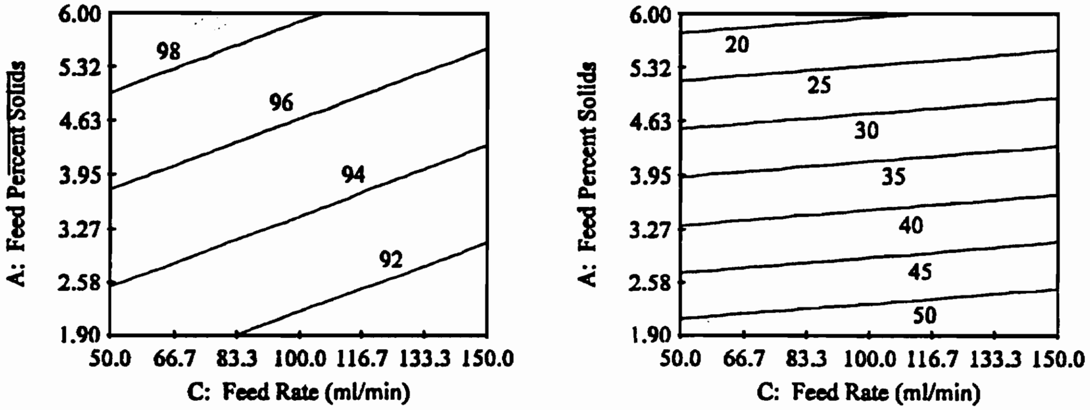


Figure 2.8 Combustible recovery and separation efficiency response surface plots obtained from the parametric testing of the Elkhorn No. 3 coal.

Table 2.4 - Correlation matrix for the lamella thickener (Elkhorn No. 3 coal).

| | Effect of Increasing: | | |
|---|---|---|---|
| Process Response | Feed Solids | Feed Rate | Water Rate |
| Clean Coal Yield | L↑ | S↓ | M↓ |
| Combustible Recovery | M↑ | S↓ | S↓ |
| Ash Rejection | L↓ | M↑ | M↑ |
| Sulfur Rejection | M↓ | S↑ | S↑ |
| Separation Efficiency | L↓ | S↑ | M↑ |

L = Large, M = Medium, S = Small
↑ = Increasing Response, ↓ = Decreasing Response

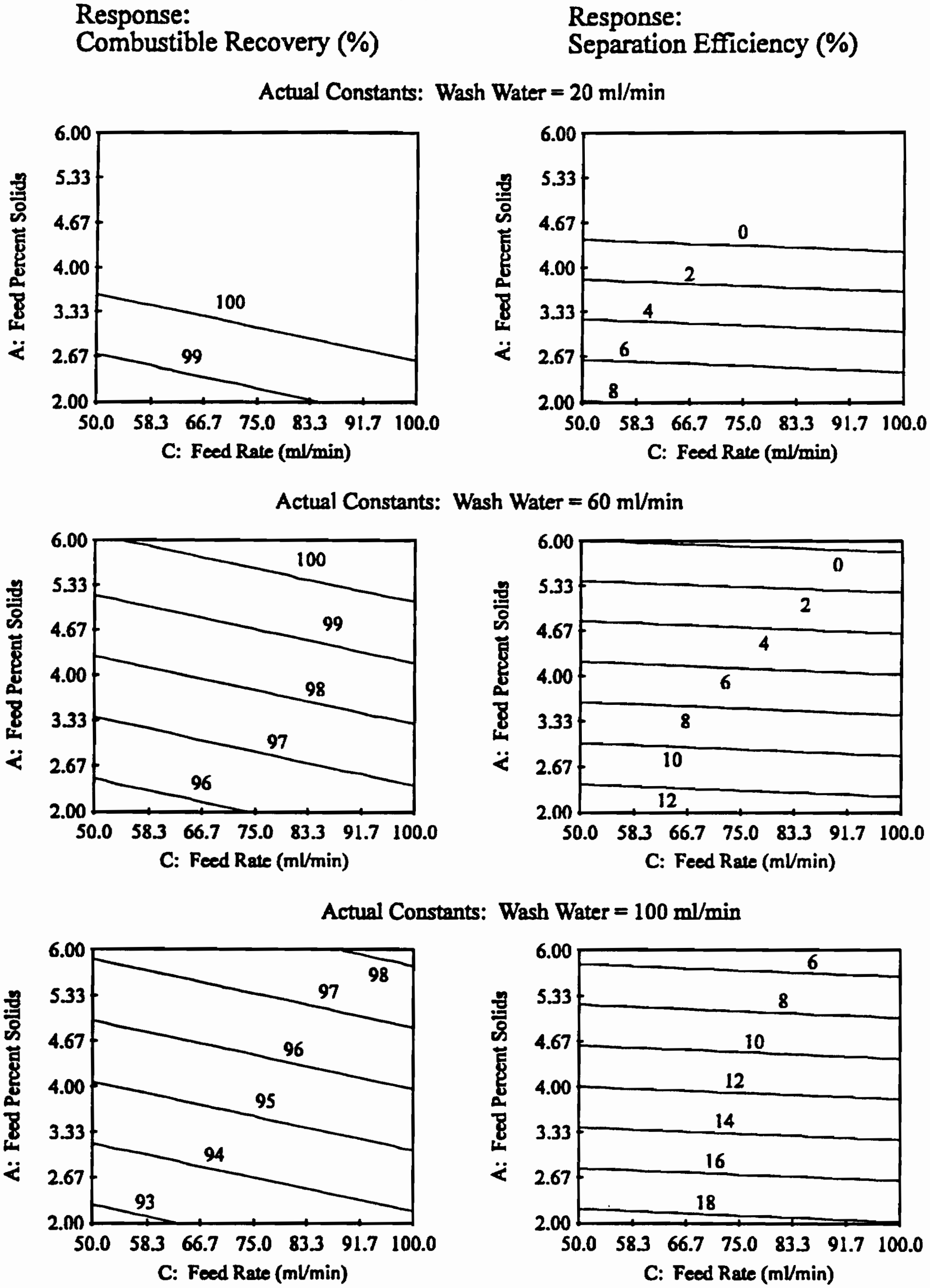


Figure 2.9 Combustible recovery and separation efficiency response surface plots obtained from the parametric testing of the Pittsburgh No. 8 coal.

Table 2.5 - Correlation matrix for the lamella thickener (Pittsburgh No. 8 coal).

| | Effect of Increasing: | | |
|---|---|---|---|
| Process Response | Feed Solids | Feed Rate | Water Rate |
| Clean Coal Yield | M↑ | S↑ | M↓ |
| Combustible Recovery | S↑ | S↑ | M↓ |
| Ash Rejection | L↓ | S↓ | L↑ |
| Sulfur Rejection | M↓ | S↓ | M↑ |
| Separation Efficiency | M↓ | S↓ | M↑ |

L = Large, M = Medium, S = Small
↑ = Increasing Response, ↓ = Decreasing Response

responses. As with the Elkhorn No. 3 seam coal, the response surface plots indicate that the separation efficiency increased with a decrease in feed solids content. The decrease in performance can be attributed to the increased entrapment of ash-forming minerals within the hydrophobic coagula at higher solids concentrations. The plots also show that an increase in the wash water rate improved the separation efficiency. Higher wash water flows tended to expand the settled coagula bed and improve the removal of fine mineral matter. The significance of the wash water rate was greater for the Pittsburgh No. 8 seam coal than the Elkhorn No. 3 seam coal. However, unlike the Elkhorn No. 3 seam coal, increasing the feed rate increased the recovery of clean coal coagula and decreased the separation efficiency.

## 2.6 Centrifugal Sedimentation

The SHC process suffers from low throughput because of the relatively low settling rate of the small coagula. One technique for alleviating this problem would be to use a centrifuge to increase the gravitational force. This would significantly increase the sedimentation rate and enhance the separation of the coagula from dispersed mineral matter.

### *a) Experimental*

A bench-scale Sharples semi-continuous centrifuge was initially set up for the centrifugal sedimentation experiments. However, it was noticed that the bowl was equipped with a metal cross beam which acted as an impeller at the feed entry point. Therefore, any coagula which was fed to the centrifuge was broken just before entering the bowl. Therefore, a batch rotor centrifuge (Figure 2.10) was used in place of the semi-continuous centrifuge. Preliminary tests were run on each coal seam to determine the key parameters and appropriate operating ranges for the experimental designs. The test data obtained from this work are provided in Appendix D. Tables 2.6 and 2.7 summarize the standard operating conditions and the parameter ranges examined in the preliminary tests.

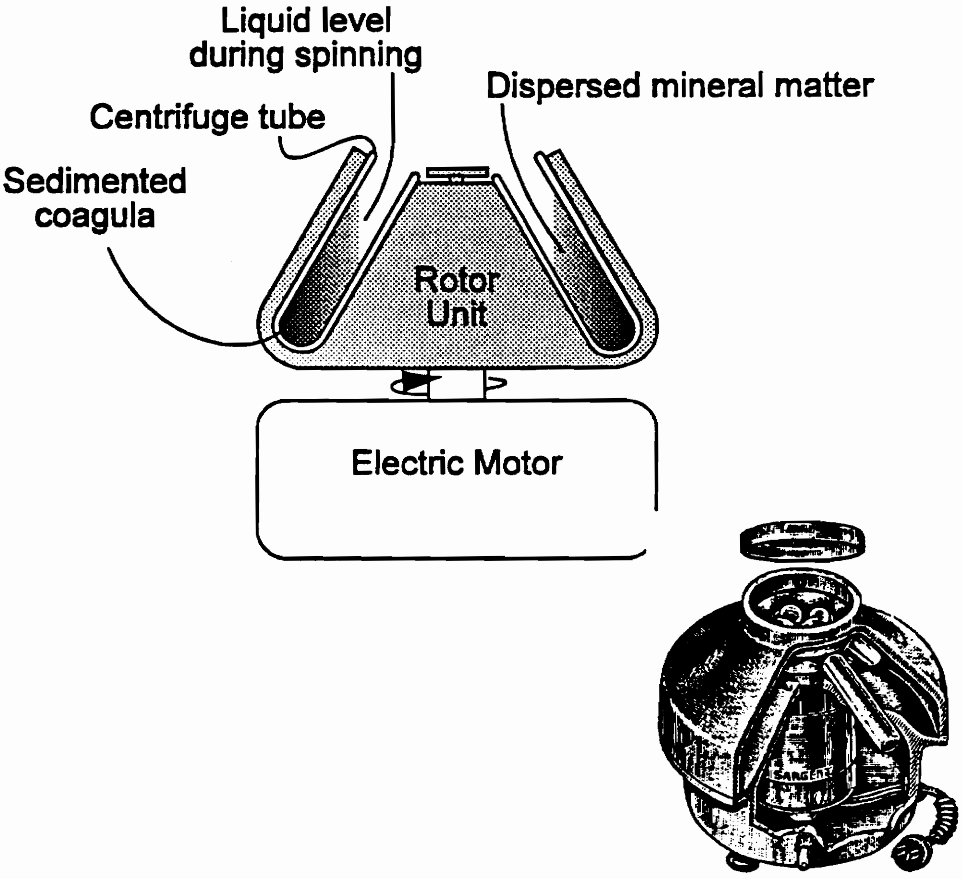


Figure 2.10 Schematic of the laboratory rotor centrifuge used in coagula recovery test work.

Table 2.6 - Standard operating conditions for the preliminary rotor centrifuge tests.

| Parameter | Value |
|---|---|
| pH Condition Time | 15 minutes |
| Chelating Agent | EDTA |
| Chelate Dosage | 0.4 gm/liter |
| Chelate Condition Time | 15 minutes |
| Feed Particle Size | -20 microns |
| Centrifuge Spin Time | 5 minutes |
| Centrifuge Temperature | 20°C |

Table 2.7 - Experimental levels for the preliminary rotor centrifuge tests.

| Coal Seam | Parameter | Units | Range |
|---|---|---|---|
| Elkhorn No. 3 | Feed Solids | (%) | 3, 5, 10, 14 |
| | pH | --- | 7.5, 10 |
| | Speed | (rpm) | 500 - 1500 |
| Pittsburgh No. 8 | Feed Solids | (%) | 4.5 |
| | pH | --- | 7.5, 10 |
| | Speed | (rpms) | 500 - 2000 |

The feed for each rotor centrifuge experiment, approximately 265 ml, was split from a continually mixed sump containing conditioned slurry. All eight centrifuge tubes, 50 ml each, were equally filled from the sump plus a feed sample was collected to be assayed as the feed for the test. The centrifuge tubes were centrifuged immediately after filling, so as not to allow any sedimentation by gravity. After centrifuging, the dispersed matter was poured off each tube and combined, making a tailings sample. The sedimented matter from each tube was then combined as a product sample. The feed samples taken during each test were then used to balance the tailing assays, since some tailing samples were less than one gram in mass.

After the preliminary test work was completed for each coal, the results were used to determine the operating ranges for the experimental designs. Since the Pittsburgh No. 8 seam coal did not have favorable results in the preliminary test work, further centrifugal sedimentation tests were not conducted using this coal. Using the values from Table 2.8, a 3-level and 4-variable Box-Behnken experimental design was generated for the Elkhorn No. 3 seam coal using the Design-Expert software package. The experimental design required 27 individual centrifugal tests. None of the Box-Behnken tests used a chelating agent since previous experiments showed little advantage in using the EDTA. Assay results were balanced to provide a consistent set of data which the software used to perform the required regression analyses. A summary of the test results is given in Appendix D.

The regression analyses were used to develop empirical expressions relating the operating conditions to the separation performance. Initial data fitting was performed using standard linear, quadratic, and cubic regression models. The cubic model typically provided the best fit to the experimental data, while the linear model provided the worst. However, many of the coefficients in the cubic model were aliased (i.e., these terms could not be uniquely determined given the available data set). Thus, quadratic models were selected throughout this investigation since they minimized model complexity, provided good predictive correlations and reduced aliasing of the model coefficients. For

Table 2.8 - Experimental levels for the rotor centrifuge parametric tests.

| | | | Parameter Range | | |
|---|---|---|---|---|---|
| Coal Seam | Parameter | Units | Low (-1) | Normal (0) | High (1) |
| Elkhorn No. 3<br>(50% Ash) | Feed Solids | (%) | 1 | 3 | 5 |
| | pH | --- | 7.5 | 8.5 | 9.5 |
| | Speed | (rpms) | 750 | 1000 | 1250 |
| | Spin Time | (minutes) | 3 | 6 | 9 |

each model, the values of regression coefficients, standard errors, variances, t-tests, etc., were determined as a means of quantifying the statistical significance of each of the coefficients in the regression model.

After completing the statistical analyses, response surface plots were constructed for predicting combustible recovery, separation efficiency, and ash rejection for the Elkhorn No. 3 seam coal. Each set of data was plotted as functions of pH and rotor speed in the form of a contour diagram. Separate diagrams were constructed for each response to represent all possible combinations of high, normal, and low settings for the feed solids content and spin time. Thus, nine separate plots were constructed for each response.

### *b) Results and Discussion*

The results of the statistical analyses for the Elkhorn No. 3 seam coal are provided in Appendix D. The corresponding response surface plots are shown in Figures 2.11-2.13 for combustible recovery, separation efficiency, and ash rejection, respectively. The parameter correlation chart for these tests is summarized in Table 2.9. The most significant parameters affecting the recovery of coagula were rotor speed (or effective G-force) and spin time. Increasing speed and spin time gave the smaller particles time to settle, which increased recovery. The pH also affected recovery, with the higher pH values providing higher recoveries for spin times greater than three minutes. At the higher pH values, the coagula are smaller and longer spin times are required to obtain a good recovery. Additionally, a higher feed solids content increased the specific gravity of the slurry. This lowered the particle settling rate and reduced the coagula recovery at the lower speeds and spin times.

The response surface plots indicate that the separation performance was most affected by the pH, with higher pH values giving higher separation efficiencies. As the pH decreased, there was more entrapment of gangue particles in the coagula. This reduced the separation efficiency and the rejection of ash. As determined from the batch

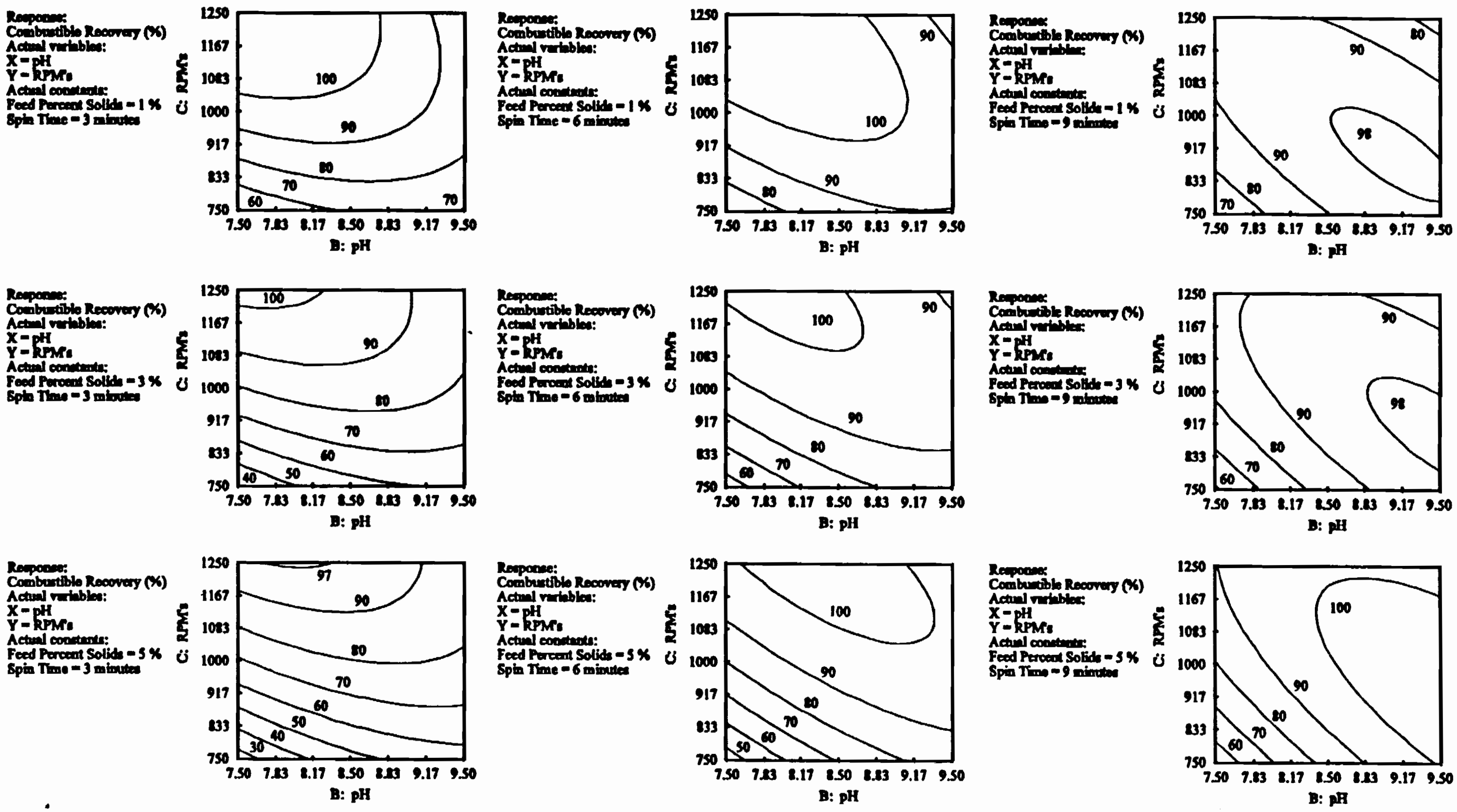


Figure 2.11 Combustible recovery response surface plots for centrifugal sedimentation of the Elkhorn No. 3 coal.

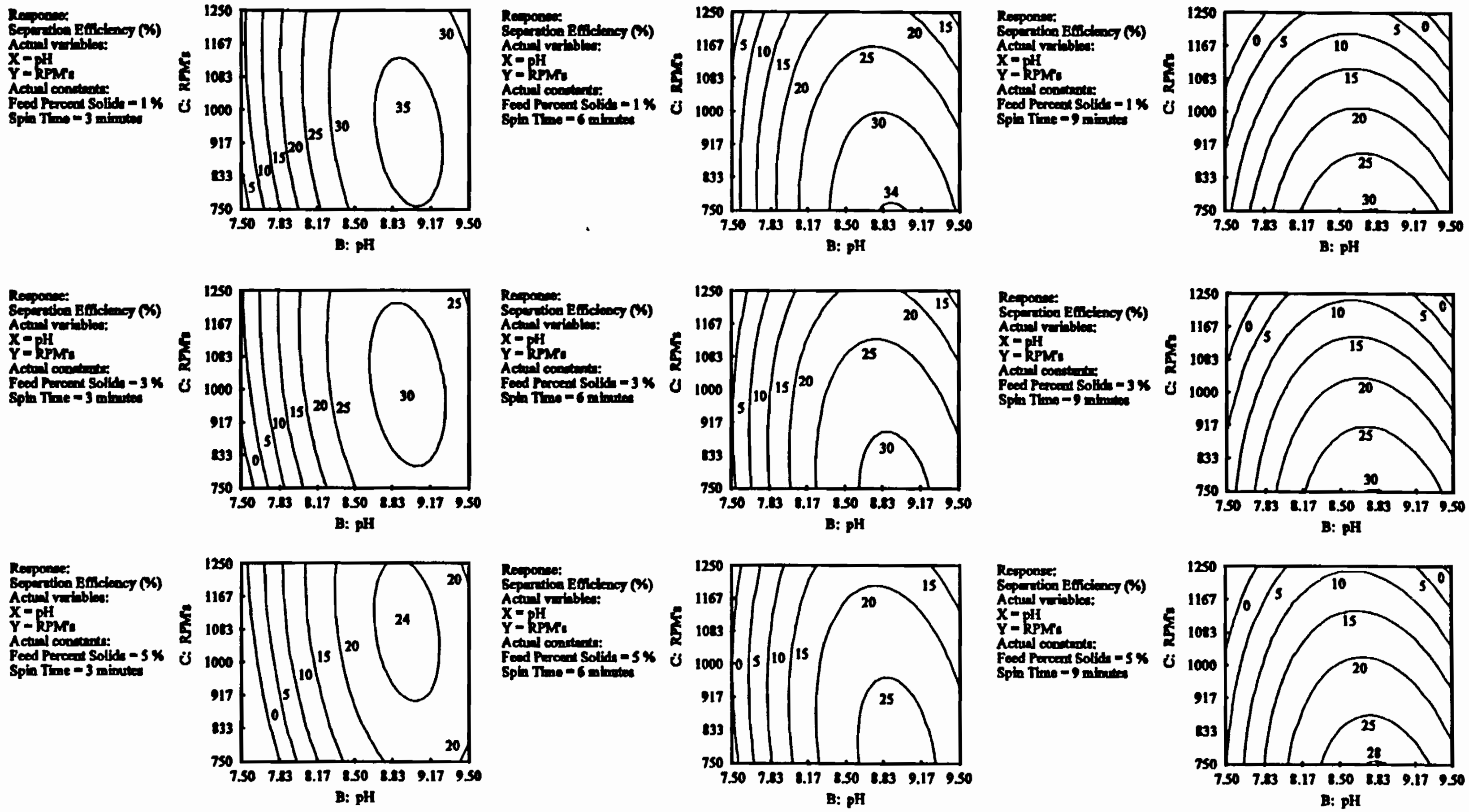


Figure 2.12 Separation efficiency response surface plots for centrifugal sedimantation of the Elkhorn No. 3 coal.

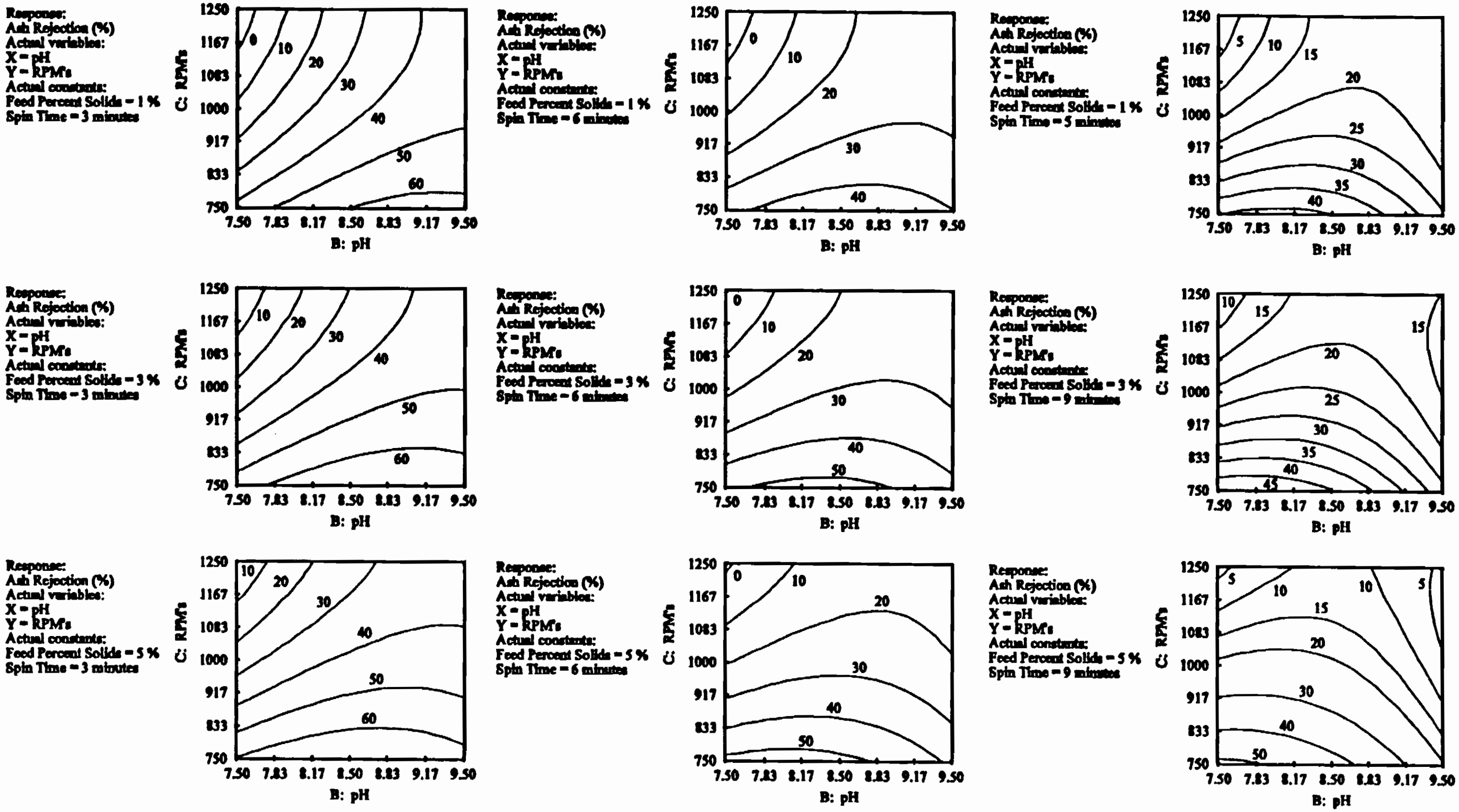


Figure 2.13 Ash rejection response surface plots for the centrifugal sedimentation tests conducted using the Elkhorn No. 3 coal.

Table 2.9 - Correlation matrix for the rotor centrifuge (Elkhorn No. 3 coal).

| | Effect of Increasing: | | | |
|---|---|---|---|---|
| Process Response | Feed Solids | Spin Time | pH Level | Rotor rpm |
| Clean Coal Yield | S↓ | M↑ | S↓ | L↑ |
| Combustible Recovery | M↓ | M↑ | M↑ | L↑ |
| Ash Rejection | S↑ | L↓ | M↑ | L↓ |
| Sulfur Rejection | S↑ | M↓ | M↑ | L↓ |
| Separation Efficiency | M↓ | M↓ | L↑ | M↓ |

L = Large, M = Medium, S = Small
↑ = Increasing Response, ↓ = Decreasing Response

sedimentation tests, pH values from 8.5 to 9 were optimum for selective coagulation without EDTA. The recovery of the dispersed gangue minerals increased with increasing rotor speed and spin time. As a result, the separation efficiency and ash rejection also decreased as spin time and rotor speed increased. Finally, increasing feed solids decreased the separation efficiency due to increased entrapment at higher feed solid levels.

The response surface plots show that, like combustible recovery, ash rejection was most affected by rotor speed and spin time. Longer spin times and higher speeds increase the recovery of finer particles. In the SHC process the finer particles are comprised of dispersed gangue particles. So the recovery of the finer gangue particles decreased the ash rejection. The pH level also affected the ash rejection. Where higher pH values have higher ash rejection. The lower the pH value, the greater the entrapment of gangue minerals in the recovered coagula. The feed solids content had little affect on the ash rejection.

Centrifugal sedimentation tests were also attempted using the Pittsburgh No. 8 seam coal. The results of these preliminary tests are summarized in Figure 2.14. Unfortunately, the centrifuge did not produce favorable results with this particular coal. Thus, no further centrifuge work was undertaken using the Pittsburgh No. 8 coal.

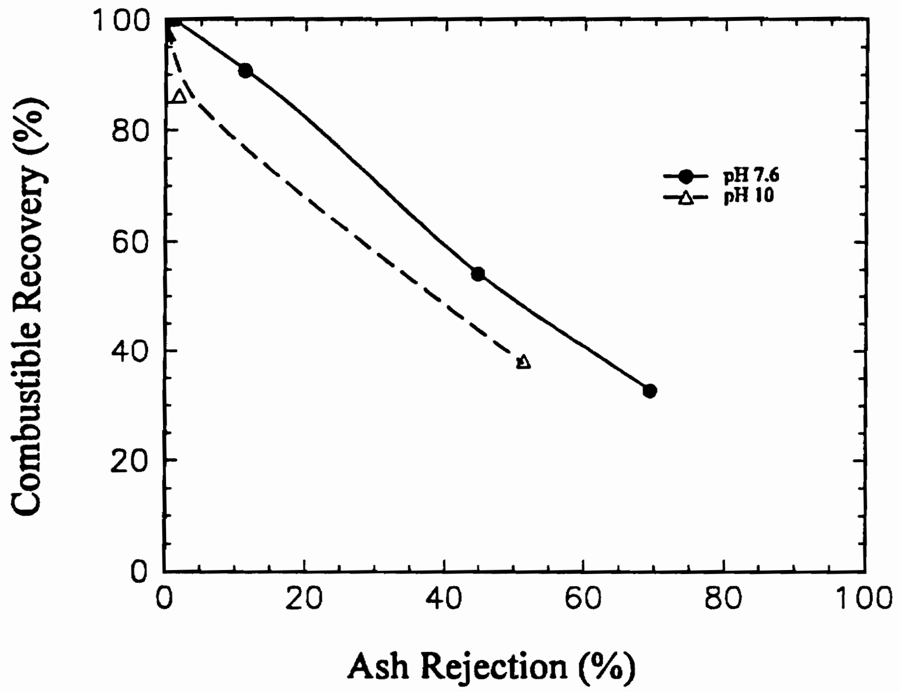


Figure 2.14 Grade-recovery curves for the centrifugal sedimentation tests conducted using the Pittsburgh No. 8 coal.

## 2.7 Vacuum Filtration

It was thought that vacuum filtration may have an advantage over the sedimentation techniques in that it is relatively unaffected by the slow sedimentation rate of the coagula. Therefore, a bench-scale test program was undertaken in the present work to evaluate the applicability of vacuum filtration for the separation of coal coagula from dispersed mineral matter.

### *a) Experimental*

The effects of filter medium, applied vacuum, and feed percent solids were studied using both a filter leaf test kit and a bench-scale continuous filtration unit. The preliminary filter leaf tests were conducted prior to continuous filtration tests in order to determine appropriate operating ranges for the continuous unit (i.e. cycle time, cake form time, form vacuum, wash time, dry time, etc.). The filter leaf batch tests also examined nine different types of filter media. Five of these were selected for use in the continuous filtration unit test work. The continuous tests were conducted using a 100 mm x 200 mm diameter drum filter (Figure 2.15). The test unit was modified to permit the use of wash water to remove entrained mineral matter from the filter cake. At least 3 different settings were examined for each operating parameter.

Figure 2.16 shows a schematic of the filter leaf vacuum filtration tests. In these tests, feed slurry was prepared in a baffled 6-inch diameter (3-liter) mixing cell mounted on a magnetic stirrer. Approximately 1 liter of minus 20 micron slurry (Elkhorn No. 3 seam coal) was added to the mixing cell and conditioned for 15 minutes with EDTA. After conditioning, the pH was adjusted to 7.5 using hydrochloric acid (HCl) or sodium hydroxide (NaOH). The slurry was agitated for 15 minutes after reaching the 7.5 pH level. After the pH stabilized, the agitation rate of the magnetic stirrer was decreased to permit the coagula to grow for a period of approximately 5 minutes. While holding the coagula in suspension by gentle mixing, a 4-inch diameter filter leaf was submerged into the slurry. Tests were run with feed solids contents from 5% to 15%, submergence times

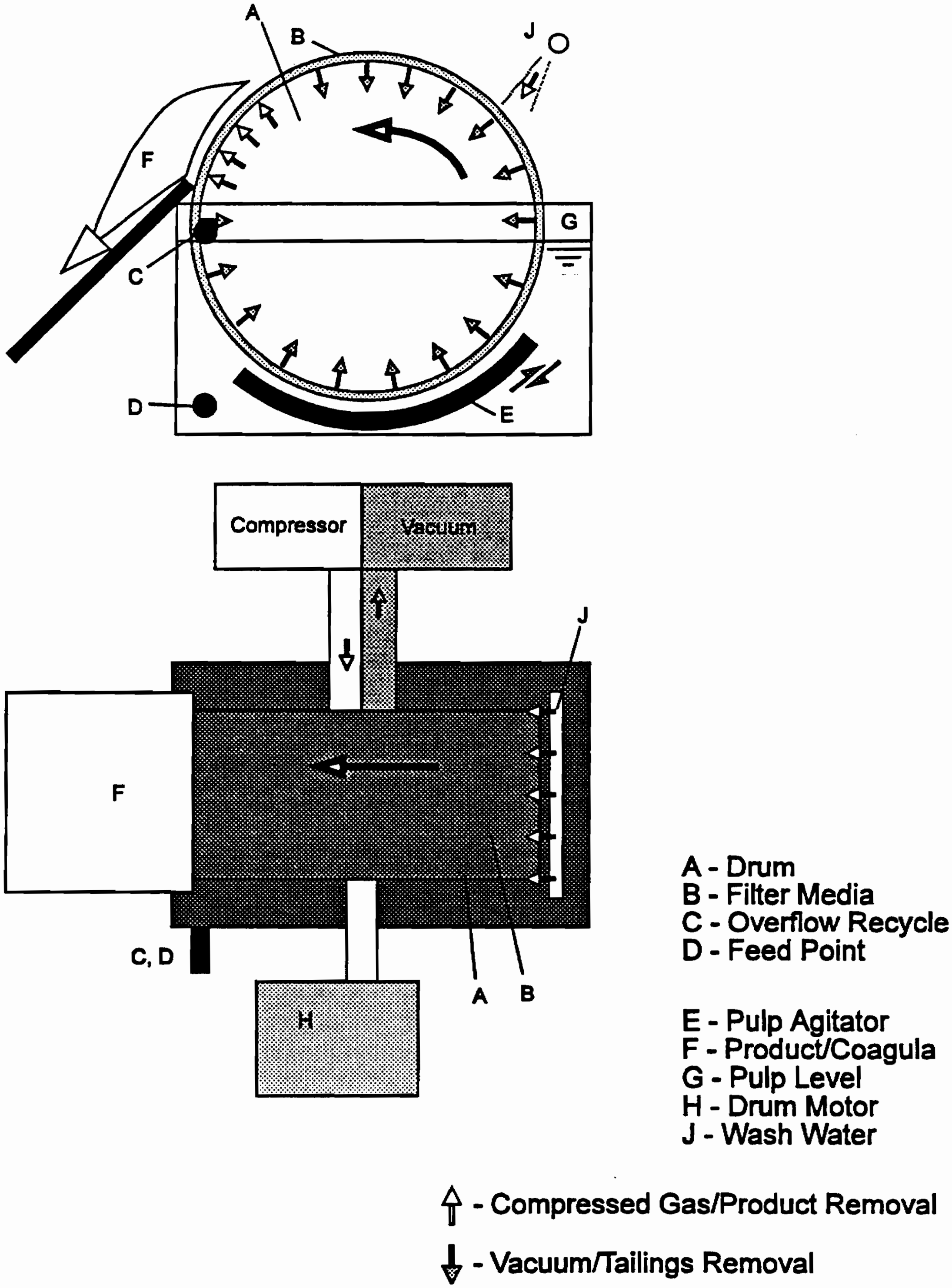


Figure 2.15 Schematic of the continuous vacuum filtration separation unit.

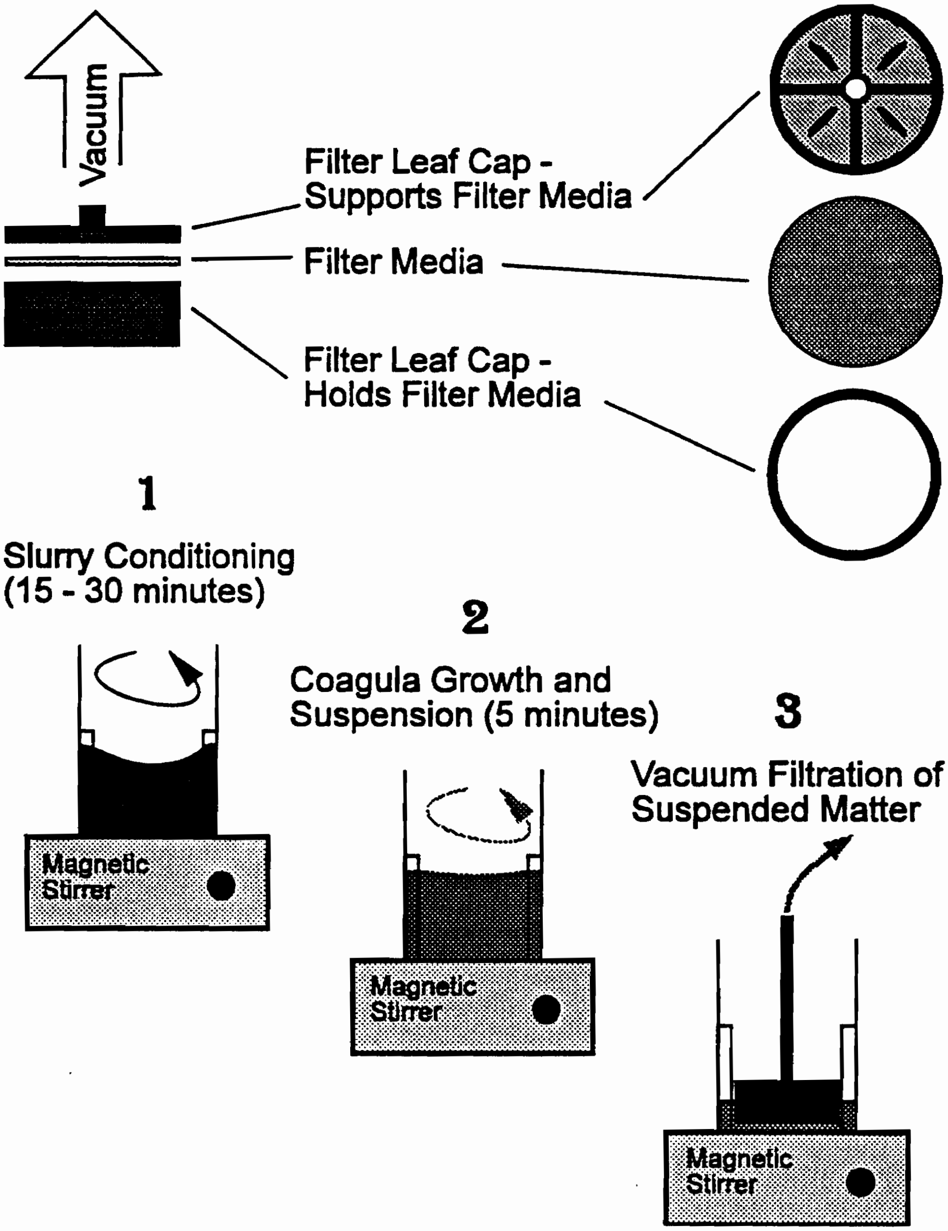


Figure 2.16 Schematic of the filter leaf batch test unit equipped with a vacuum pump.

as long as 3 minutes, and applied vacuums ranging from full to minimum. The first round of filter leaf tests was conducted using a laboratory vacuum pump.

The second round of filter leaf batch tests was run by feeding the conditioned slurry directly onto the filter medium. In these tests, the coagulated slurry was pumped into an inverted filter leaf (Figure 2.17) in place of the 3-liter mixing cell. The slurry was then filtered using a positive-displacement peristaltic pump operating at a volume flow of 50 ml/min. The peristaltic pump was used to decrease the applied vacuum to the filter leaf. The feed solids content was held constant at 5% solids while testing both the Elkhorn No. 3 and Pittsburgh No. 8 seam coals.

The continuous drum filter tests were attempted using only the Elkhorn No. 3 coal because of the poor results obtained during the filter leaf testing of the Pittsburgh No. 8 coal. In these tests, the pH was adjusted to 8.5 using hydrochloric acid (HCl) or sodium hydroxide (NaOH) and no EDTA was added. Five different filter media were examined. The applied vacuum and drum cycle time were independently varied from their maximum to minimum settings during each of the five filter media tests. Although higher feed solid contents would normally be preferred to promote the formation of the filter-cake, the solids content was kept at 5% to minimize the entrapment of gangue in the coagula.

### *b) Results and Discussion*

The first round of filter leaf batch tests was performed using the Elkhorn No. 3 coal. The test data are summarized in Appendix E. Unfortunately, these tests did not produce favorable results. Both the dispersed and coagulated particles were consistently pulled through the filter medium and no filter cake was formed. In an attempt to correct these problems, a peristaltic pump was used in place of the vacuum pump to reduce the intensity of the applied vacuum. The second round of filter leaf batch tests also performed poorly despite using the lower vacuum. Separation efficiencies were less than 4% with one filtration pass. The feed slurry either passed through the filter media or the

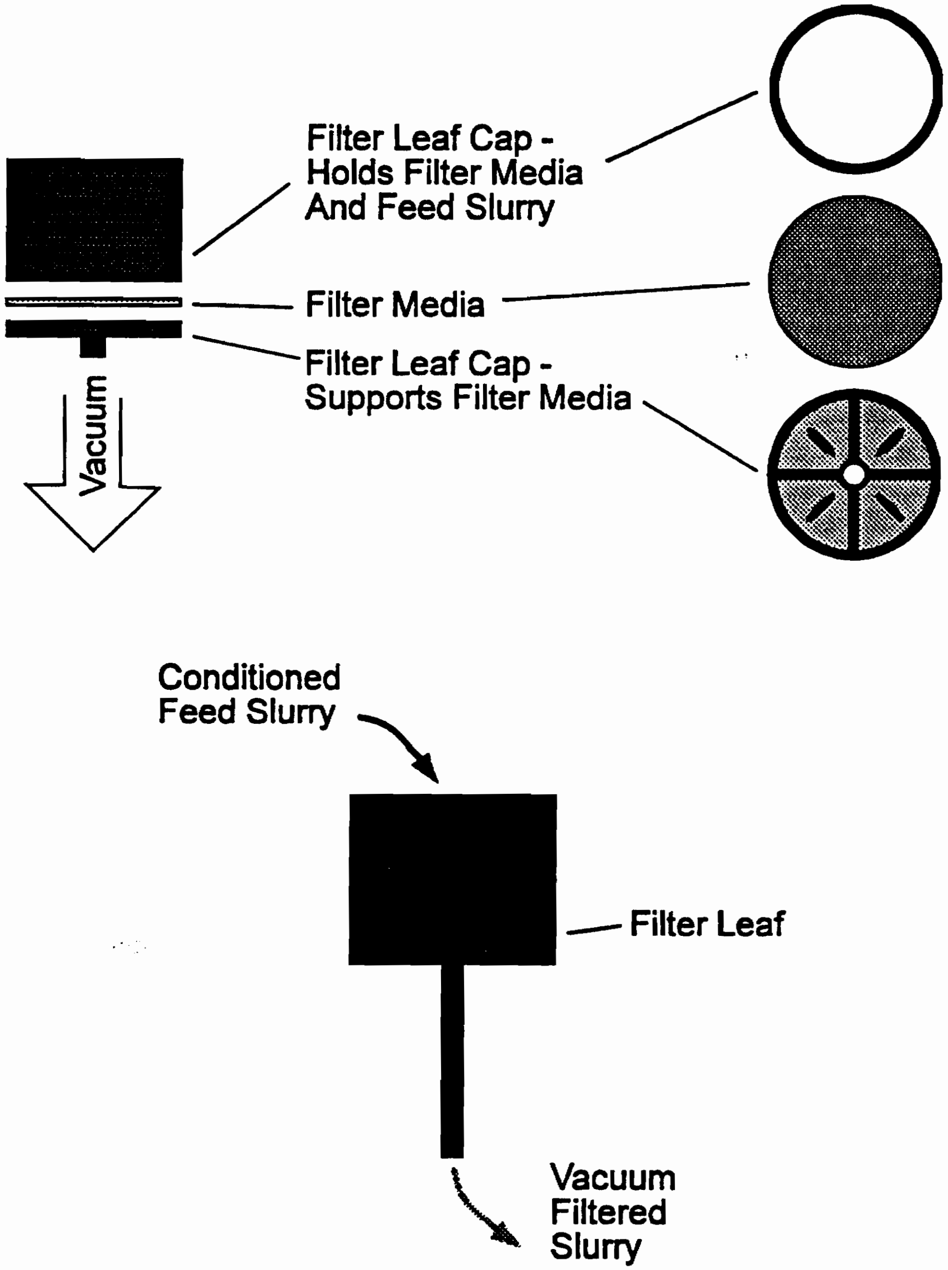


Figure 2.17 Schematic of the inverted filter leaf batch test unit equipped with a peristaltic pump.

media blinded and trapped the solids within the filter cake. In one test, the slurry which passed through the media was filtered twice without removing the filter cake. This produced the best filtration result with an overall separation efficiency of 12% at a 77% recovery of combustibles. The second round filter leaf tests are summarized in Appendix E.

The second round of filter leaf batch tests was conducted using the Pittsburgh No. 8 coal. As with the Elkhorn No. 3 coal, the separation efficiencies were very poor and did not exceed 1%. The filter media either formed a very thin cake (through which most of the solids passed) or the media became blinded (which retained all solids). The data for the filter leaf tests conducted using the Pittsburgh No. 8 coal are also given in Appendix E.

The continuous drum filter tests conducted with the Elkhorn No. 3 coal also did not produce encouraging results. There was no filter cake formation.even at the lowest vacuum pump setting (< 1" of Hg). Furthermore, there was no improvement in separation performance when the pulp agitator was reduced to its lowest speed and the drum cycle time was increased to 3.5 minutes. In all cases, the coagulated feed slurry was pulled through the filter media without any separation occurring.

## 2.8 Froth Flotation

A unique characteristic of the SHC process is that the coagula formed during the process are hydrophobic. As a result, it is theoretically possible to recover the coagula by froth flotation. This would offer an attractive technique for overcoming the limitations associated with the low settling rates of the coal coagula. Furthermore, the use of hydrophobic coagulation should significantly increase the capacity of the froth flotation process since flotation rates increase sharply with increasing particle size. Therefore, a series of tests was conducted to evaluate the potential advantages of using froth flotation to separate the coal coagula from dispersed mineral matter.

### *a) Experimental*

A 5 cm diameter and 150 cm tall high Microcel$^{TM}$ flotation column was used in the froth flotation tests (Figure 2.18). A column was employed because it provides a relatively quiescent environment which should minimize the break-up of coagula. In addition, the column wash water can be used to minimize fine particle entrainment in the froth product. The tests were conducted as a function of volumetric feed rate, feed percent solids, aeration rate, and wash water rate. Three different settings were examined for each operating parameter. Standard operating conditions for the flotation tests are summarized in Table 2.10. The test ranges for each operating parameter are given in Table 2.11. The feed slurry was introduced 114 cm above the bubble generator. The pH of the feed slurry and wash water was maintained at pH 7.5 throughout the test program. Both the Elkhorn No. 3 and Pittsburgh No. 8 coals were tested using this approach.

Separate 3-level and 4-variable factorial designs (with repeat tests at the central point) were generated for each coal using the Design-Expert software package. Each experimental design required 20 individual flotation tests. Assay values were material-balanced to provide a consistent set of data prior to using the software to perform the required regression analyses. A summary of the test results is given in Appendix F. The regression analyses were used to develop empirical expressions relating the operating

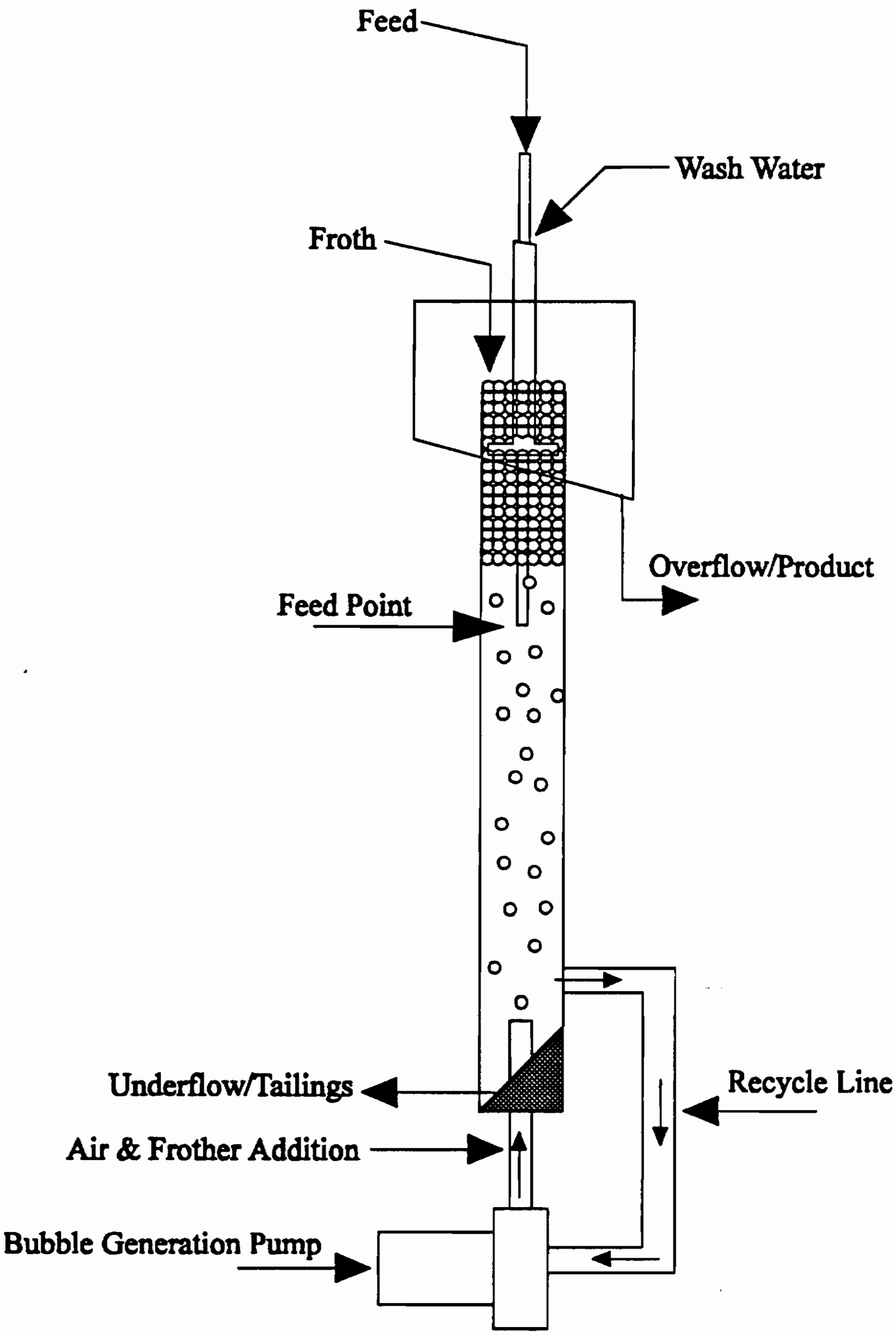


Figure 2.18 Schematic of laboratory flotation column used in coagula recovery test work.

Table 2.10 - Standard operating conditions for the flotation column tests.

| Parameter | Value |
|---|---|
| pH | 7.5 |
| pH Condition Time | 15 minutes |
| Chelating Agent | EDTA |
| Chelate Dosage | 0.4 gm/liter |
| Chelate Condition Time | 15 minutes |
| Frother Dosage | 4 - 5 lb/ton |
| Feed Particle Size | -20 microns |

Table 2.11 - Experimental levels for the column flotation parametric tests.

| Coal Seam | Parameter | Units | Parameter Range<br>Low (-1) | Normal (0) | High (1) |
|---|---|---|---|---|---|
| Elkhorn No. 3<br>(50% Ash) | Feed Solids | (%) | 4 | 7 | 10 |
| | Wash Water | (ml/min) | 200 | 400 | 600 |
| | Feed Rate | (ml/min) | 150 | 200 | 250 |
| | Air Rate | (cc/min) | 1000 | 1500 | 2000 |
| Pittsburgh No. 8 | Feed Solids | (%) | 4 | 7 | 10 |
| | Wash Water | (ml/min) | 200 | 400 | 600 |
| | Feed Rate | (ml/min) | 150 | 200 | 250 |
| | Air Rate | (cc/min) | 1000 | 1500 | 2000 |

conditions to separator performance. Data fitting was performed using standard linear, quadratic, and cubic regression models. While the cubic model typically provided the best fits, many of the coefficients were aliased (i.e., these terms could not be uniquely determined given the available data set). Thus, quadratic models were selected since they minimized model complexity, provided good predictive correlations and reduced aliasing of the model coefficients. For each model, the values of regression coefficients, standard errors, variances, t-tests, etc., were determined as a means of quantifying the statistical significance of each of the coefficients in the regression model.

After completing the statistical analyses, response surface plots were constructed for predicting combustible recovery, concentrate ash, and concentrate sulfur for each of the two base coals. Each set of data were plotted as functions of feed flow rate and solids content in the form of a contour diagram. Thus, nine separate plots were constructed for each response to represent all possible combinations of high, normal, and low settings for the aeration rate and wash water rate.

### *b) Results and Discussion*

The results of the statistical analyses for the Elkhorn No. 3 seam coal are provided in Appendix F. The corresponding response surface plots are shown in Figures 2.19-2.21 for combustible recovery, concentrate ash, and concentrate sulfur, respectively. The parameter correlation chart for these tests is summarized in Table 2.12. The test data indicate that wash water rate was by far the most significant parameter affecting the recovery of the hydrophobic coagula (Figure 2.19). Recovery typically decreased with increasing wash water rate, suggesting that the coagula formed by the SHC process are too weak to withstand the shear forces created in the froth by the wash water. The fact that flotation was unable to achieve recoveries greater than approximately 25-35% at high wash water rates demonstrates the difficulty in capturing fine particles using traditional flotation techniques. Therefore, the development of new flotation cells that are more

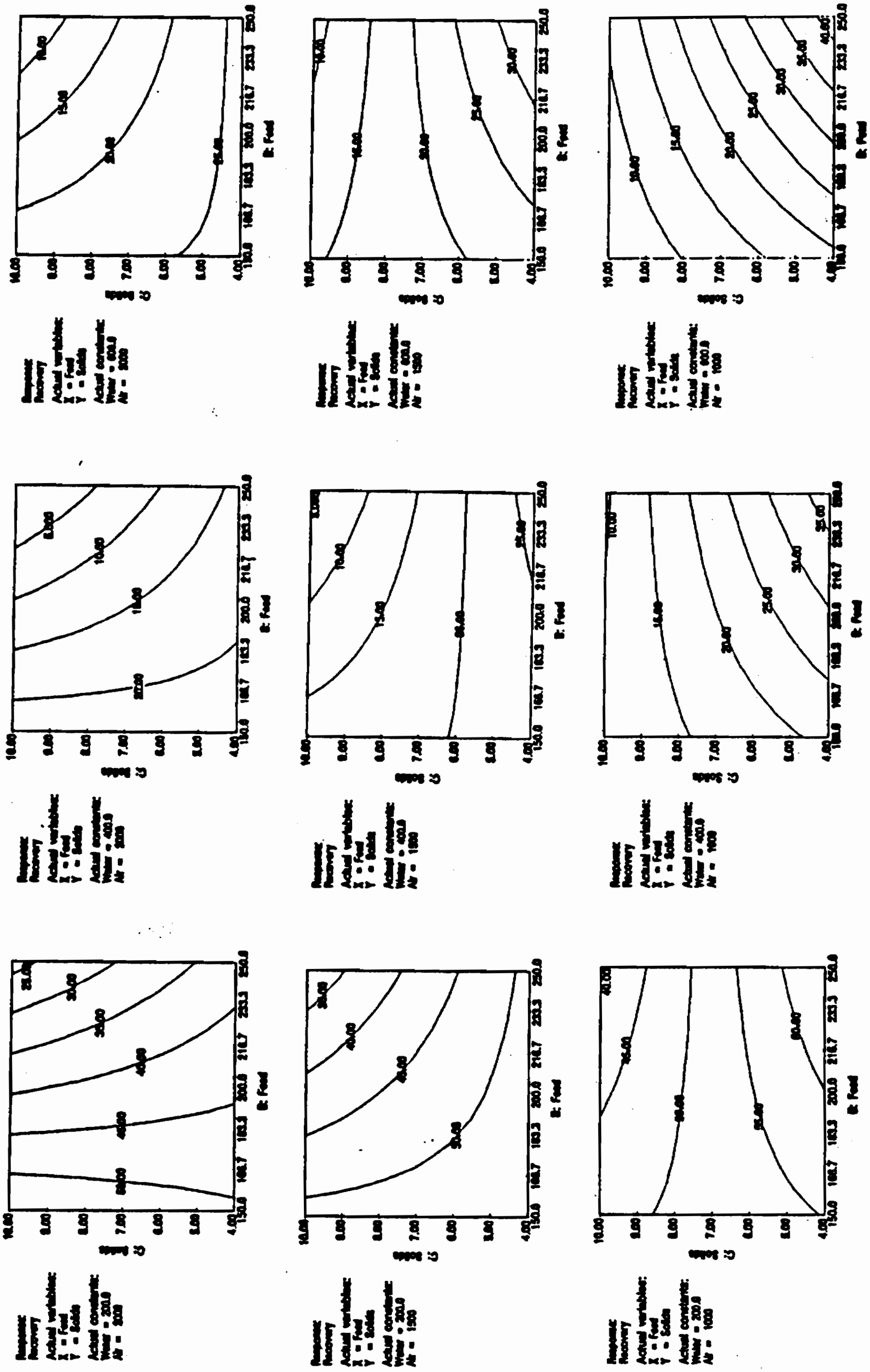


Figure 2.19 Combustible recovery response surface plots for column flotation from the parametric testing of the Elkhorn No. 3 coal.

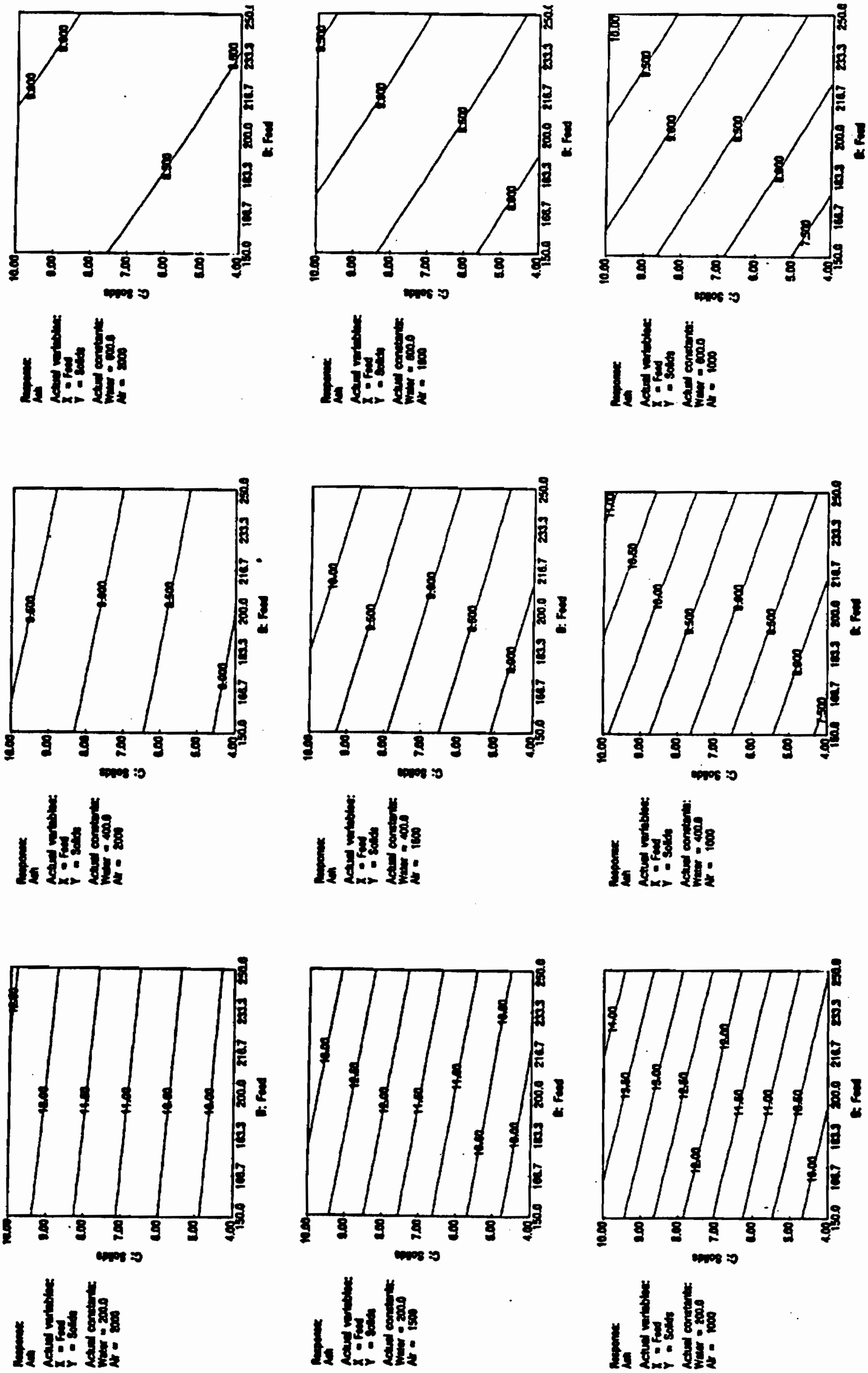


Figure 2.20 Ash content response surface plots for column flotation from the parametric testing of the Elkhorn No. 3 coal.

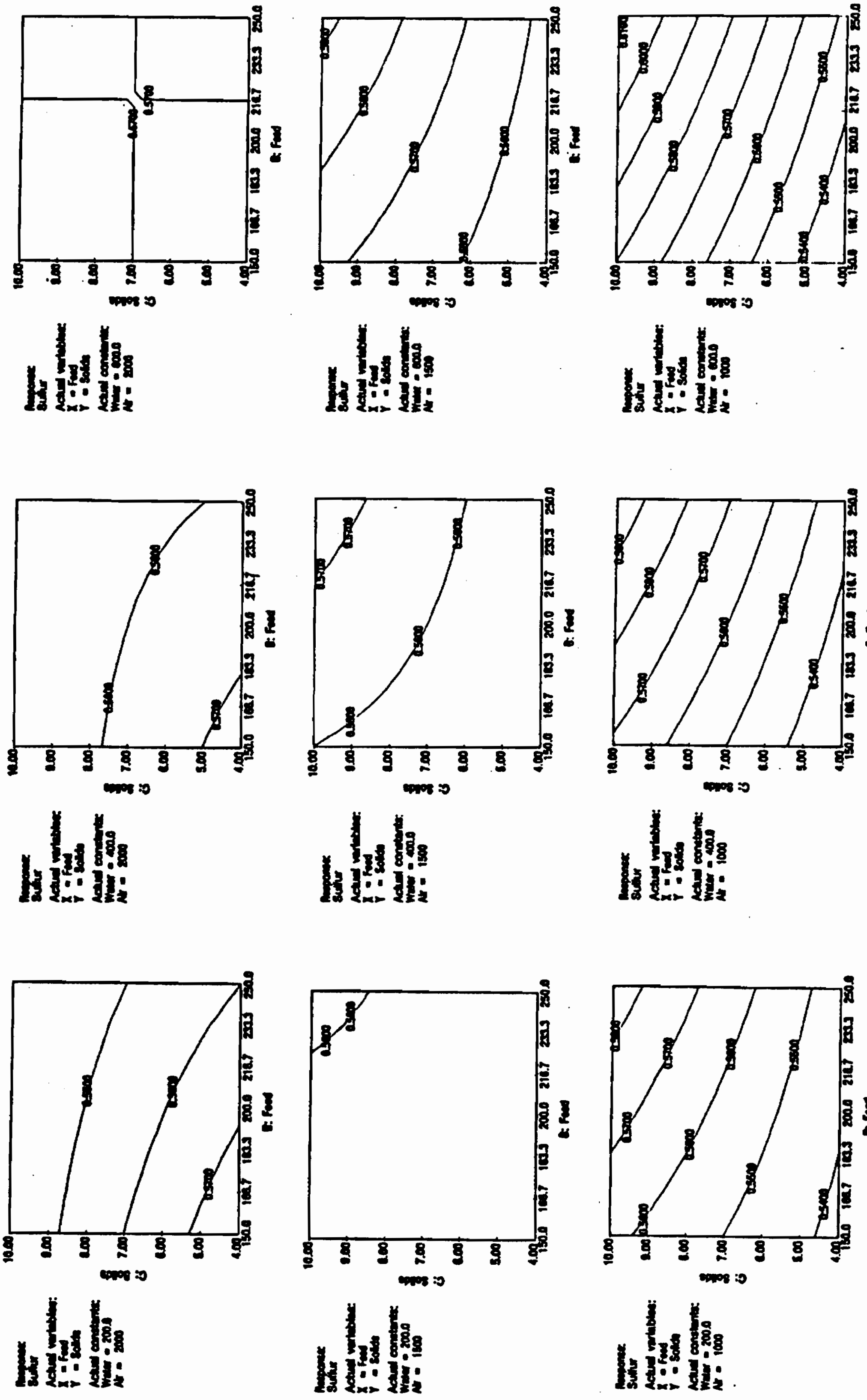


Figure 2.21 Sulfur content response surface plots for column flotation from the parametric testing of the Elkhorn No. 3 coal.

Table 2.12 - Correlation matrix for the flotation column (Elkhorn No. 3 coal).

| | Effect of Increasing: | | | |
|---|---|---|---|---|
| Process Response | Feed Solids | Air Rate | Feed Rate | Water Rate |
| Clean Coal Yield | M↓ | S↓ | S↓ | L↑ |
| Combustible Recovery | M↓ | S↓ | S↓ | L↓ |
| Ash Rejection | S↑ | S↑ | S↑ | M↑ |
| Sulfur Rejection | M↑ | S↑ | S↑ | L↑ |
| Separation Efficiency | M↓ | S↓ | S↓ | L↓ |

L = Large, M = Medium, S = Small
↑ = Increasing Response, ↓ = Decreasing Response

quiescent and can take advantage of the particle size enlargement created by the SHC process my prove very beneficial.

Wash water rate was also found to produce the most significant change in the quality of the froth concentrate. High wash water rates provided the lowest ash contents (Figure 2.20) because of reduction in fine particle entrainment and a decrease in entrapment as a result of coagula breakup. This data suggests that, in addition to quiescent conditions, multiple stages of cleaner flotation may be required to effectively process the coagula formed by the SHC process. In contrast, little variation was observed in the sulfur contour plots (Figure 2.21) due to the relatively low sulfur content of the Elkhorn No. 3 seam coal.

Combustible recovery was generally found to decrease with increasing feed solids content (Figure 2.19). This finding was expected since higher solids loading often result in excessive crowding of the bubble surfaces and a corresponding loss of floatable particles. The same mechanism was responsible for the improved concentrate ash and sulfur values obtained at the higher solids contents (Figures 2.20 and 2.21). Next to wash water rate, feed solids content was found to be the most significant parameter in determining the recovery and quality of the froth concentrate.

Aeration rate was found to have a small negative impact on coagula recovery (Figure 2.19). This trend is opposite to that typically observed during the flotation of well-dispersed hydrophobic particles. In the present work, the higher gas rates are believed to create increased levels of turbulence that are detrimental to the formation of large, stable coagula. The increase in mixing turbulence with gas rate has been previously reported by researchers at Virginia Tech. Thus, high aeration rates and associated turbulence should be avoided when floating hydrophobic coagula. Aeration rate had little impact on either the ash or sulfur contents of the froth products (Figures 2.20 and 2.21).

Recovery tended to decrease with an increase in feed flow rate for most of the operating conditions examined in the present work (Figure 2.19). Similar responses were noted for the ash and sulfur contents of the froth concentrate (Figures 2.20 and 2.21).

The reduced recovery can be attributed to a decrease in retention time and increase in coagula breakage at the higher feed flow rates. The only exception to this trend was observed when low aeration rates were used together with low solids contents or high wash water flow rates. Since the lb/ton frother was held constant throughout the test program, the higher feed flow rates typically resulted in an increased concentration of frother in the flotation pulp. The additional frother reduced the bubble size and resulted in higher particle recoveries. This trend was not observed at low wash water rates since less dilution of the frother occurred under this condition. The incremental increase in frother concentration was too small to have an impact at the higher aeration rates.

A second set of statistical analyses was performed to examine the effects of flotation operating parameters on the recovery of hydrophobic coagula from the Pittsburgh No. 8 seam coal. Details related to the fitting of the various empirical models are provided in Appendix F. The response surface plots for combustible recovery, concentrate ash, and concentrate sulfur are shown in Figures 2.22-2.24. The parameter correlation chart for these tests is summarized in Table 2.13.

As with the Elkhorn No. 3 seam coal, the wash water rate was again found to have a strong adverse effect on the flotation recovery of the hydrophobic coagula (Figure 2.22). This data reinforces the hypothesis that the coagula formed by the SHC process are too weak to withstand the shear forces created in the froth by the wash water. Wash water rate also produced very large changes in the ash and sulfur contents of the froth concentrate (Figures 2.23 and 2.24). It is believed that the high wash water rates reduce fine particle entrainment and decrease entrapment as a result of coagula breakup. These data again suggest that the development of multi-stage quiescent flotation cells may be worth investigating.

Combustible recovery was found to be relatively insensitive to feed solids content, particularly when the air rate or wash water rate was high (Figure 2.22). The same trends were observed in the concentrate ash and sulfur contour plots (Figures 2.23

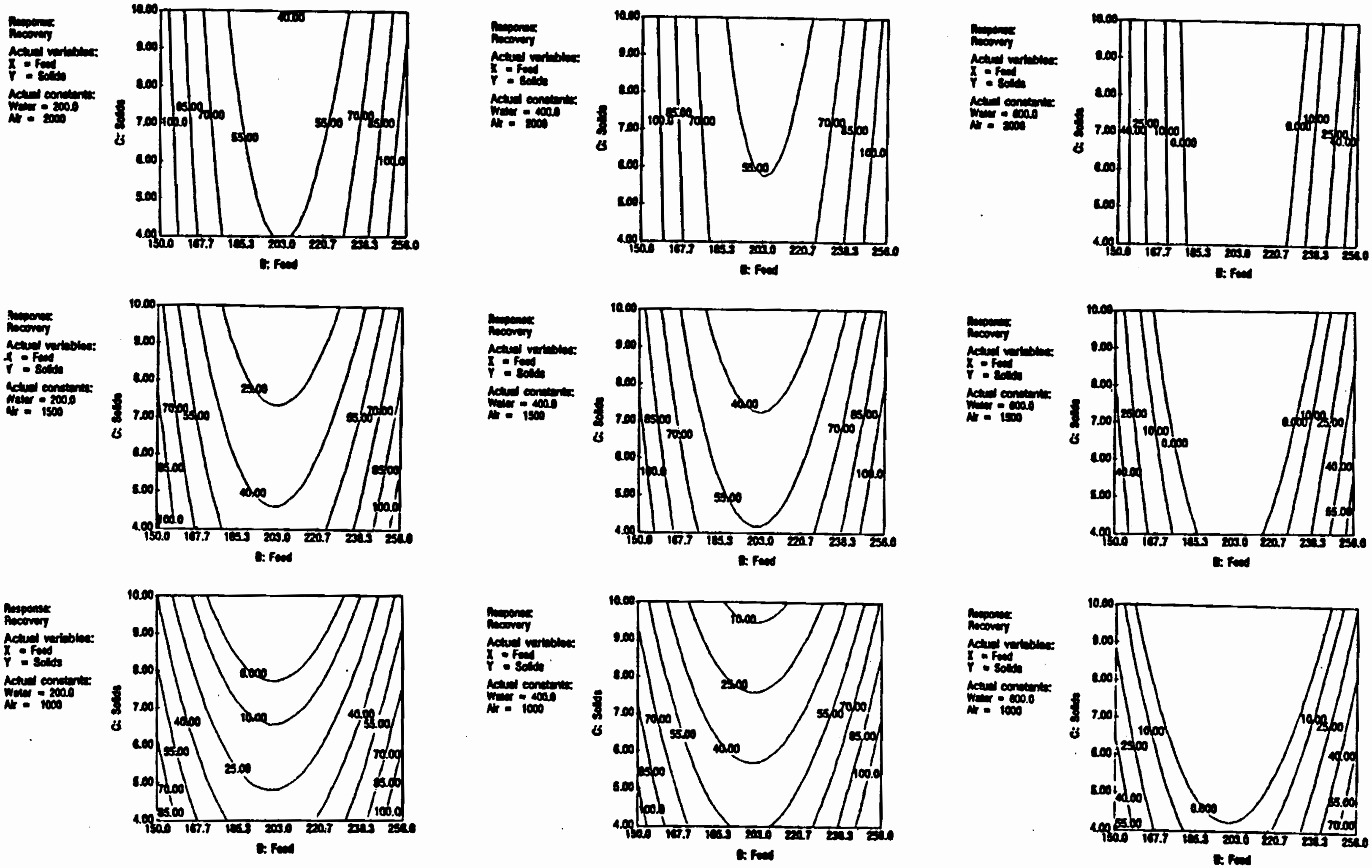


Figure 2.22 Combustible recovery response surface plots for column flotation from the parametric testing of the Pittsburgh No. 8 coal.

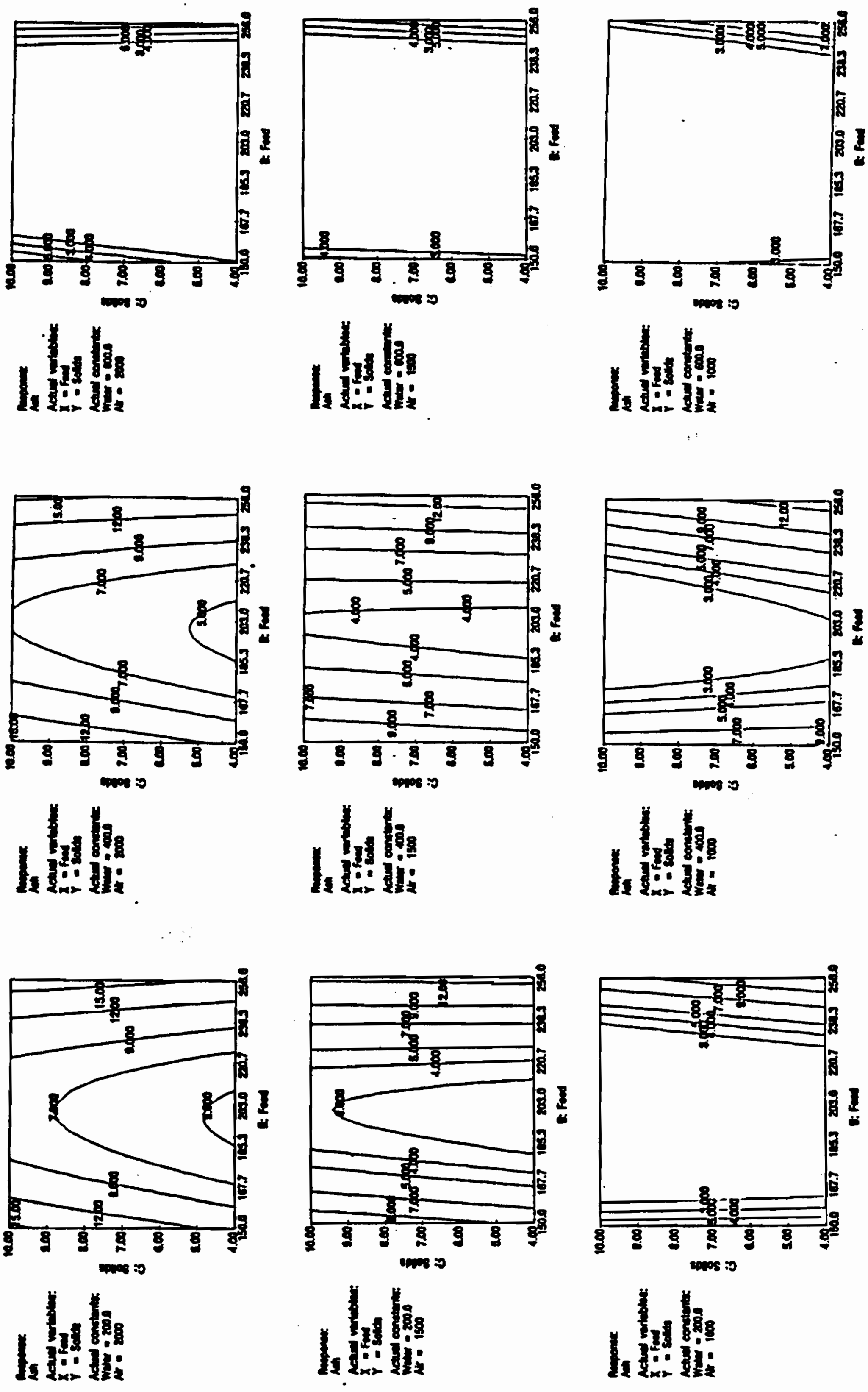


Figure 2.23 Ash content response surface plots for column flotation from the parametric testing of the Pittsburgh No. 8 coal.

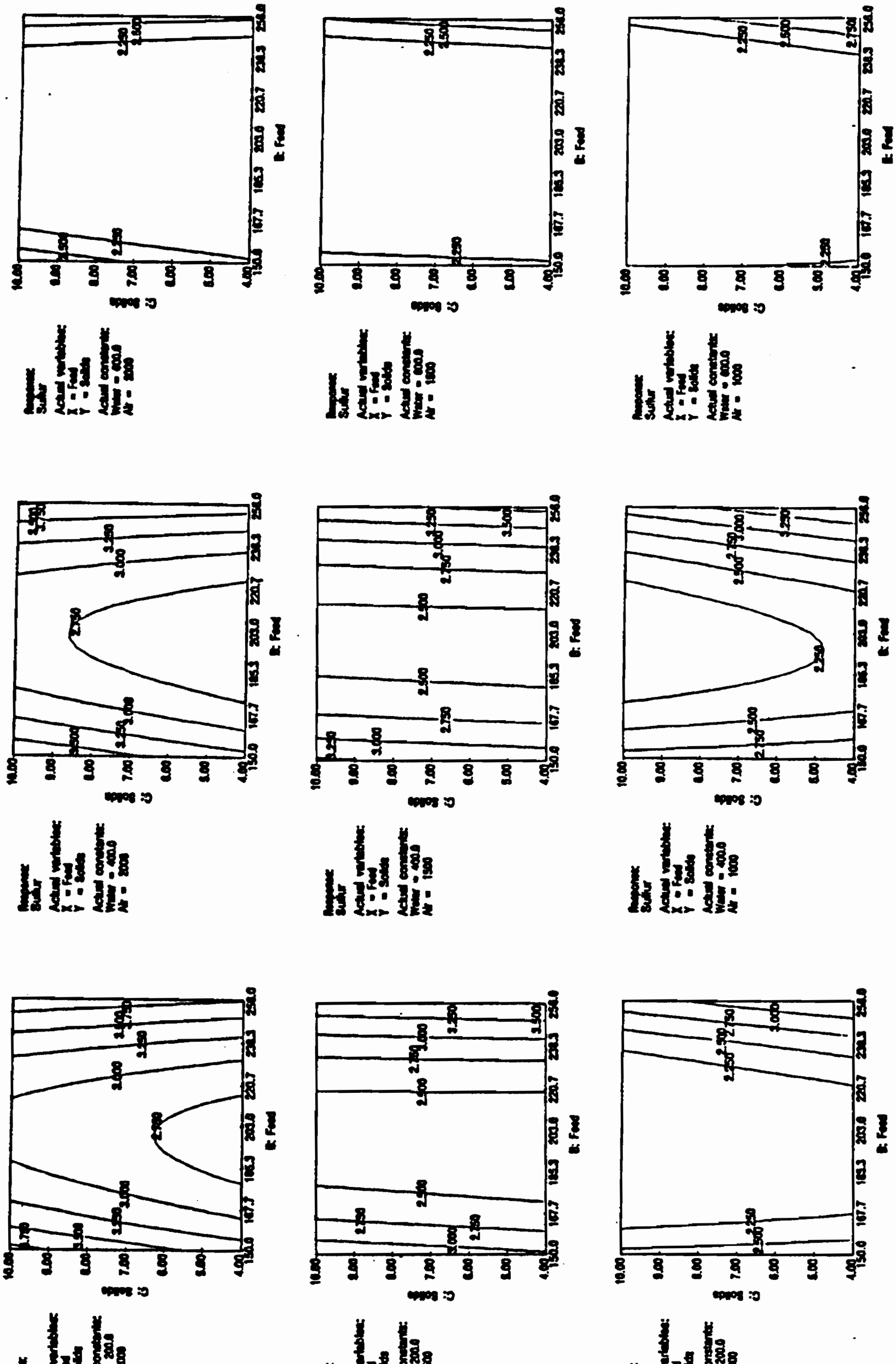


Figure 2.24 Sulfur content response surface plots for column flotation from the parametric testing of the Pittsburgh No. 8 coal.

Table 2.13 - Correlation matrix for the flotation column (Pittsburgh No. 8 coal).

| | Effect of Increasing: | | | |
|---|---|---|---|---|
| Process Response | Feed Solids | Air Rate | Feed Rate | Water Rate |
| Clean Coal Yield | L↓ | L↑ | S↑ | L↓ |
| Combustible Recovery | L↓ | M↑ | S↑ | L↓ |
| Ash Rejection | S↑ | L↓ | M↓ | L↑ |
| Sulfur Rejection | M↑ | L↓ | M↓ | L↑ |
| Separation Efficiency | L↓ | M↓ | M↓ | M↑ |

L = Large, M = Medium, S = Small
↑ = Increasing Response, ↓ = Decreasing Response

and 2.24). These trends can be largely attributed to the overall poor response of the Pittsburgh No. 8 seam coal to selective coagulation, i.e., the Pittsburgh No. 8 coal either coagulated nonselectively or remained completely dispersed.

Aeration rate was found to have only a small impact on combustible recovery for the Pittsburgh No. 8 seam coal (Figure 2.22). In flotation, higher gas rates typically increase recovery by enhancing the flotation kinetics. However, in this case, higher gas rates can also result in higher coagula breakage rates which may reduce the recovery. For this particular coal, higher recoveries associated with enhanced flotation kinetics appear to be offset by the increase in coagula breakage rate with increasing gas rate. Similar trends are observed in the ash and sulfur contour plots (Figures 2.23 and 2.24).

The effect of feed flow rate on the recovery of the Pittsburgh No. 8 seam coal was completely unexpected (Figure 2.22). Typically, good recoveries were only achieved at very low or very high feed flow rates. Similarly, high ash and sulfur values were observed in the same operating regions (Figures 2.23 and 2.24). The batch sedimentation tests conducted in section 2.4 indicated that the coagulation of the Pittsburgh No. 8 seam coal was very nonselective, but much stronger than that observed for the Elkhorn No. 3 seam coal. Under conditions of low turbulence (i.e., low aeration, feed, and wash water flow rates), the strong coagulation tendency resulted in nearly 100% coal recoveries. Higher feed rates increased the level of turbulence, leading to a sharp increase in coagula breakup and corresponding loss of recovery. However, as discussed earlier, an increase in feed rate also increased the frother concentration. The higher frother addition rate resulted in the formation of smaller air bubbles, eventually leading to increased recoveries at the higher feed rates. These complex interactions, which have not yet been addressed by the research community, need to be investigated further in order to develop improved flotation and selective coagulation technologies.

Additional tests were conducted with each of the two coals to determine whether separation performance could be improved by using different pH levels. In general, low pH values cause greater coagulation of coal than do higher pH values. Therefore, tests were conducted at pH values of 4, 6, 7.5 and 10 and feed flow rates of 100, 150 and 225 ml/min in order to assess whether coagulated coal floats faster and more cleanly than dispersed coal. Standard operating conditions for the flotation tests are summarized in Table 2.14. Test conditions, assay values, and various performance parameters for the tests on Elkhorn No. 3 coal are given in Appendix F. Plots of combustible recovery versus ash rejection and product rate versus feed rate are given in Figures 2.25 and 2.26. Similar information for the Pittsburgh No. 8 coal is given in Appendix F and Figures 2.27 and 2.28.

Figures 2.25 and 2.27 show that higher pH levels generally give cleaner products, presumably because the dispersion of both coal and clay is greatly enhanced above pH 7.5. This would be expected to lead to better flotation of coal and less entrapment of mineral matter in the froth. The product versus feed rate plots (Figures 2.26 and 2.28) also show that there are no significant differences in the rates of flotation of the coals at the different pH levels. Since both theory and experience indicate that larger coagula should float faster than dispersed particles, it must be concluded that the coagula present in the flotation feed are being destroyed by turbulence in the column. Analysis of the flow rates of water, particles, and bubbles in the pulp/froth transition zone of the typical flotation column gives Reynolds numbers of about 15,000. This is much higher than the Reynolds number range (100-3000) found to be necessary for acceptable coagula growth by researchers at Virginia Tech. Therefore, these analyses indicate that conventional column flotation is an unsuitable process for upgrading hydrophobic coagula.

Table 2.14 - Standard operating conditions for the flotation column pH tests.

| Parameter | Value |
|---|---|
| pH | 4, 6, 7.5, 10 |
| pH Condition Time | 15 minutes |
| Chelating Agent | EDTA |
| Chelate Dosage | 0.4 gm/liter |
| Chelate Condition Time | 15 minutes |
| Feed Particle Size | -20 microns |
| Feed Rate (ml/min) | 100, 150, 225 |
| Feed Solids Content | 4 % |
| Wash Water | 200 ml/min |
| Aeration Rate | 1500 cc/min |
| Frother Dosage | 3 - 4 lb/ton |

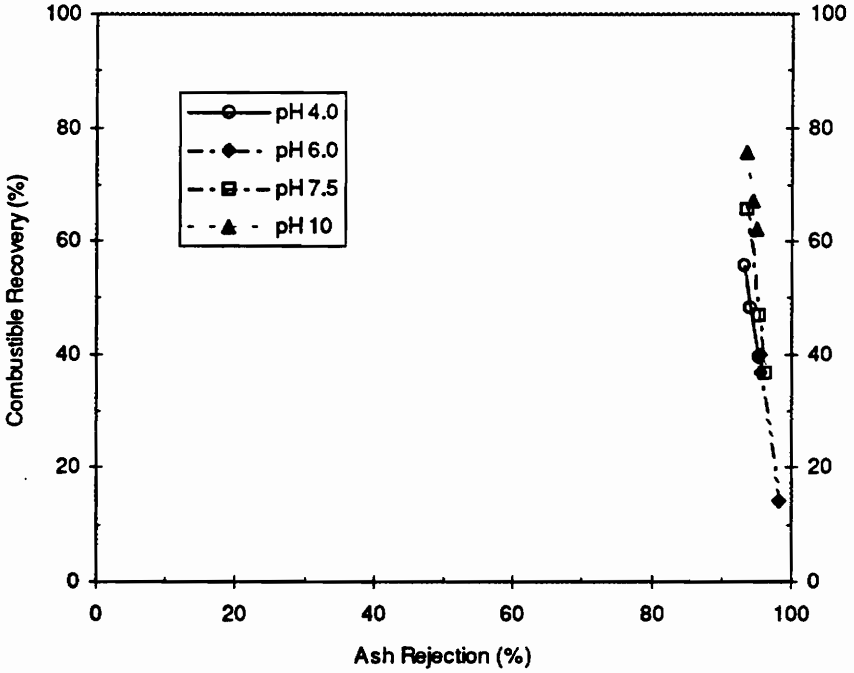


Figure 2.25 Combustible recovery versus ash rejection for the flotation of Elkhorn No. 3 coal at different pH values.

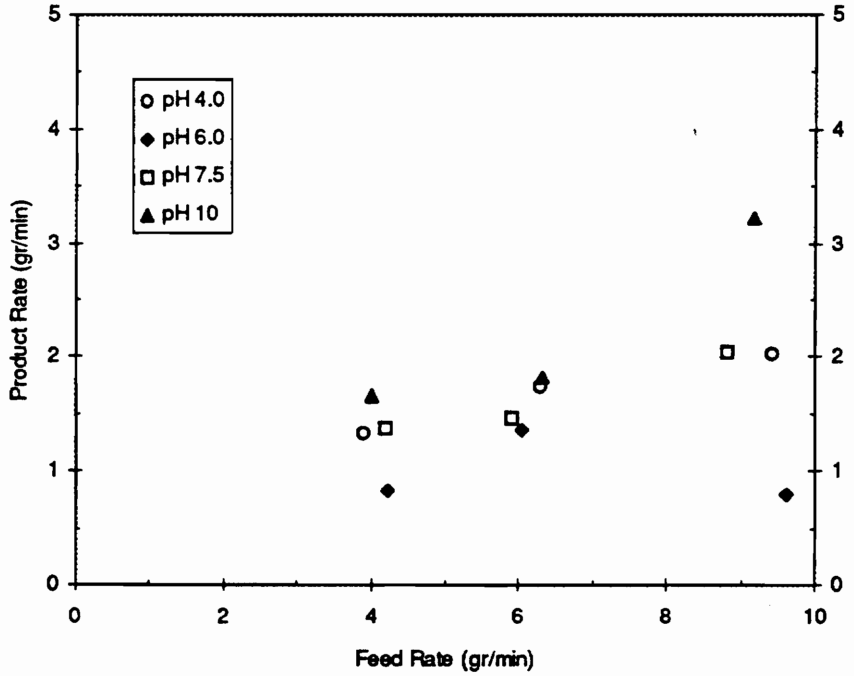


Figure 2.26 Product rate versus feed rate for the flotation of Elkhorn No. 3 coal at different pH values.

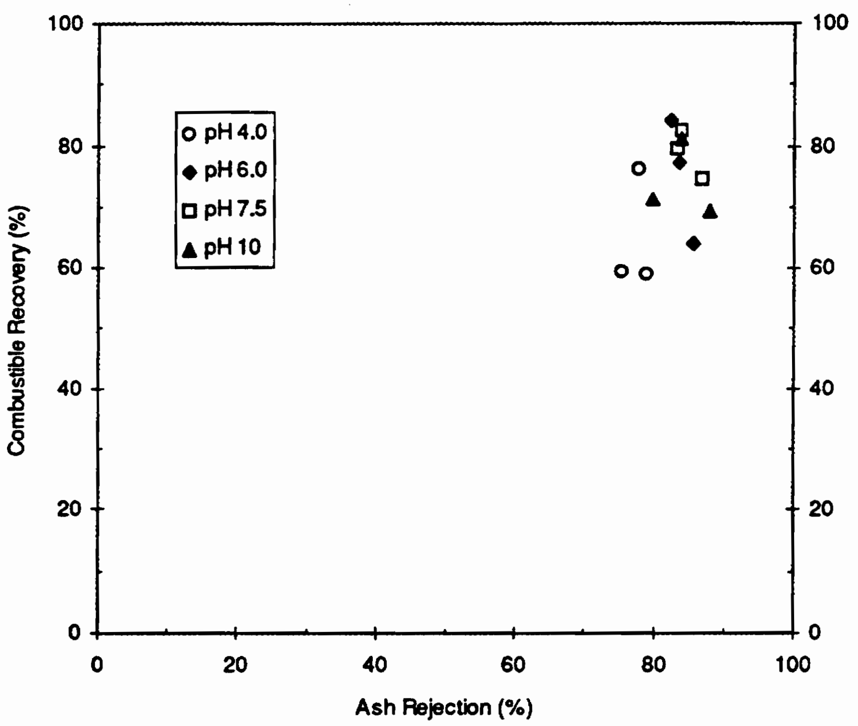


Figure 2.27 Combustible recovery versus ash rejection for the flotation of Pittsburgh No. 8 coal at different pH values.

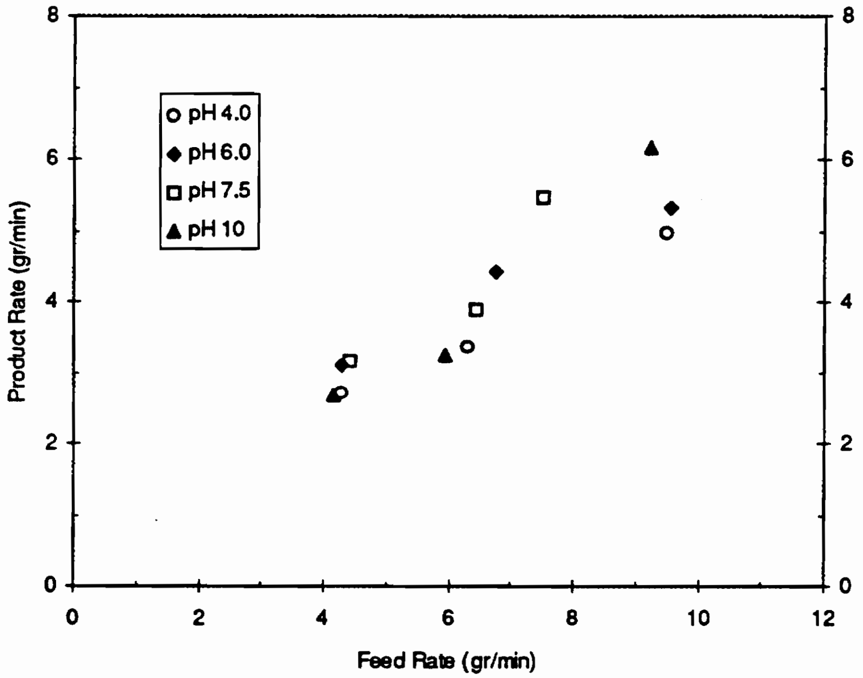


Figure 2.28 Product rate versus feed rate for the flotation of Pittsburgh No. 8 coal at different pH values.

## 2.9 Drum Screen and Low Oil Agglomeration (LOA)

All of the test work conducted to this point indicate that the coagula formed by the SHC process are too weak to be effectively recovered by centrifugation, flotation and filtration processes. Therefore, the use of low oil agglomeration was examined as a means of increasing coagula strength and size.

### *a) Experimental*

A rotating drum screen (Figure 2.29) was used in the low oil agglomeration tests to separate the coal coagula from dispersed mineral matter. In these tests, micronized feed slurry was adjusted to a pH of 8.5 using hydrochloric acid or sodium hydroxide. After the pH stabilized, kerosene was added to the feed slurry as an emulsion and conditioned with the feed slurry for a minimum of 15 minutes. The feed slurry was then pumped through a static pipe into the interior of an eight-inch diameter drum covered with a 400 mesh nylon screen. Coagulated particles which were too large to pass through the screen were carried to the top of the drum by the slow drum rotation speed (1 rpm). At the top of the drum, wash water adjusted to the same pH (i.e., 8.5) as the feed slurry was used to flush the coal coagula off the screen and into a collection trough. Dispersed particles which flowed through the screen were collected separately as tailings. Variables examined in the test program are shown in Table 2.15 and include percent solids, kerosene dosage and feed rate. Standard operating conditions for the drum screen separation tests are summarized in Table 2.16. All of the drum screen tests were performed using an Elkhorn No. 3 coal having a 22% feed ash.

### *b) Results and Discussion*

The test data obtained using the rotating drum screen and low oil agglomeration technique are shown in Figure 2.30. Test conditions, assay values, and various performance parameters are given in Appendix G. As shown, the tests produced poor results with less than 6% separation efficiencies. Figure 2.31 shows that increasing the

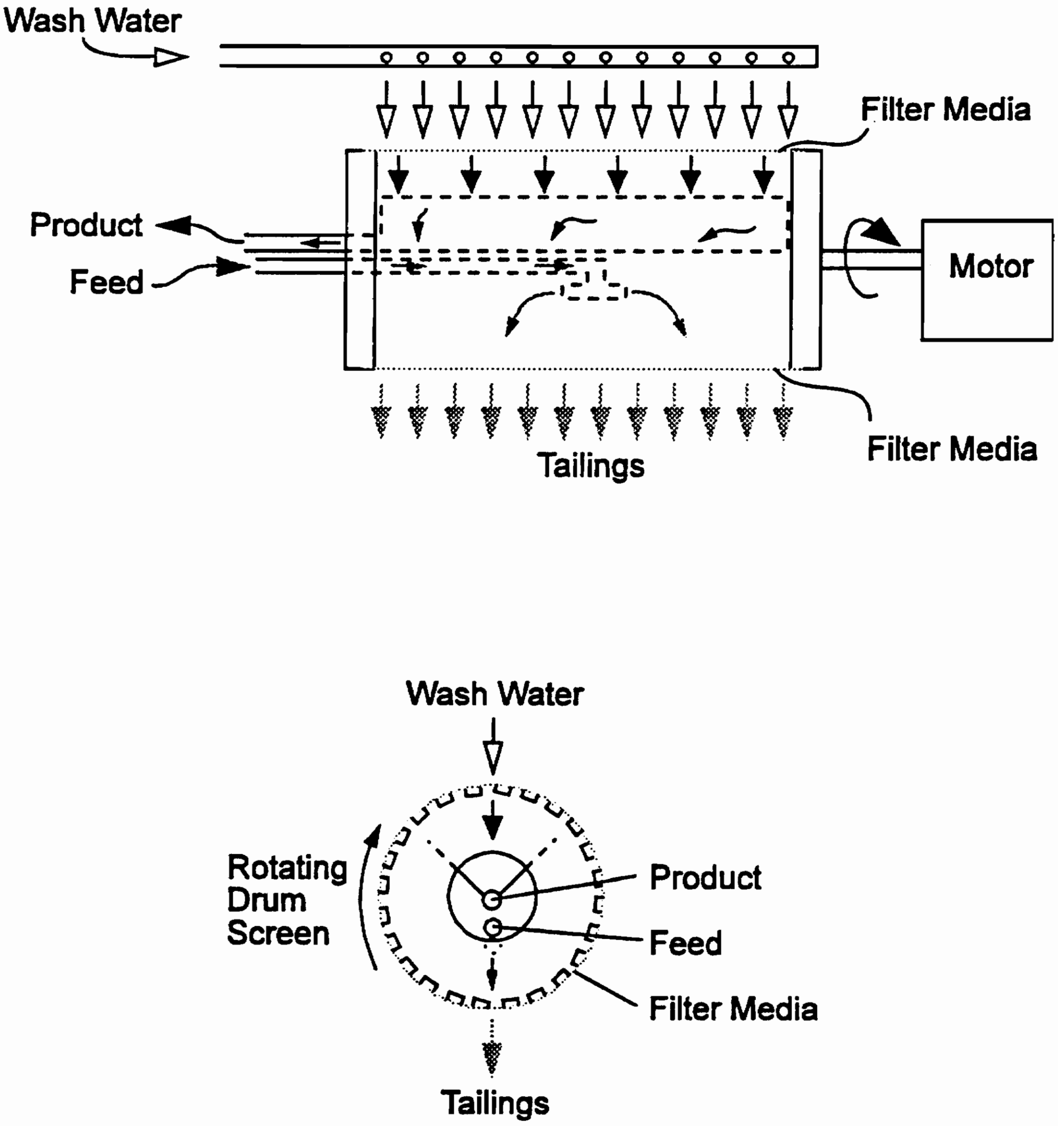


Figure 2.29 Schematic drawing of the rotating drum screen.

Table 2.15 - Operating conditions for the drum screen tests.

| Parameter | Values |
|---|---|
| Feed Rate (ml/min) | 40,70,100 |
| Feed Solids Content (%) | 3,5,7 |
| Kerosene Dosage (lb/ton coal) | 0, 3, 6, 12, 24, 48 |

Table 2.16 - Standard operating conditions for the drum screen tests.

| Parameter | Value |
|---|---|
| pH | 8.5 |
| pH Condition Time | 15 minutes |
| Chelating Agent | none |
| Kerosene Condition Time | 15 minutes |
| Feed Particle Size | -20 microns |
| Filter Medium | nylon (400 mesh) |
| Pulp Depth | below drum |
| Drum Rotational Speed | 0.95 rpm |

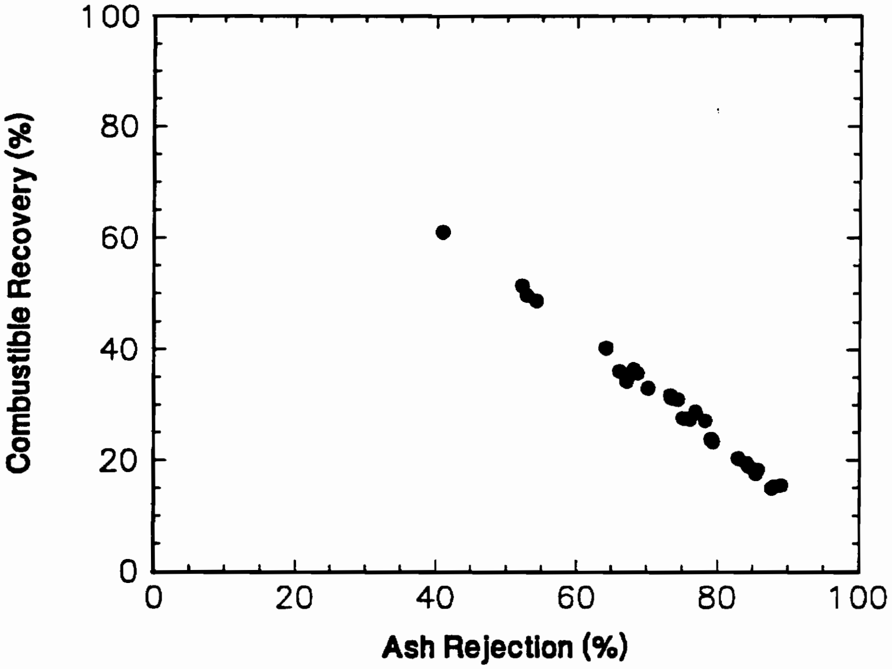


Figure 2.30 Separation results obtained using the drum screen.

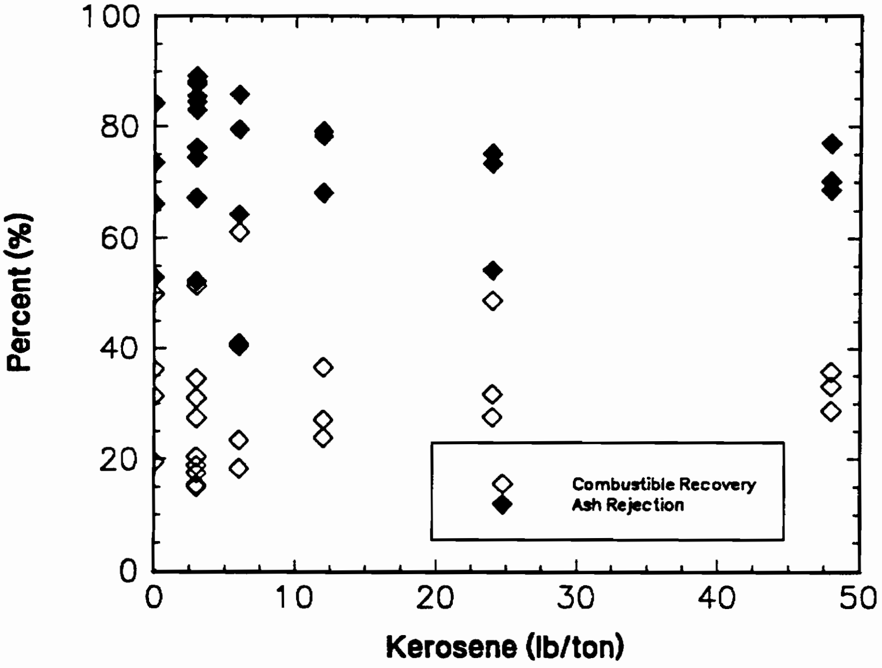


Figure 2.31 Effect of kerosene dosage on the performance of the drum screen.

kerosene dosage improved the coagula recovery. However, the ash rejection decreased at the higher kerosene dosages. This suggests that the higher kerosene dosages increased the coagula size which, in turn, increased coagula recovery and mineral matter entrapment.

## 2.10 Summary

Figure 2.32 shows the grade-recovery curves obtained using the various separation techniques evaluated in the present work for the upgrading of the Elkhorn No. 3 coal. As shown, the lamella thickener outperformed the other coagula separation techniques based on recovery of combustibles and separation efficiency. The lamella thickener obtained a 51% separation efficiency with a 92% recovery of combustibles.

The performance curves also indicate that conventional column flotation worked comparatively well for both coal seams tested. Unfortunately, the turbulence in the columns was found to disrupt coagula growth, making it an unsuitable separation method for selectively coagulated coal particles.

The use of vacuum filtration to separate coagulated coal particles from dispersed matter proved ineffective. The coagula were either broken by the applied vacuum, passing through the filter medium, or the medium became blinded and retained the feed solids. Either way, the filtration separation efficiencies were less than 4%.

As with filtration, the use of the drum screen and low oil agglomeration also proved ineffective in separating the coal coagula from dispersed mineral matter. The low oil agglomeration process did not prove to be selective enough while increasing coagula size and strength. Separation efficiencies with the drum screen were less than 6%.

The use of batch centrifugal sedimentation on the Elkhorn No. 3 seam coal produced high recovery results with moderate to low ash rejections. The best separation efficiency obtained was 40% with a 95% recovery of combustibles. The use of a continuous unit may provide results with slightly higher separation efficiencies, since the batch tests did not make accurate cuts between sedimented and dispersed particles. The

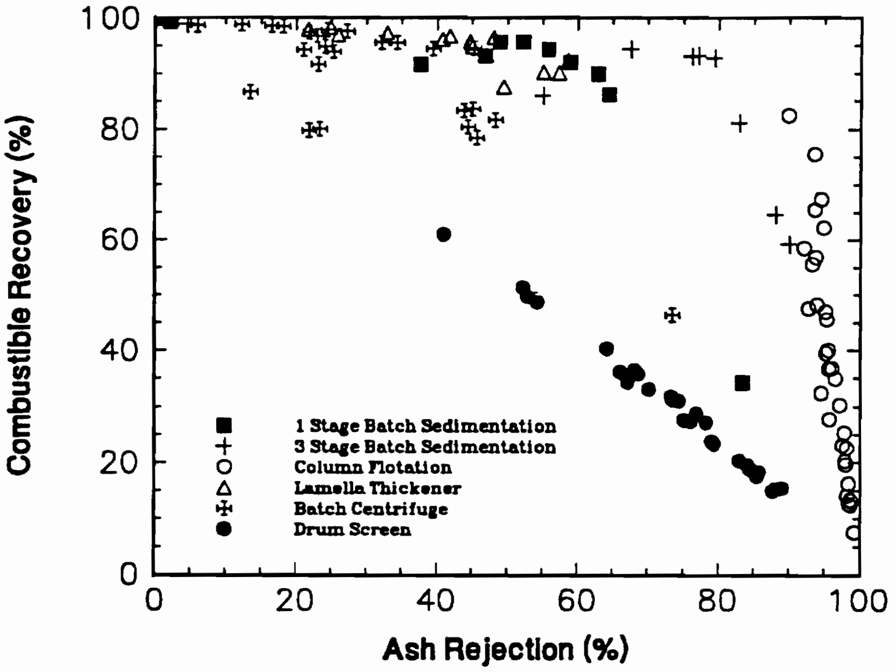


Figure 2.32 Summary of results obtained using the various separation devices for the Elkhorn No. 3 coal.

use of a continuous centrifuge may also reduce retention times and increase throughputs over the other sedimentation techniques examined since low feed solids provided a better separation efficiency.

Aside from froth flotation, the Pittsburgh No. 8 seam coal did not perform well using the other separation methods (Figure 2.33). The coagulation of the Pittsburgh No. 8 seam coal did not prove to be selective enough for upgrading. Sedimentation techniques rejected very little ash at suitable recovery values due to the heterocoagulation of gangue and coal particles. Further testing with dispersants and chelating agents may improve the selective coagulation of this coal, although insufficient resources were available in this project to investigate this possibility.

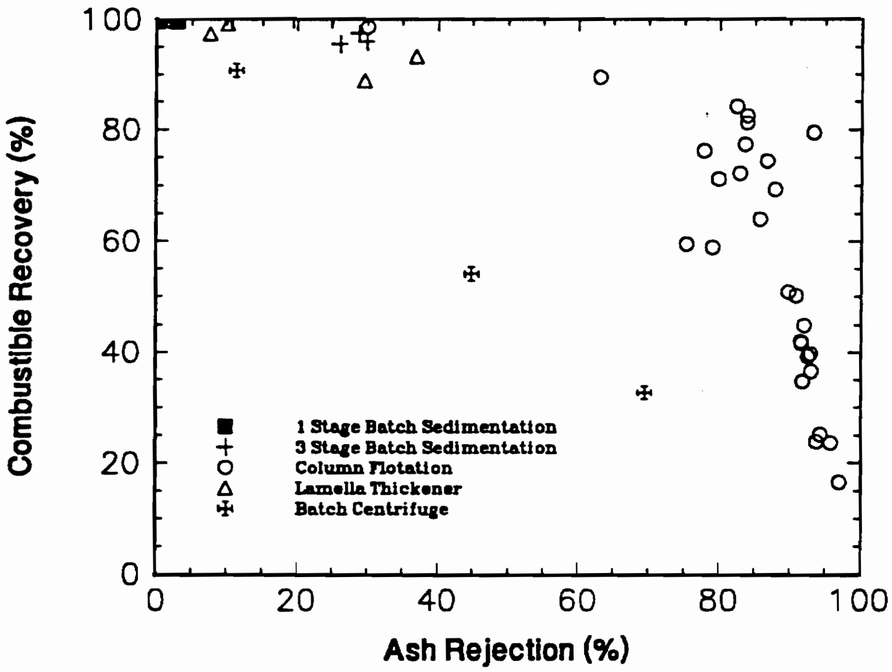


Figure 2.33 Summary of results obtained using the various separation devices for the Pittsburgh No. 8 coal.

# Chapter 3 Bench-Scale Process Optimization

## 3.1 Preliminary Optimization

The objective of this task was to optimize the performance of the best combination of mixer and separator examined in the present work. It was concluded by researchers at Virginia Tech that any level of turbulence created by mixing was detrimental to the formation and subsequent growth of the hydrophobic coagula. However, some degree of mixing was found to be required between separation stages to redisperse mineral matter that may have become entrapped within the coal coagula. A simple mixing tank and impeller was deemed to be the most reliable and least costly agitator for this purpose. In section 2.10, it was concluded that the lamella thickener provided the only viable method of recovering coal coagula of the various separation processes tested. The lamella thickener was able to achieve a 51% separation efficiency with a 92% recovery of combustibles. Therefore, the optimization tests were conducted using multiple-stage cleaning with a simple mixer and lamella thickener separator.

### *a) Experimental*

The first series of optimization tests were conducted using the Elkhorn No. 3 coal which had been wet-ground in a stirred ball mill to a topsize of 20 microns. In these tests, the lamella thickener was operated continuously with three cleaning stages. The standard operating parameters are shown in Table 3.1. The optimum operating conditions were chosen based on the test data obtained in section 2.5. The main criteria for selecting the best operating parameters were high separation efficiencies. In all tests, the wash water rate was set at 40 ml/min since higher wash water rates tended to increase the separation efficiency. EDTA was not utilized in these tests and the pH of the feed slurry was adjusted to 8.5 using hydrochloric acid (HCl) or sodium hydroxide (NaOH). This pH was found to be near the optimum pH for selective coagulation from the batch sedimentation tests reported in section 2.4. The middle feed rate of 100 ml/min was

Table 3.1 - Standard operating conditions for the 3-stage lamella thickener tests.

| Parameter | Value |
|---|---|
| pH | 8.5 |
| pH Condition Time | 15 minutes |
| Chelating Agent | none |
| Feed Particle Size | -20 microns |
| Feed Rate | 100 ml/min |
| Wash Water Rate | 40 ml/min |
| Mudline | constant |
| Lamella Plate Angle | 45° |
| Cell Actual Area | 42 $inch^2$ |
| Cell Effective Area | 170 $inch^2$ |
| Cell Volume | 11 liters |

chosen since higher feed rates decreased recovery and lower feed rates decreased separation efficiency. The feed solids content in the first stage of cleaning was set at 4% solids. Because of dilution, the solids content was reduced to 3% and 2% in stages 2 and 3, respectively. The test data indicated that a higher separation efficiency could have been obtained in the first and second stages using a 2% feed solids content. However, a 4% feed solids content was used in the first stage to increase the feed mass flow rate to 0.5 lb/hr. The results of the multi-stage cleaning tests are summarized in Appendix H.

In the second series of optimization tests, an oil emulsion of kerosene and water was added to the feed slurry to improve the separation efficiency of the lamella thickener. Kerosene dosages of 0, 3, 6, 9, 12, 24 and 48 lbs/ton of coal were examined in these tests. Table 3.2 shows the standard operating conditions for the low-oil agglomeration lamella thickener tests. The lamella thickener was operated at a feed rate of 100 ml/min, a solids content of 4%, and a wash water rate of 40 ml/min. These settings were found to be near the optimum (based on separation efficiency) for the Elkhorn No. 3 coal. The test data obtained during this series of experiments are summarized in Appendix H.

### *b) Results and Discussion*

Figure 3.1 shows the results of the lamella thickener tests conducted using the Elkhorn No. 3 coal. After three stages of cleaning, the 50% ash coal produced a final product of 16.9% ash. The overall combustible recovery and separation efficiency values were 84.1% and 64.2% respectively. A larger drop in combustible recovery was observed with the staged lamella thickener than with the batch sedimentation tests. For comparison, the three-stage batch sedimentation test conducted at 3% solids, pH 8.5 and no EDTA gave a combustible recovery of 93.3% and a separation efficiency of 70.5%. It is believed that the performance of the lamella thickener could have been improved by reducing the feed solids content in the first and second cleaning stages.

Table 3.2 - Standard operating conditions for the LOA lamella thickener tests.

| Parameter | Value |
|---|---|
| pH | 8.5 |
| pH Condition Time | 15 minutes |
| Chelating Agent | none |
| Kerosene Condition Time | 30 minutes |
| Feed Rate | 100 ml/min |
| Feed Solids Content | 4% |
| Wash Water Rate | 40 ml/min |
| Feed Particle Size | -20 microns |
| Mudline | constant |
| Lamella Plate Angle | 45° |
| Cell Actual Area | 42 inch$^2$ |
| Cell Effective Area | 170 inch$^2$ |
| Cell Volume | 11 liters |

Figure 3.2 shows the results obtained during the low-oil agglomeration tests conducted using the lamella thickener. The addition of the kerosene emulsion into the feed slurry increased the ash rejection as much as 18% with only a 2.5% reduction in the combustible recovery. The separation efficiency peaked at 56% with a kerosene addition of 12 lbs/ton of feed coal.

The response surface plots shown in Figure 2.8 for the lamella type thickener show that the combustible recovery increased with increasing feed solids content and decreased with increasing feed rate. The increasing feed solids content increased the pulp density in the thickener which enhanced particle-particle collision and subsequent coagulation. The larger coagula settled faster, thereby increasing the coal recovery. The higher feed rates increased the superficial velocity which forced more coagula to the tailings overflow and decreased the recovery. The highest recovery values (99%) were obtained at high feed solids contents and low feed rates.

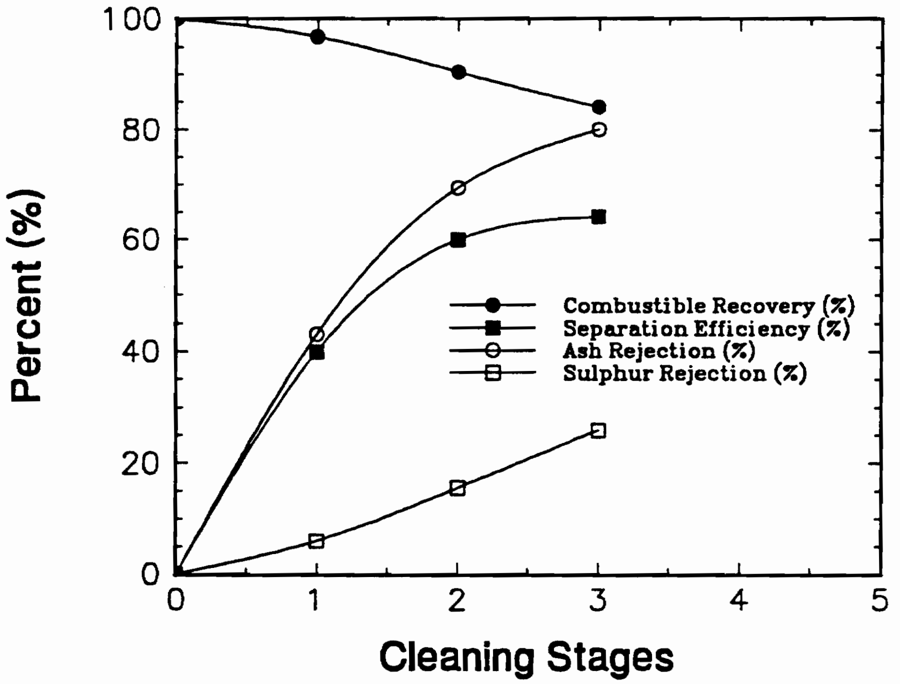


Figure 3.1 Test results obtained after 3 stages of cleaning using the lamella thickener.

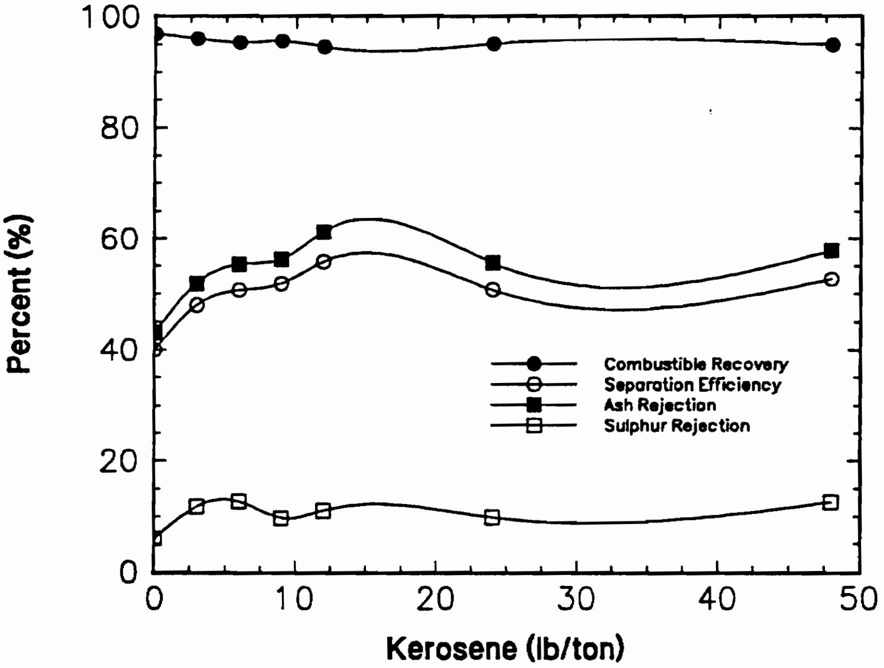


Figure 3.2 Effect of kerosene dosage on the recovery of combustibles, separation efficiency, and ash rejection obtained using the lamella thickener.

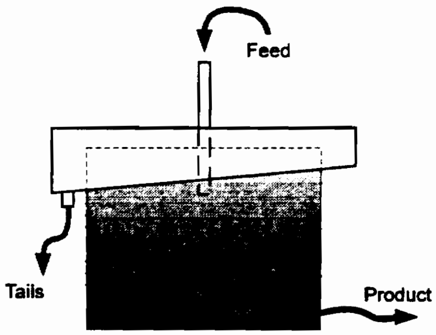
## 3.2 Comparison of Thickener Designs

The data obtained from the preliminary optimization tests indicate that the lamella thickener is capable of efficiently separating the coal coagula and dispersed mineral matter. However, this data does not indicate whether the lamella thickener design offers any advantages over the "open tank" design of traditional sedimentation processes. Therefore, an additional series of optimization tests was conducted in the present work to compare the performance of a conventional thickener with that of the lamella thickener.

### *a) Experimental*

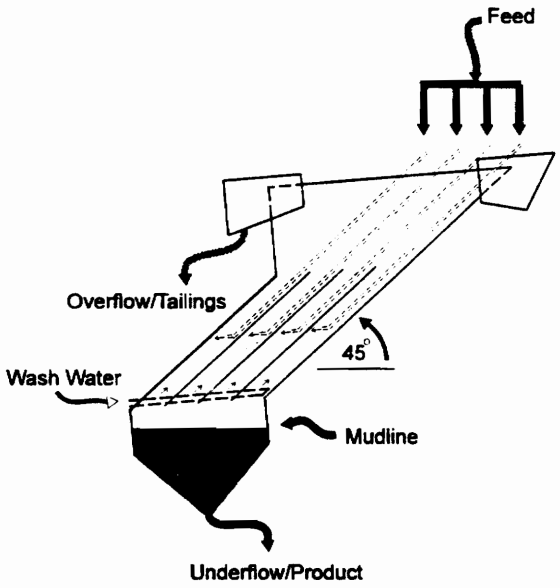
A 27 cm diameter conventional thickener with an effective area of 559 $cm^2$ was used in the comparison tests. Figure 3.3 compares the effective areas and volumes of the conventional and lamella thickeners. The two operating parameters studied in this series of tests were feed solids content and volumetric feed rate. Three different settings were examined for each operating parameter. The test ranges for each operating parameter are given in Table 3:3 while the standard operating parameters for these tests are given in Table 3.4. Using these values, a 3-level and 2-variable factorial design was generated for the Elkhorn No. 3 coal using the Design-Expert software package. The experimental design required nine individual tests. Appendix H provides a summary of the comparative test results.

After completing the experiments, regression analyses were used to develop empirical expressions relating the operating conditions to the separation performance. For each model, the values of regression coefficients, standard errors, variances, t-tests, etc., were determined as a means of quantifying the statistical significance of each of the coefficients in the regression model. Response surface plots were then constructed for predicting combustible recovery, ash rejection, and separation efficiency. Each set of data was plotted as a function of feed solids content and feed flow rate in the form of a contour diagrams. The results of the statistical analyses are provided in Appendix H.



Conventional Thickener

Diameter = 27 cm
Actual Area = Effective Area = 559 $cm^2$
Volume = 10.5 liters



Lamella Thickener

Effective Area = n x a x cos (alpha)
n = number of plates
a = area of one plate
alpha = angle of plates

Effective Area = 4 x 387 x cos (45) = 1095 $cm^2$

Actual Area = 271 $cm^2$
Volume = 11 liters

Figure 3.3 Schematic of the conventional and lamella thickener test units.

Table 3.3 - Experimental levels for the conventional thickener parametric tests.

| Coal Seam | Parameter | Units | Parameter Range<br>Low (-1) | <br>Normal (0) | <br>High (1) |
|---|---|---|---|---|---|
| Elkhorn No. 3 (50% Ash) | Feed Solids | (%) | 2 | 3 | 4 |
| | Feed Rate | (ml/min) | 50 | 100 | 150 |

Table 3.4 - Standard operating conditions for the conventional thickener tests.

| Parameter | Value |
|---|---|
| pH | 8.5 |
| pH Condition Time | 15 minutes |
| Chelating Agent | none |
| Wash Water | none |
| Feed Point Depth | 1.5 inches |
| Feed Particle Size | -20 microns |
| Mudline | constant |
| Cell Actual Area | 87 $inch^2$ |
| Cell Volume | 10.5 liters |
| Cell Diameter | 10.5 inches |

### *b) Results and Discussion*

The statistical correlations between the model predictions and the experimental results were found to be satisfactory with the exception of one test run. Test number 3 of the conventional thickener tests (Appendix H) was omitted as an outlier in the statistical analyses. Based on these statistical correlations, a correlation matrix (Table 3.5) was constructed to summarize the effects of the operating parameters on the separation performance. The corresponding response surface plots are shown in Figure 3.4 for combustible recovery, ash rejection, and separation efficiency. The trends observed in these plots are discussed in the following sections.

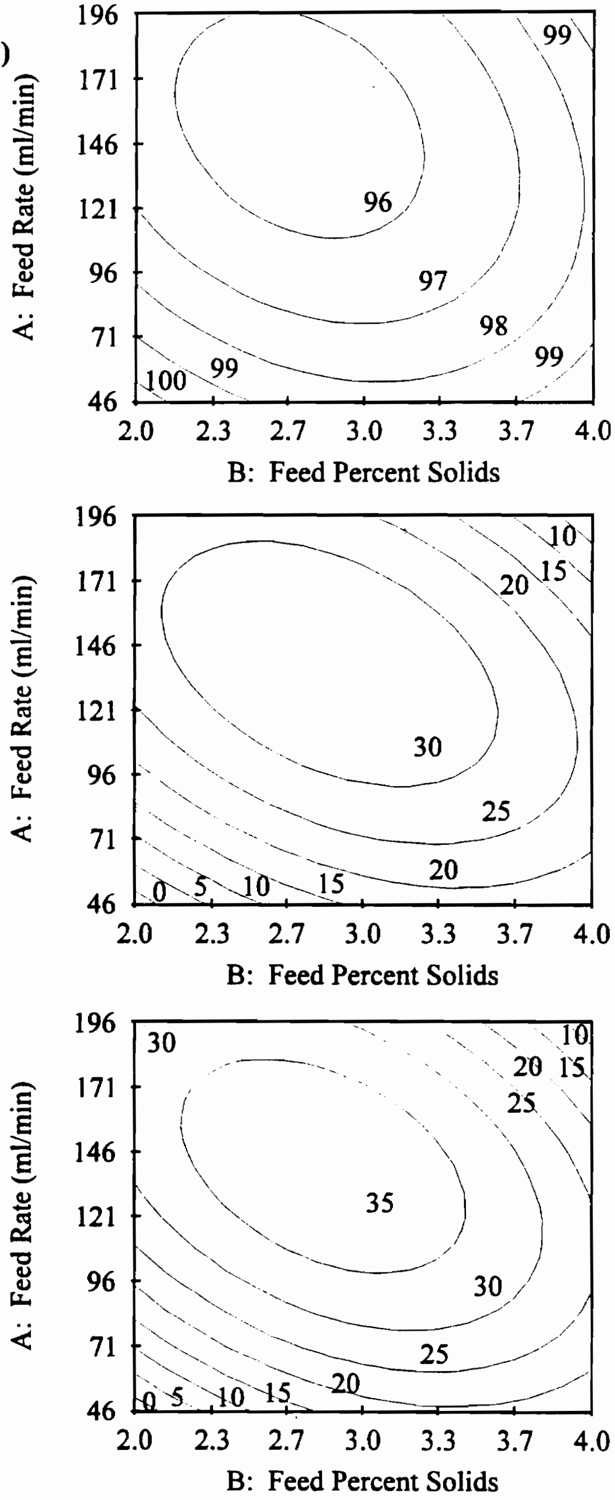
As with the lamella type thickener, increasing the feed rate also increased the separation efficiency for the conventional thickener design. However, the effect of increasing feed rate was greater for the conventional thickener than for the lamella thickener. The higher feed rates increased the superficial velocity which improved the removal of fine mineral matter. Unlike the lamella type thickener results, an increase in the feed solids content slightly increased the separation efficiency. This result was unexpected since all previous coagulation data showed a decreased rejection with increasing solids content. The decrease in rejection was attributed to an increase in the entrapment of mineral matter in the coagula at the higher solids contents. This reverse result for the conventional thickener could be due to the smaller range of feed solids examined and the effect of the omission of the outlier test #3. The maximum separation efficiency (30%) occurred at the moderate feed solids contents and feed rates.

The response surface plots indicate that the ash rejection was most affected by increasing the feed rate. The higher feed rates increased the superficial velocity and provided an increase in the rejection of mineral matter. The rejection of ash increased slightly with increasing feed solids content. This finding was unexpected since previous selective coagulation tests indicated a decrease in ash rejection with increasing feed solids content. As noted in the above paragraph, this unexpected result could be due to

Table 3.5 - Correlation matrix for the conventional thickener.

| | Effect of Increasing: | |
|---|---|---|
| Process Response | Feed Solids | Feed Rate |
| Combustible Recovery | S↑ | S↓ |
| Ash Rejection | S↑ | M↑ |
| Separation Efficiency | S↑ | M↑ |

L = Large, M = Medium, S = Small
↑ = Increasing Response, ↓ = Decreasing Response



Response:
**Combustible Recovery (%)**

Actual variables:
X = Feed Percent Solids
Y = Feed Rate

Response:
**Separation Efficiency (%)**

Actual variables:
X = Feed Percent Solids
Y = Feed Rate

Response:
**Ash Rejection (%)**

Actual variables:
X = Feed Percent Solids
Y = Feed Rate

Figure 3.4 Response surface plots obtained from the statistical analysis of the conventional thickener test data.

the lack-of-fit of the regression model created by the omission of test run #3. The highest ash rejection (35%) was seen at moderate feed solids contents and feed rates.

## 3.3 Summary

Figure 3.5 shows the grade-recovery curves for the various thickener separation methods examined using the Elkhorn No. 3 seam coal. While all of the methods maintained high recoveries, the lamella thickener with low-oil agglomeration produced the best separation efficiencies with one stage of cleaning. The use of the lamella thickener without low-oil agglomeration had a slight drop in combustible recovery at comparable ash rejection values. The conventional thickener unit could not achieve ash rejections as high as the lamella thickener. The best single-stage thickener test employed low-oil agglomeration and produced a 95% recovery of combustibles at a 56% separation efficiency. The three-stage lamella thickener test without low-oil agglomeration achieved an overall recovery of 84% at a 64% separation efficiency.

The throughput for the lamella type thickener and the conventional thickener were compared using the results obtained from the lamella thickener, low-oil agglomeration thickener, and conventional thickener tests. Table 3.6 shows the tests with the maximum separation efficiencies from these experiments. Based on the calculated effective areas of the test units, the conventional thickener had the highest throughput of 10.4 lb/hr/m$^2$ with a separation efficiency of 34%. The lamella thickener provided only half the conventional thickener's effective area throughput with a maximum separation efficiency of 56%. However, when the comparison was based on the actual area of the test units, the lamella thickener had nearly double the throughput at 19.6 lb/hr/m$^2$ with separation efficiencies greater than the conventional thickener. Both units operated at about the same level when the throughput was compared based on the unit volume of the thickener, i.e., the conventional and the lamella thickener had throughputs of 0.055 and 0.048 lb/hr/liter respectively.

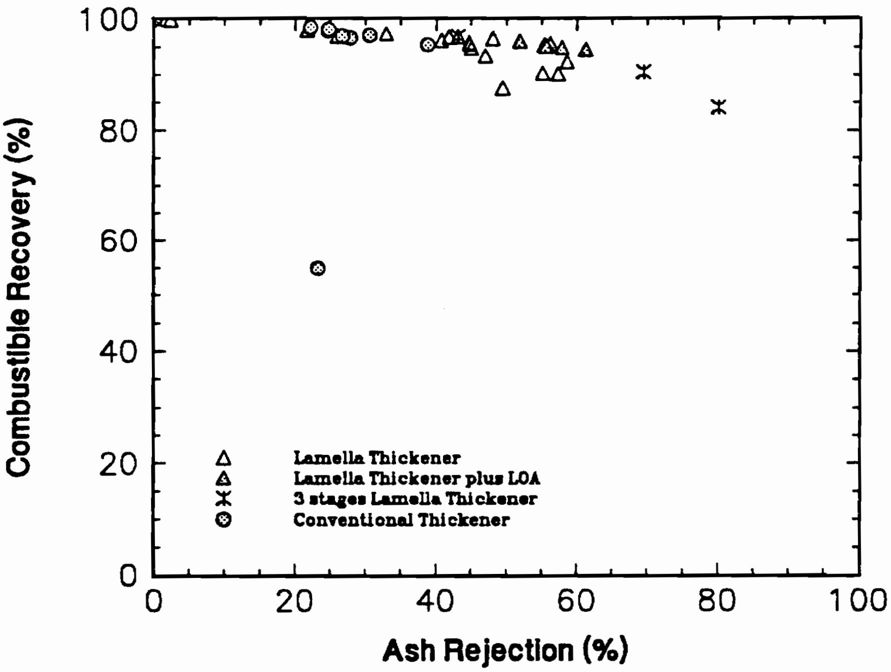


Figure 3.5 Summary of results obtained using the lamella and conventional thickener test units.

Table 3.6 - Comparison of the lamella and conventional thickeners.

| | Thickener Design | | | |
|---|---|---|---|---|
| | Conventional | Lamella | Lamella | Lamella |
| Test Conditions: | | | | |
| Feed Solids Content (%) | 3.0 | 2.0 | 4.0 | 4.0 |
| Feed Rate (ml/min) | 150 | 50 | 100 | 100 |
| Feed Rate (lb/hr) | 0.58 | 0.13 | 0.53 | 0.53 |
| Kerosene (lb/ton) | 0.0 | 0.0 | 0.0 | 12.0 |
| Capacity Parameters: | | | | |
| Effective Area (lb/hr/m$^2$) | 10.4 | 1.19 | 4.84 | 4.84 |
| Actual Area (lb/hr/m$^2$) | 10.4 | 4.80 | 19.6 | 19.6 |
| Volume (lb/hr/liter) | 0.055 | 0.012 | 0.048 | 0.048 |
| Separation Performance: | | | | |
| Combustible Recovery (%) | 95 | 92 | 97 | 95 |
| Separation Efficiency (%) | 34 | 50 | 40 | 56 |
| Ash Rejection (%) | 39 | 60 | 43 | 61 |

## 3.4 Conclusions

The previous tests conducted at Virginia Tech employing the *Selective Hydrophobic Coagulation* (SHC) process to selectively coagulate and recover finely pulverized coal from dispersed mineral matter showed that the hydrophobic coagula were difficult to separate from dispersed mineral matter due to their small size and their susceptibility to breakage. In the present work, a variety of laboratory bench-scale tests were undertaken to determine the most effective methodology to recover the coal coagula. Several devices were evaluated in this study including lamella and conventional thickeners, a rotary centrifuge, a vacuum drum filter, a froth flotation column, and a rotating drum screen. Each unit was tested under optimum reagent conditions established from batch experiments. The test data indicate that the thickener was the best overall method for separating hydrophobic coagula from dispersed mineral matter based on overall process performance (e.g., recovery and grade), unit capacity, and engineering feasibility.

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# APPENDIX A - ELZONE SIZE ANALYSIS DATA

## Wet Screen Size Data
## Stirred Ball Mill Feed

### Pittsburgh No. 8 seam coal

| Size (microns) | Pass (%) |
|---|---|
| 150 | 83.31 |
| 106 | 67.65 |
| 75 | 55.03 |
| 53 | 42.63 |
| 38 | 31.67 |

### Elkhorn No. 3 seam coal

| Size (microns) | Pass (%) |
|---|---|
| 150 | 90.92 |
| 106 | 79.69 |
| 75 | 69.62 |
| 53 | 57.74 |
| 38 | 48.01 |

## Elzone 80-XY Particle Size Data
## Stirred Ball Mill Product
## Elkhorn No. 3 seam coal

| Size (microns) | Pass (%) | Size (microns) | Pass (%) | Size (microns) | Pass (%) | Size (microns) | Pass (%) |
|---|---|---|---|---|---|---|---|
| 0.660 | 0.000 | 1.500 | 21.114 | 3.770 | 73.817 | 8.460 | 93.409 |
| 0.670 | 0.532 | 1.530 | 21.916 | 3.850 | 75.022 | 8.640 | 93.537 |
| 0.680 | 2.051 | 1.560 | 22.802 | 3.930 | 76.075 | 8.830 | 93.811 |
| 0.700 | 2.932 | 1.600 | 23.634 | 4.020 | 77.014 | 9.020 | 93.957 |
| 0.710 | 3.634 | 1.630 | 24.539 | 4.110 | 77.759 | 9.210 | 93.957 |
| 0.730 | 4.205 | 1.670 | 25.538 | 4.190 | 78.598 | 9.410 | 94.289 |
| 0.750 | 4.669 | 1.710 | 26.505 | 4.280 | 79.612 | 9.610 | 94.289 |
| 0.760 | 5.131 | 1.740 | 27.593 | 4.380 | 80.277 | 9.820 | 94.665 |
| 0.780 | 5.536 | 1.780 | 28.564 | 4.470 | 80.972 | 10.030 | 94.866 |
| 0.800 | 5.910 | 1.820 | 29.707 | 4.570 | 81.503 | 10.240 | 95.294 |
| 0.810 | 6.290 | 1.860 | 30.958 | 4.660 | 82.171 | 10.460 | 95.522 |
| 0.830 | 6.626 | 1.900 | 32.454 | 4.760 | 82.922 | 10.690 | 95.764 |
| 0.850 | 6.973 | 1.940 | 33.844 | 4.870 | 83.631 | 10.920 | 95.764 |
| 0.870 | 7.319 | 1.990 | 34.983 | 4.970 | 84.415 | 11.150 | 96.041 |
| 0.890 | 7.671 | 2.030 | 36.358 | 5.080 | 85.092 | 11.390 | 96.041 |
| 0.910 | 8.026 | 2.080 | 37.761 | 5.190 | 85.676 | 11.640 | 96.041 |
| 0.930 | 8.404 | 2.120 | 38.896 | 5.300 | 86.121 | 11.890 | 96.041 |
| 0.950 | 8.786 | 2.170 | 40.336 | 5.410 | 86.500 | 12.140 | 96.041 |
| 0.970 | 9.189 | 2.220 | 41.677 | 5.530 | 87.003 | 12.410 | 96.420 |
| 0.990 | 9.587 | 2.270 | 42.985 | 5.650 | 87.542 | 12.670 | 96.420 |
| 1.010 | 10.058 | 2.320 | 44.733 | 5.770 | 87.924 | 12.940 | 96.420 |
| 1.030 | 10.539 | 2.370 | 46.143 | 5.890 | 88.169 | 13.220 | 96.420 |
| 1.060 | 11.032 | 2.420 | 47.846 | 6.020 | 88.559 | 13.510 | 96.420 |
| 1.080 | 11.540 | 2.470 | 49.446 | 6.150 | 89.021 | 13.800 | 96.420 |
| 1.100 | 12.101 | 2.530 | 50.697 | 6.280 | 89.515 | 14.090 | 96.420 |
| 1.130 | 12.601 | 2.580 | 52.042 | 6.410 | 89.777 | 14.400 | 97.013 |
| 1.150 | 13.161 | 2.640 | 53.354 | 6.550 | 90.280 | 14.710 | 97.013 |
| 1.180 | 13.692 | 2.700 | 54.515 | 6.690 | 90.519 | 15.020 | 97.013 |
| 1.200 | 14.248 | 2.760 | 55.953 | 6.840 | 90.582 | 15.350 | 97.732 |
| 1.230 | 14.851 | 2.820 | 56.931 | 6.980 | 90.718 | 15.680 | 97.732 |
| 1.260 | 15.438 | 2.880 | 58.495 | 7.130 | 91.223 | 16.010 | 98.550 |
| 1.290 | 16.039 | 2.940 | 59.923 | 7.290 | 91.300 | 16.360 | 98.550 |
| 1.310 | 16.752 | 3.250 | 61.527 | 7.440 | 91.546 | 16.710 | 98.550 |
| 1.340 | 17.432 | 3.320 | 62.561 | 7.600 | 91.721 | 17.070 | 98.550 |
| 1.370 | 18.127 | 3.390 | 66.271 | 7.770 | 91.814 | 17.430 | 98.550 |
| 1.400 | 18.883 | 3.460 | 68.171 | 7.930 | 92.610 | 17.810 | 98.550 |
| 1.430 | 19.535 | 3.540 | 69.463 | 8.110 | 92.716 | 18.190 | 98.550 |
| 1.470 | 20.365 | 3.610 | 70.865 | 8.280 | 93.168 | 18.580 | 98.550 |
|  |  | 3.690 | 72.431 |  |  | 18.980 | 98.550 |

### Elzone 80-XY Particle Size Data
### Stirred Ball Mill Product
### Pittsburgh No. 8 seam coal

| Size (microns) | Pass (%) | Size (microns) | Pass (%) | Size (microns) | Pass (%) | Size (microns) | Pass (%) |
|---|---|---|---|---|---|---|---|
| 0.660 | 0.000 | 1.530 | 3.655 | 3.850 | 37.863 | 8.830 | 80.174 |
| 0.670 | 0.033 | 1.560 | 3.916 | 3.930 | 39.326 | 9.020 | 80.713 |
| 0.680 | 0.139 | 1.600 | 4.196 | 4.020 | 40.942 | 9.210 | 80.856 |
| 0.700 | 0.193 | 1.630 | 4.472 | 4.110 | 42.455 | 9.410 | 81.315 |
| 0.710 | 0.241 | 1.670 | 4.759 | 4.190 | 43.936 | 9.610 | 81.967 |
| 0.730 | 0.283 | 1.710 | 5.111 | 4.280 | 45.506 | 9.820 | 82.662 |
| 0.750 | 0.323 | 1.740 | 5.507 | 4.380 | 47.055 | 10.030 | 82.662 |
| 0.760 | 0.356 | 1.780 | 5.877 | 4.470 | 48.749 | 10.240 | 83.452 |
| 0.780 | 0.387 | 1.820 | 6.312 | 4.570 | 50.393 | 10.460 | 84.083 |
| 0.800 | 0.421 | 1.860 | 6.689 | 4.660 | 51.962 | 10.690 | 84.755 |
| 0.810 | 0.459 | 1.900 | 7.172 | 4.760 | 53.507 | 10.920 | 84.994 |
| 0.830 | 0.495 | 1.940 | 7.610 | 4.870 | 55.195 | 11.150 | 84.994 |
| 0.850 | 0.530 | 1.990 | 8.176 | 4.970 | 56.122 | 11.390 | 85.536 |
| 0.870 | 0.563 | 2.030 | 8.831 | 5.080 | 57.227 | 11.640 | 85.826 |
| 0.890 | 0.605 | 2.080 | 9.368 | 5.190 | 58.485 | 11.890 | 86.443 |
| 0.910 | 0.647 | 2.120 | 9.965 | 5.300 | 59.825 | 12.140 | 87.430 |
| 0.930 | 0.692 | 2.170 | 10.687 | 5.410 | 60.991 | 12.410 | 87.430 |
| 0.950 | 0.738 | 2.220 | 11.358 | 5.530 | 62.261 | 12.670 | 88.178 |
| 0.970 | 0.792 | 2.270 | 12.084 | 5.650 | 63.288 | 12.940 | 88.178 |
| 0.990 | 0.850 | 2.320 | 12.778 | 5.770 | 64.594 | 13.220 | 88.178 |
| 1.010 | 0.907 | 2.370 | 13.629 | 5.890 | 65.985 | 13.510 | 88.630 |
| 1.030 | 0.980 | 2.420 | 14.442 | 6.020 | 67.225 | 13.800 | 88.630 |
| 1.060 | 1.041 | 2.470 | 15.338 | 6.150 | 68.079 | 14.090 | 88.630 |
| 1.080 | 1.126 | 2.530 | 16.101 | 6.280 | 69.535 | 14.400 | 90.273 |
| 1.100 | 1.214 | 2.580 | 17.023 | 6.410 | 70.553 | 14.710 | 92.026 |
| 1.130 | 1.308 | 2.640 | 18.048 | 6.550 | 71.327 | 15.020 | 92.026 |
| 1.150 | 1.417 | 2.700 | 19.037 | 6.690 | 71.987 | 15.350 | 92.689 |
| 1.180 | 1.531 | 2.760 | 20.096 | 6.840 | 72.690 | 15.680 | 92.689 |
| 1.200 | 1.635 | 2.820 | 21.175 | 6.980 | 73.316 | 16.010 | 92.689 |
| 1.230 | 1.749 | 2.880 | 22.295 | 7.130 | 74.048 | 16.360 | 92.689 |
| 1.260 | 1.879 | 2.940 | 23.354 | 7.290 | 74.474 | 16.710 | 93.546 |
| 1.290 | 2.030 | 3.250 | 24.383 | 7.440 | 75.005 | 17.070 | 93.546 |
| 1.310 | 2.191 | 3.320 | 25.579 | 7.600 | 75.972 | 17.430 | 93.546 |
| 1.340 | 2.350 | 3.390 | 29.024 | 7.770 | 76.573 | 17.810 | 93.546 |
| 1.370 | 2.519 | 3.460 | 30.626 | 7.930 | 77.033 | 18.190 | 93.546 |
| 1.400 | 2.720 | 3.540 | 32.142 | 8.110 | 77.716 | 18.580 | 94.724 |
| 1.430 | 2.937 | 3.610 | 33.401 | 8.280 | 78.238 | 18.980 | 97.235 |
| 1.470 | 3.176 | 3.690 | 35.095 | 8.460 | 78.682 | 19.390 | 98.573 |
| 1.500 | 3.396 | 3.770 | 36.521 | 8.640 | 79.038 | | |

# APPENDIX B - BATCH SEDIMENTATION DATA

## Batch sedimentation SHC tests using Elkhorn No. 3 seam coal

| Test Number | pH | EDTA (g/l) | Stage No. | % Solids | | | Yield (%) | Comb. Rec. (%) | Rejection | | Separation Efficiency (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Feed (%) | Product (%) | Tails (%) | | | Ash (%) | Sulphur (%) | |
| 1 | 4.0 | 0.4 | 1 | 3.05 | 3.05 | 0.00 | 100.00 | 100.00 | 0.00 | 0.00 | 0.00 |
| 2 | 5.0 | 0.4 | 1 | 3.05 | 3.05 | 0.00 | 100.00 | 100.00 | 0.00 | 0.00 | 0.00 |
| 3 | 6.0 | 0.4 | 1 | 2.82 | 2.82 | 0.00 | 100.00 | 100.00 | 0.00 | 0.00 | 0.00 |
| 4 | 6.5 | 0.4 | 1 | 2.82 | 2.82 | 0.00 | 100.00 | 100.00 | 0.00 | 0.00 | 0.00 |
| 5 | 6.6 | 0.4 | 1 | 2.93 | 2.93 | 0.00 | 100.00 | 100.00 | 0.00 | 0.00 | 0.00 |
| 6 | 7.0 | 0.4 | 1 | 2.82 | 2.82 | 0.00 | 100.00 | 100.00 | 0.00 | 0.00 | 0.00 |
| 7 | 7.5 | 0.4 | 1 | 2.77 | 7.56 | 0.91 | 72.74 | 93.22 | 46.87 | 13.85 | 40.08 |
| 8 | 7.5 | 0.4 | 1 | 2.98 | 8.09 | 1.13 | 73.02 | 96.08 | 49.52 | 11.49 | 45.60 |
| 9 | 7.6 | 0.4 | 1 | 2.97 | 7.94 | 1.12 | 72.61 | 96.31 | 50.37 | 11.49 | 46.69 |
| 10 | 8.0 | 0.4 | 1 | 2.78 | 7.35 | 1.09 | 71.39 | 95.76 | 52.23 | 12.97 | 47.99 |
| 11 | 9.0 | 0.4 | 1 | 2.77 | 8.29 | 1.30 | 63.58 | 89.96 | 62.91 | 16.78 | 52.87 |
| 12 | 10.0 | 0.4 | 1 | 2.78 | 0.00 | 2.78 | 0.00 | 0.00 | 100.00 | 100.00 | 0.00 |
| 13 | 7.5 | 0.4 | 1-3 | 2.86 | 5.23 | 0.54 | 65.35 | 94.40 | 67.55 | 16.78 | 61.95 |
| 14 | 8.5 | 0.4 | 1-3 | 2.90 | 5.54 | 0.57 | 57.85 | 92.76 | 79.44 | 19.23 | 72.21 |
| 15 | 9.6 | 0.4 | 1-3 | 2.89 | 5.49 | 0.82 | 35.86 | 59.26 | 90.08 | 47.80 | 49.34 |
| 16 | 7.6 | 0.4 | 1-2 | 2.87 | 6.00 | 0.74 | 62.60 | 91.53 | 64.55 | 19.34 | 56.07 |
| 16-1 | 7.5 | 0.4 | 1 | 2.87 | 7.19 | 1.01 | 73.42 | 94.11 | 45.90 | 11.54 | 40.02 |
| 16-2 | 7.7 | 0 | 2 | 2.23 | 6.00 | 0.46 | 85.17 | 97.44 | 34.61 | 5.49 | 32.05 |
| 17 | 7.6 | 0.4 | 1-3 | 2.92 | 5.41 | 0.58 | 57.70 | 93.06 | 76.22 | 19.05 | 69.28 |
| 17-1 | 7.6 | 0.4 | 1 | 2.92 | 7.15 | 1.09 | 71.89 | 95.85 | 51.02 | 11.66 | 46.87 |
| 17-2 | 7.7 | 0 | 2 | 2.10 | 6.13 | 0.41 | 86.33 | 98.22 | 35.94 | 5.49 | 34.16 |
| 17-3 | 7.7 | 0 | 3 | 1.88 | 5.41 | 0.19 | 92.94 | 98.90 | 24.21 | 2.94 | 23.11 |
| 18 | 7.5 | 0.4 | 1-5 | 2.90 | 4.73 | 0.39 | 54.75 | 91.70 | 81.95 | 21.37 | 73.65 |
| 18-1 | 7.5 | 0.4 | 1 | 2.90 | 7.76 | 1.04 | 74.68 | 96.28 | 46.98 | 10.42 | 43.25 |
| 18-2 | 7.5 | 0 | 2 | 2.20 | 6.22 | 0.42 | 86.50 | 97.97 | 34.39 | 5.77 | 32.36 |
| 18-3-5 | 7.5 | 0 | 3-5 | 0.80 | 4.73 | 0.14 | 85.12 | 97.35 | 47.95 | 7.80 | 45.30 |
| 1 | 7.0 | 0.2 | 1 | 2.82 | 2.82 | 0.00 | 100.00 | 100.00 | 0.00 | 0.00 | 0.00 |
| 2 | 7.5 | 0.2 | 1 | 2.77 | 7.15 | 0.93 | 77.04 | 91.76 | 37.70 | 12.82 | 29.46 |
| 3 | 8.0 | 0.2 | 1 | 2.82 | 7.44 | 1.13 | 67.92 | 94.37 | 55.82 | 13.95 | 50.19 |
| 4 | 9.0 | 0.2 | 1 | 2.79 | 8.18 | 1.42 | 61.22 | 86.32 | 64.45 | 19.28 | 50.77 |
| 5 | 10.0 | 0.2 | 1 | 2.80 | 0.00 | 2.80 | 0.00 | 0.00 | 100.00 | 100.00 | 0.00 |
| 6 | 7.5 | 0.2 | 1-3 | 2.86 | 5.07 | 0.58 | 67.08 | 86.11 | 55.04 | 20.72 | 41.15 |
| 7 | 9.5 | 0.2 | 1-3 | 2.89 | 5.18 | 0.79 | 40.02 | 65.67 | 88.01 | 44.56 | 53.68 |
| 1 | 4.0 | 0 | 1 | 3.05 | 3.05 | 0.00 | 100.00 | 100.00 | 0.00 | 0.00 | 0.00 |
| 2 | 5.0 | 0 | 1 | 3.05 | 3.05 | 0.00 | 100.00 | 100.00 | 0.00 | 0.00 | 0.00 |
| 3 | 6.0 | 0 | 1 | 2.82 | 2.82 | 0.00 | 100.00 | 100.00 | 0.00 | 0.00 | 0.00 |
| 4 | 7.0 | 0 | 1 | 2.82 | 2.82 | 0.00 | 100.00 | 100.00 | 0.00 | 0.00 | 0.00 |
| 5 | 7.5 | 0 | 1 | 2.77 | 6.22 | 0.08 | 98.68 | 99.37 | 2.01 | 4.63 | 1.38 |
| 6 | 8.3 | 0 | 1 | 2.78 | 6.99 | 1.04 | 72.86 | 95.74 | 48.93 | 11.23 | 44.67 |
| 7 | 9.0 | 0 | 1 | 2.79 | 7.71 | 1.25 | 66.53 | 92.01 | 58.93 | 15.87 | 50.94 |
| 8 | 9.0 | 0 | 1 | 3.05 | 8.34 | 1.41 | 65.82 | 92.91 | 59.44 | 16.30 | 52.35 |
| 9 | 9.1 | 0 | 1 | 2.98 | 7.76 | 1.37 | 66.65 | 92.35 | 58.21 | 13.99 | 50.56 |
| 10 | 9.0 | 0 | 1 | 2.98 | 7.22 | 1.41 | 72.72 | 94.08 | 50.03 | 12.31 | 44.11 |
| 11 | 10.0 | 0 | 1 | 2.78 | 9.06 | 2.37 | 25.34 | 34.31 | 83.49 | 65.41 | 17.80 |
| 12 | 10.5 | 0 | 1 | 2.93 | 0.00 | 2.93 | 0.00 | 0.00 | 100.00 | 100.00 | 0.00 |
| 13 | 7.5 | 0 | 1-3 | 2.87 | 3.32 | 0.08 | 97.35 | 99.09 | 4.54 | 18.71 | 3.63 |
| 14 | 8.5 | 0 | 1-3 | 2.90 | 5.55 | 0.58 | 59.33 | 93.31 | 77.15 | 18.46 | 70.46 |
| 15 | 9.5 | 0 | 1-3 | 2.89 | 5.31 | 0.71 | 50.63 | 81.15 | 82.95 | 30.77 | 64.10 |

## Batch sedimentation SHC tests using Elkhorn No. 3 seam coal

| Test Number | % Ash (adjusted) | | | % Combustible (adj.) | | | % Sulphur (adjusted) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) |
| 1 | 51.96 | 51.96 | 0.00 | 48.04 | 48.04 | 100.00 | 0.36 | 0.36 | 0.00 |
| 2 | 51.96 | 51.96 | 0.00 | 48.04 | 48.04 | 100.00 | 0.36 | 0.36 | 0.00 |
| 3 | 51.70 | 51.70 | 0.00 | 48.30 | 48.30 | 100.00 | 0.36 | 0.36 | 0.00 |
| 4 | 51.70 | 51.70 | 0.00 | 48.30 | 48.30 | 100.00 | 0.36 | 0.36 | 0.00 |
| 5 | 47.00 | 47.00 | 0.00 | 53.00 | 53.00 | 100.00 | 0.40 | 0.40 | 0.00 |
| 6 | 51.70 | 51.70 | 0.00 | 48.30 | 48.30 | 100.00 | 0.36 | 0.36 | 0.00 |
| 7 | 51.09 | 37.32 | 87.83 | 48.91 | 62.68 | 12.17 | 0.39 | 0.48 | 0.18 |
| 8 | 50.56 | 34.95 | 92.81 | 49.44 | 65.05 | 7.19 | 0.36 | 0.44 | 0.15 |
| 9 | 50.76 | 34.69 | 93.37 | 49.24 | 65.31 | 6.63 | 0.36 | 0.44 | 0.15 |
| 10 | 50.78 | 33.98 | 92.70 | 49.22 | 66.02 | 7.30 | 0.37 | 0.46 | 0.16 |
| 11 | 49.90 | 29.11 | 86.19 | 50.10 | 70.89 | 13.81 | 0.39 | 0.51 | 0.18 |
| 12 | 50.84 | 0.00 | 50.84 | 49.16 | 100.00 | 49.16 | 0.38 | 0.00 | 0.38 |
| 13 | 46.90 | 23.29 | 91.42 | 53.10 | 76.71 | 8.58 | 0.37 | 0.47 | 0.18 |
| 14 | 48.35 | 17.18 | 91.13 | 51.65 | 82.82 | 8.87 | 0.39 | 0.54 | 0.18 |
| 15 | 47.43 | 13.12 | 66.61 | 52.57 | 86.88 | 33.39 | 0.39 | 0.57 | 0.29 |
| 16 | 51.58 | 29.21 | 89.03 | 48.42 | 70.79 | 10.97 | 0.39 | 0.51 | 0.19 |
| 16-1 | 51.72 | 38.11 | 89.31 | 48.28 | 61.89 | 10.69 | 0.39 | 0.46 | 0.18 |
| 16-2 | 38.28 | 29.39 | 89.33 | 61.72 | 70.61 | 10.67 | 0.47 | 0.51 | 0.20 |
| 17 | 51.03 | 21.03 | 91.96 | 48.97 | 78.97 | 8.04 | 0.36 | 0.50 | 0.16 |
| 17-1 | 51.12 | 34.83 | 92.79 | 48.88 | 65.17 | 7.21 | 0.36 | 0.44 | 0.15 |
| 17-2 | 34.82 | 25.84 | 91.52 | 65.18 | 74.16 | 8.48 | 0.44 | 0.48 | 0.17 |
| 17-3 | 25.80 | 21.04 | 88.42 | 74.20 | 78.96 | 11.58 | 0.48 | 0.50 | 0.20 |
| 18 | 50.17 | 16.54 | 90.86 | 49.83 | 83.46 | 9.14 | 0.36 | 0.52 | 0.17 |
| 18-1 | 49.94 | 35.46 | 92.64 | 50.06 | 64.54 | 7.36 | 0.36 | 0.43 | 0.15 |
| 18-2 | 35.44 | 26.88 | 90.30 | 64.56 | 73.12 | 9.70 | 0.43 | 0.47 | 0.18 |
| 18-3-5 | 27.00 | 16.51 | 87.02 | 73.00 | 83.49 | 12.98 | 0.47 | 0.52 | 0.22 |
| 1 | 51.70 | 51.70 | 0.00 | 48.30 | 48.30 | 100.00 | 0.36 | 0.36 | 0.00 |
| 2 | 49.97 | 40.41 | 82.05 | 50.03 | 59.59 | 17.95 | 0.39 | 0.44 | 0.22 |
| 3 | 52.70 | 34.28 | 91.70 | 47.30 | 65.72 | 8.30 | 0.37 | 0.47 | 0.16 |
| 4 | 49.43 | 28.70 | 82.16 | 50.57 | 71.30 | 17.84 | 0.39 | 0.50 | 0.21 |
| 5 | 51.07 | 0.00 | 51.07 | 48.93 | 100.00 | 48.93 | 0.36 | 0.00 | 0.36 |
| 6 | 46.26 | 31.01 | 77.33 | 53.74 | 68.99 | 22.67 | 0.37 | 0.44 | 0.23 |
| 7 | 47.78 | 14.31 | 70.11 | 52.22 | 85.69 | 29.89 | 0.39 | 0.57 | 0.28 |
| 1 | 51.96 | 51.96 | 0.00 | 48.04 | 48.04 | 100.00 | 0.36 | 0.36 | 0.00 |
| 2 | 51.96 | 51.96 | 0.00 | 48.04 | 48.04 | 100.00 | 0.36 | 0.36 | 0.00 |
| 3 | 51.70 | 51.70 | 0.00 | 48.30 | 48.30 | 100.00 | 0.36 | 0.36 | 0.00 |
| 4 | 51.70 | 51.70 | 0.00 | 48.30 | 48.30 | 100.00 | 0.36 | 0.36 | 0.00 |
| 5 | 49.99 | 49.64 | 76.16 | 50.01 | 50.36 | 23.84 | 0.39 | 0.37 | 1.36 |
| 6 | 51.23 | 35.91 | 92.35 | 48.77 | 64.09 | 7.65 | 0.38 | 0.46 | 0.16 |
| 7 | 50.02 | 30.88 | 88.07 | 49.98 | 69.12 | 11.93 | 0.39 | 0.50 | 0.18 |
| 8 | 51.76 | 31.90 | 90.00 | 48.24 | 68.10 | 10.00 | 0.37 | 0.48 | 0.17 |
| 9 | 50.84 | 31.88 | 88.73 | 49.16 | 68.12 | 11.27 | 0.33 | 0.41 | 0.15 |
| 10 | 48.44 | 33.29 | 88.82 | 51.56 | 66.71 | 11.18 | 0.35 | 0.42 | 0.16 |
| 11 | 50.40 | 32.84 | 56.36 | 49.60 | 67.16 | 43.64 | 0.37 | 0.48 | 0.33 |
| 12 | 47.00 | 0.00 | 47.00 | 53.00 | 0.00 | 53.00 | 0.40 | 0.00 | 0.40 |
| 13 | 48.08 | 47.15 | 82.19 | 51.92 | 52.85 | 17.81 | 0.42 | 0.35 | 3.21 |
| 14 | 48.22 | 18.57 | 91.48 | 51.78 | 81.43 | 8.52 | 0.39 | 0.53 | 0.18 |
| 15 | 47.62 | 16.04 | 80.00 | 52.38 | 83.96 | 20.00 | 0.39 | 0.54 | 0.24 |

## Batch Sedimentation SHC tests using Pittsburgh No. 8 seam coal

| Test Number | pH | EDTA (g/l) | Stage No. | % Solids | | | Yield (%) | Comb. Rec. (%) | Rejection | | Separation Efficiency (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Feed (%) | Product (%) | Tails (%) | | | Ash (%) | Sulphur (%) | |
| 1 | 6.6 | 0.4 | 1 | 2.95 | 6.19 | nes | 99 | 100 | nes | nes | 7 |
| 2 | 7.5 | 0.4 | 1 | 2.86 | 6.26 | nes | 98 | 99 | nes | nes | 10 |
| 3 | 8.5 | 0.4 | 1 | 2.89 | 6.24 | nes | 98 | 99 | nes | nes | 6 |
| 4 | 6.5 | 0.4 | 1-3 | 2.89 | 6.29 | 0.05 | 95.89 | 99.12 | 19.38 | 9.13 | 18.50 |
| 5 | 7.6 | 0.4 | 1-3 | 2.87 | 6.44 | 0.06 | 94.64 | 98.73 | 24.79 | 11.15 | 23.52 |
| 6 | 8.5 | 0.4 | 1-3 | 2.90 | 5.59 | 0.11 | 91.82 | 95.61 | 26.05 | 16.09 | 21.65 |
| 7 | 9.5 | 0.4 | 1-3 | 2.90 | 3.44 | 0.30 | 106.77 | 106.94 | -5.98 | -5.32 | 0.96 |
| 8 | 7.5 | 0.4 | 1-6 | 2.95 | 6.60 | 0.05 | 92.82 | 97.54 | 28.73 | 16.08 | 26.27 |
| 9 | 7.5 | 0.2 | 1 | 2.86 | 6.59 | nes | 99 | 100 | nes | nes | 6 |
| 10 | 8.5 | 0.2 | 1 | 2.98 | 6.38 | nes | 99 | 99 | nes | nes | 4 |
| 11 | 6.5 | 0.0 | 1 | 2.95 | 5.81 | nes | 98 | 100 | nes | nes | 9 |
| 12 | 7.5 | 0.0 | 1 | 2.86 | 6.15 | nes | 99 | 100 | nes | nes | 5 |
| 13 | 8.5 | 0.0 | 1 | 2.98 | 6.63 | 0.04 | 99.12 | 99.54 | 2.94 | nes | 2.47 |
| 14 | 6.5 | 0.0 | 1-3 | 2.89 | 5.86 | 0.02 | 97.76 | 99.50 | 10.47 | 4.92 | 9.97 |
| 15 | 7.5 | 0.0 | 1-3 | 2.87 | 6.52 | 0.01 | 97.65 | 99.42 | 10.71 | 4.09 | 10.13 |
| 16 | 8.5 | 0.0 | 1-3 | 2.90 | 6.95 | 0.14 | 91.42 | 95.96 | 29.85 | 17.74 | 25.81 |
| 17 | 9.5 | 0.0 | 1 | 2.89 | 0.00 | 2.89 | 0.00 | 0.00 | 100.00 | 100.00 | 0.00 |

'nes' - Not Enough Sample

## Batch Sedimentation SHC tests using Pittsburgh No. 8 seam coal

| Test Number | % Ash (adjusted) | | | % Combustible (adj.) | | | % Sulfur (adjusted) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) |
| 1 | 17.96 | 16.88 | nes | 82.04 | 83.12 | nes | 4.15 | 4.08 | nes |
| 2 | 17.23 | 15.84 | nes | 82.77 | 84.16 | nes | 3.46 | 3.48 | nes |
| 3 | 16.87 | 16.06 | nes | 83.13 | 83.94 | nes | 3.27 | 3.29 | nes |
| 4 | 17.46 | 14.68 | 82.30 | 82.54 | 85.32 | 17.7 | 4.01 | 3.80 | 8.91 |
| 5 | 17.39 | 13.82 | 80.39 | 82.61 | 86.18 | 19.61 | 3.92 | 3.68 | 8.16 |
| 6 | 17.47 | 14.07 | 55.65 | 82.53 | 85.93 | 44.35 | 3.98 | 3.64 | 7.76 |
| 7 | 17.46 | 17.33 | 15.41 | 82.54 | 82.67 | 84.59 | 3.98 | 3.95 | 3.46 |
| 8 | 17.96 | 13.79 | 71.89 | 82.04 | 86.21 | 28.11 | 4.15 | 3.74 | 9.70 |
| 9 | 17.23 | 16.31 | nes | 82.77 | 83.69 | nes | 3.46 | 3.52 | nes |
| 10 | 16.87 | 16.33 | nes | 83.13 | 83.67 | nes | 3.27 | 3.32 | nes |
| 11 | 17.96 | 16.59 | nes | 82.04 | 83.41 | nes | 4.15 | 4.09 | nes |
| 12 | 17.23 | 16.48 | nes | 82.77 | 83.52 | nes | 3.46 | 3.53 | nes |
| 13 | 16.87 | 16.52 | 56.29 | 83.13 | 83.48 | 43.71 | 3.27 | 3.35 | nes |
| 14 | 17.46 | 15.99 | 81.66 | 82.54 | 84.01 | 18.34 | 4.01 | 3.90 | 8.81 |
| 15 | 17.39 | 15.9 | 79.42 | 82.61 | 84.10 | 20.58 | 3.92 | 3.85 | 6.834 |
| 16 | 17.58 | 13.49 | 61.17 | 82.42 | 86.51 | 38.83 | 3.95 | 3.55 | 8.27 |
| 17 | 17.46 | 0.00 | 17.46 | 82.54 | 0.00 | 82.54 | 4.01 | 0.00 | 4.01 |

'nes' - Not Enough Sample

# APPENDIX C - LAMELLA THICKENER DATA

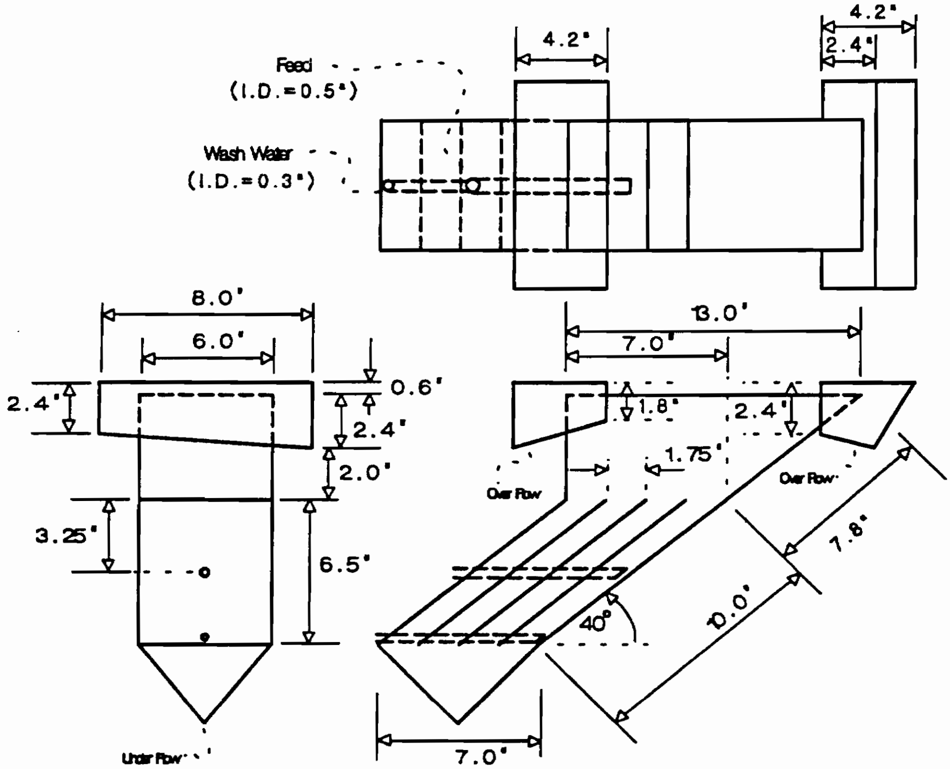


Plate Surface Area = A = 60 inches$^2$
Number of plates = **n** = 4
Distance between plates = 1.75 inches
Cell Volume = 720 inches$^3$

Plate Angle (***alpha***) for the cell is adjustable from 30 to 55 degrees

- plate angle when using wash water = 45 to 55 degrees
- plate angle without wash water = 30 to 40 degrees (von Prof. Dr. sc.techn. Heinrich Schubert, Aufbereitung fester mineralischer Rohstoffe Band III. 1984).

Effective area = **n** * **A** * cosine(***alpha***)

- effective area using wash water = 4*(60)*cosine(50) = 154 inches$^2$
- effective area without wash water = 4*(60)*cosine(35) = 197 inches$^2$

Lamella type Thickener

- shorter retention time than a conventional thickener
- underflow has a lower solids content than a conventional thickener; may apply low amplitude vibrations to provide solids compression and increased flow

Projected Output of Lamella type Thickener

- Feed rate = ?
- Feed solids content = ?
- Throughput = ? (0.5 - 1.0 lb/hr required)
- Underflow solids content = ?

**Lamella Thickener retention time data using Elkhorn No. 3 coal seam**

| Number | Sample Time (minutes) | Flow Rates | | | % Solids | | | Mass Flow Rates | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Wash Water (ml/min) | Feed (ml/min) | Product (ml/min) | Feed (%) | Product (%) | Tails (%) | Feed (g/min) | Product (g/min) | Tails (g/min) |
| 1 | 20 | 0 | 100 | 21 | | 8.66 | 0.51 | | 2.02 | 0.40 |
| 2 | 53 | 0 | 100 | 19 | | 9.91 | 0.71 | | 1.10 | 0.56 |
| 3 | 90 | 0 | 100 | 19 | | 9.96 | 0.81 | | 1.11 | 0.62 |
| 4 | 127 | 0 | 100 | 20 | | 9.92 | 0.84 | | 1.65 | 0.63 |
| 5 | 157 | 0 | 100 | 21 | | 10.49 | 0.85 | | 2.17 | 0.62 |
| 6 | 186 | 0 | 100 | 20 | 2.87 | 10.41 | 0.89 | 3.28 | 2.16 | 0.65 |

**Lamella Thickener retention time data using Elkhorn No. 3 coal seam**

| Number | Yield (%) | Combustible Recovery (%) | Rejection | | Separation Efficiency (%) |
|---|---|---|---|---|---|
| | | | Ash (%) | Sulfur (%) | |
| 1 | 70.25 | 92.23 | 51.86 | 12.70 | 44.09 |
| 2 | 70.86 | 92.60 | 50.96 | 12.70 | 43.56 |
| 3 | 73.16 | 93.84 | 47.48 | 11.49 | 41.32 |
| 4 | 73.07 | 94.22 | 47.81 | 10.37 | 42.03 |
| 5 | 74.17 | 95.04 | 46.71 | 10.37 | 41.74 |
| 6 | 72.69 | 94.75 | 49.02 | 11.29 | 43.76 |

**Lamella Thickener retention time data using Elkhorn No. 3 coal seam**

| Number | % Ash (adjusted) | | | % Combustible (adjusted) | | | % Sulfur (adjusted) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) |
| 1 | 49.86 | 34.17 | 86.91 | 50.14 | 65.83 | 13.09 | 0.36 | 0.44 | 0.16 |
| 2 | 49.92 | 34.55 | 87.29 | 50.08 | 65.45 | 12.71 | 0.36 | 0.44 | 0.16 |
| 3 | 50.06 | 35.94 | 88.54 | 49.94 | 64.06 | 11.46 | 0.36 | 0.44 | 0.15 |
| 4 | 50.32 | 35.94 | 89.34 | 49.68 | 64.06 | 10.66 | 0.36 | 0.44 | 0.14 |
| 5 | 49.99 | 35.92 | 90.39 | 50.01 | 64.08 | 9.61 | 0.36 | 0.44 | 0.14 |
| 6 | 50.40 | 35.35 | 90.46 | 49.60 | 64.65 | 9.54 | 0.36 | 0.45 | 0.14 |

**Lamella thickener parametric test data using Elkhorn No. 3 seam coal**

| Test Number | Flow Rates | | | | | % Solids | | | Yield | Combustible | Rejection | | Separation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wash Water (ml/min) | Feed (ml/min) | Feed (lb/hr) | Product (ml/min) | Tails (ml/min) | Feed (%) | Product (%) | Tails (%) | (%) | Recovery (%) | Ash (%) | Sulfur (%) | Efficiency (%) |
| 1 | 0 | 50 | 0.11 | 7 | 41 | 1.97 | 9.74 | 0.48 | 75.47 | 96.55 | 48.05 | 9.21 | 44.60 |
| 2 | 0 | 150 | 0.34 | 19 | 128 | 1.98 | 10.35 | 0.66 | 68.54 | 90.30 | 55.10 | 15.64 | 45.40 |
| 3 | 0 | 50 | 0.36 | 20 | 30 | 5.71 | 10.11 | 0.37 | 98.84 | 99.87 | 2.27 | 0.00 | 2.14 |
| 4* | 0 | 148 | 1.12 | 50 | 98 | 5.81 | 10.81 | 1.02 | 88.40 | 98.06 | 21.72 | 4.17 | 19.78 |
| 5 | 40 | 50 | 0.11 | 7 | 83 | 1.90 | 11.12 | 0.33 | 67.97 | 92.40 | 58.59 | 15.32 | 50.99 |
| 6 | 40 | 149 | 0.33 | 19 | 170 | 1.86 | 8.64 | 0.55 | 67.92 | 90.21 | 57.33 | 16.07 | 47.54 |
| 7 | 40 | 49 | 0.31 | 20 | 70 | 5.49 | 10.40 | 0.44 | 87.33 | 98.39 | 24.86 | 3.67 | 23.25 |
| 8* | 40 | 150 | 1.04 | 50 | 140 | 5.52 | 9.91 | 0.96 | 86.03 | 97.01 | 25.96 | 6.48 | 22.96 |
| 9 | 20 | 100 | 0.52 | 27 | 93 | 3.76 | 9.10 | 1.01 | 75.29 | 95.81 | 44.67 | 8.97 | 40.48 |
| 10 | 18 | 94 | 0.47 | 30 | 82 | 3.89 | 9.26 | 0.95 | 74.71 | 94.78 | 45.03 | 11.11 | 39.81 |
| 11 | 20 | 89 | 0.43 | 28 | 81 | 3.70 | 9.04 | 0.93 | 75.33 | 95.45 | 44.75 | 8.97 | 40.20 |

* - uncontrollable mudline

**Lamella thickener parametric test data using Elkhorn No. 3 seam coal**

| Test Number | % Ash (adjusted) | | | % Combustible (adj.) | | | % Sulfur (adjusted) | | | Superficial Velocity | | Throughput | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) | Overflow (mm/min) | Per Plate (mm/min) | Eff. Area (lb/hr/sq.in.) | Actual Area (lb/hr/sq.in.) | Volume (lb/hr/litre) |
| 1 | 47.26 | 32.53 | 92.58 | 52.74 | 67.47 | 7.42 | 0.38 | 0.46 | 0.14 | 8.15 | 15.13 | 0.0007 | 0.0027 | 0.0102 |
| 2 | 47.92 | 31.39 | 83.94 | 52.08 | 68.61 | 16.06 | 0.37 | 0.46 | 0.18 | 25.44 | 47.24 | 0.0020 | 0.0081 | 0.0310 |
| 3 | 47.92 | 47.38 | 94.09 | 52.08 | 52.62 | 5.91 | 0.37 | 0.37 | 0.09 | 5.96 | 11.07 | 0.0021 | 0.0087 | 0.0332 |
| 4* | 48.86 | 43.27 | 91.45 | 51.14 | 56.73 | 8.55 | 0.36 | 0.39 | 0.13 | 19.47 | 36.17 | 0.0066 | 0.0266 | 0.1016 |
| 5 | 47.90 | 29.18 | 87.63 | 52.10 | 70.82 | 12.37 | 0.37 | 0.47 | 0.17 | 16.49 | 30.63 | 0.0006 | 0.0026 | 0.0098 |
| 6 | 46.88 | 29.45 | 83.79 | 53.12 | 70.55 | 16.21 | 0.38 | 0.47 | 0.19 | 33.78 | 62.74 | 0.0019 | 0.0078 | 0.0298 |
| 7 | 47.57 | 40.93 | 93.32 | 52.43 | 59.07 | 6.68 | 0.38 | 0.41 | 0.13 | 13.91 | 25.83 | 0.0018 | 0.0075 | 0.0285 |
| 8* | 47.78 | 41.12 | 88.81 | 52.22 | 58.88 | 11.19 | 0.38 | 0.42 | 0.16 | 27.82 | 51.67 | 0.0061 | 0.0248 | 0.0949 |
| 9 | 50.70 | 37.26 | 91.64 | 49.30 | 62.74 | 8.36 | 0.35 | 0.42 | 0.13 | 18.48 | 34.32 | 0.0031 | 0.0124 | 0.0473 |
| 10 | 50.42 | 37.10 | 89.76 | 49.58 | 62.90 | 10.24 | 0.35 | 0.42 | 0.15 | 16.30 | 30.26 | 0.0028 | 0.0112 | 0.0429 |
| 11 | 50.05 | 36.71 | 90.78 | 49.95 | 63.29 | 9.22 | 0.35 | 0.42 | 0.13 | 16.10 | 29.89 | 0.0025 | 0.0102 | 0.0388 |

* - uncontrollable mudline

## STATISTICAL DATA ANALYSIS

| | |
|---|---|
| Description: | Lamella Thickener |
| Coal Sample: | Elkhorn No. 3 (50% Ash) |
| Response: | Combustible Recovery (%) |

**Design Summary**

| FAC | FACTOR | UNITS | -1 LEVEL | +1 LEVEL |
|---|---|---|---|---|
| A | Feed % Solids | (%) | 2.000 | 6.000 |
| B | Wash water | (ml/min) | 0.000 | 40.000 |
| C | Feed Rate | (ml/min) | 50.000 | 150.000 |

**Analysis Summary**

Sequential Model Sum of Squares

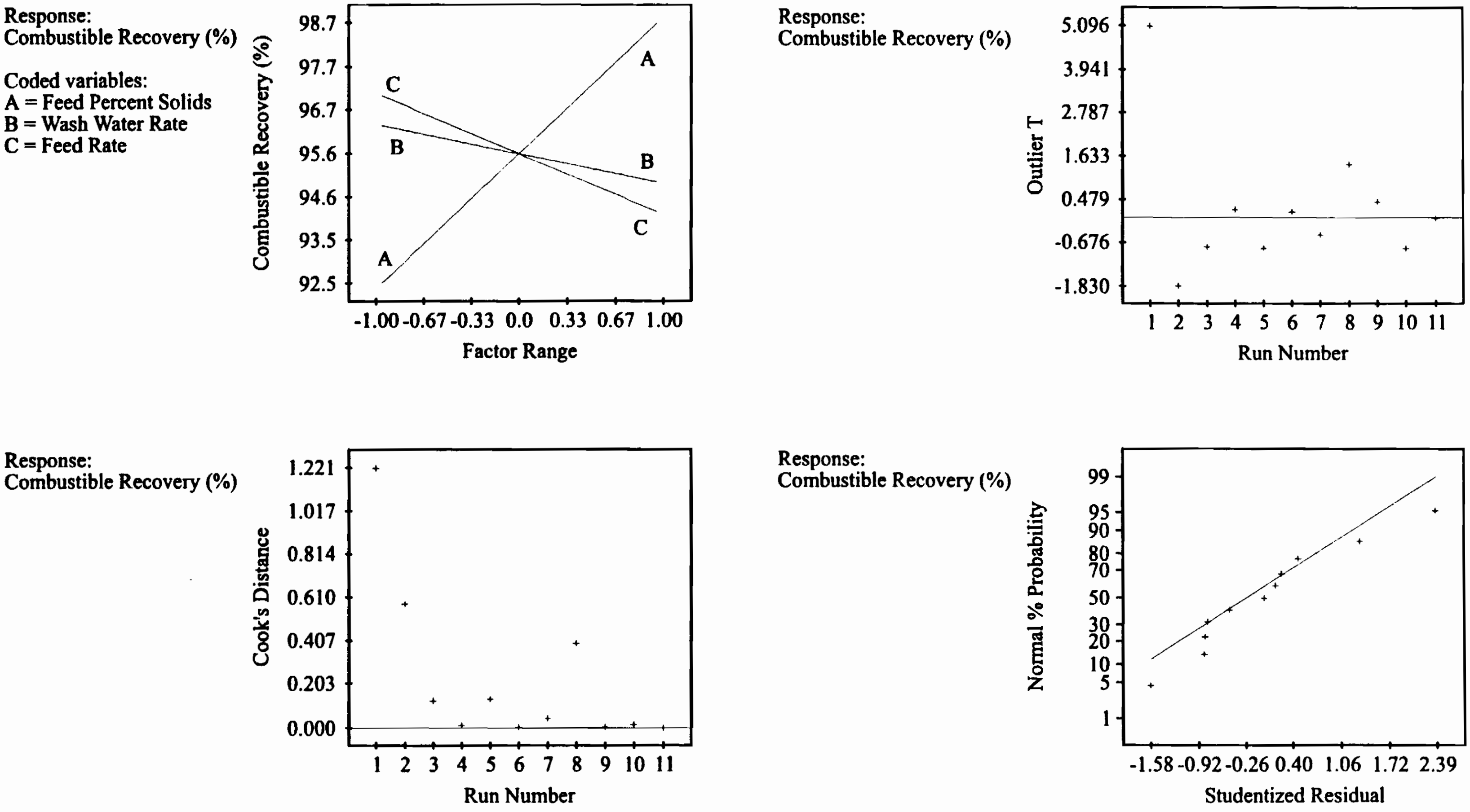
| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROB > F |
|---|---|---|---|---|---|
| MEAN | 100004.0 | 1 | 100004.0 | | |
| Linear | 93.0 | 3 | 31.0 | 23.13 | 0.0005 |
| Quadratic | 8.6 | 6 | 1.4 | 1.718 | 0.5256 |
| Cubic | 0.8 | 1 | 0.8 | | |
| RESIDUAL | 0.0 | 0 | | | |
| TOTAL | 100106.4 | 11 | | | |

ANOVA Summary Statistics of Models Fit

| SOURCE | UNALIASED TERMS | RESID DF | ROOT MSE | R-SQR | ADJ R-SQR | PRESS |
|---|---|---|---|---|---|---|
| Linear | 4 | 7 | 1.16 | 0.9084 | 0.8691 | 30.39 |
| Quadratic | 10 | 1 | 0.91 | 0.9919 | 0.9190 | 16825.88 |
| Cubic | 11 | 0 | | | | |

```
ANOVA for Linear Model (Combustible Recovery/Lamella Thickener/Elkhorn)

                 SUM OF                 MEAN          F
   SOURCE        SQUARES      DF        SQUARE        VALUE     PROB > F

    MODEL         93.0         3         31.00        23.13      0.0005
  RESIDUAL         9.4         7          1.34
 COR TOTAL       102.4        10

  ROOT MSE         1.16               R-SQUARED      0.9084
  DEP MEAN        95.35           ADJ R-SQUARED      0.8691
      C.V.         1.21%

Predicted Residual Sum of Squares (PRESS) = 30.4


 INDEPENDENT   COEFFICIENT              STANDARD     t FOR H0
  VARIABLE       ESTIMATE        DF       ERROR    COEFFICIENT=0   PROB > |t|

  Intercept        95.61          1        0.35         271.4
  A                 3.25          1        0.45         7.253        0.0002
  B                -0.71          1        0.41        -1.732        0.1268
  C                -1.45          1        0.41        -3.533        0.0096

Final Equation in Terms of Coded Factors:

     Combustible Recovery = 95.61 + (3.25 * A) - (0.71 * B) - (1.45 * C)

Final Equation in Terms of Actual Factors:

     Combustible Recovery = 92.73 + (1.6252 * Feed % Solids)
                           - (3.546E-02 * Wash water)
                           - (2.905E-02 * Feed Rate)

Obs       ACTUAL     PREDICTED                           STUDENT COOK'S OUTLIER
Ord        VALUE       VALUE        RESIDUAL    LEVER     RESID    DIST      t

  1        96.55        94.53          2.02    0.462     2.385    1.221    5.096
  3        99.87       100.54         -0.67    0.454    -0.781    0.127   -0.757
  5        92.40        93.11         -0.71    0.448    -0.821    0.137   -0.800
  7        98.39        98.79         -0.40    0.454    -0.473    0.047   -0.445
  9        95.81        95.29          0.52    0.091     0.472    0.006    0.444
 10        94.78        95.70         -0.92    0.093    -0.831    0.018   -0.811
 11        95.45        95.45          0.00    0.096     0.004    0.000    0.003
  2        90.30        91.62         -1.32    0.481    -1.583    0.581   -1.830
  4        98.06        97.85          0.21    0.479     0.246    0.014    0.229
  6        90.21        90.07          0.14    0.471     0.168    0.006    0.156
  8        97.01        95.89          1.12    0.471     1.330    0.395    1.425
```

```
ANOVA for Quadratic Model (Comb. Recovery/Lamella Thickener/Elkhorn)

               SUM OF                   MEAN          F
    SOURCE     SQUARES       DF         SQUARE       VALUE      PROB > F

     MODEL      101.6         9          11.28        13.60       0.2076
  RESIDUAL        0.8         1           0.83
 COR TOTAL      102.4        10

  ROOT MSE       0.91               R-SQUARED      0.9919
  DEP MEAN      95.35           ADJ R-SQUARED      0.9190
      C.V.       0.96%

Predicted Residual Sum of Squares (PRESS) = 16825.9

 INDEPENDENT  COEFFICIENT             STANDARD    t FOR H0
  VARIABLE     ESTIMATE      DF       ERROR    COEFFICIENT=0  PROB > |t|

  Intercept      95.69        1         0.59       161.2
  A               7.23        1         3.78       1.914        0.3066
  B               0.39        1         0.95      0.4081        0.7533
  C              -1.84        1         0.46      -4.002        0.1559
  A2             19.84        1        18.41       1.078        0.4761
  B2            -16.22        1        33.82     -0.4796        0.7153
  C2             -0.11        1        22.36   -5.00E-03        0.9968
  AB              1.84        1         1.24       1.483        0.3778
  AC              0.65        1         0.37       1.756        0.3295
  BC              0.64        1         0.34       1.900        0.3085

Final Equation in Terms of Coded Factors:

     Combustible Recovery = 95.69 + (7.23 * A) + (0.39 * B) - (1.84 * C)
                                  + (19.84 * A2) - (16.22 * B2) - (0.11 * C2)
               + (1.84 * AB) + (0.65 * AC) + (0.64 * BC)

Final Equation in Terms of Actual Factors:

     Combustible Recovery = 154.81 - (37.646 * Feed % Solids)
                                           + (1.3932 * Wash water)
                                           - (6.697E-02 * Feed Rate)
                                           + (4.9609 * Feed % Solids^2)
                                           - (4.055E-02 * Wash water^2)
                                           - (4.472E-05 * Feed Rate^2)
                                           + (4.592E-02 * Feed % Solids * Wash water)
                                           + (6.550E-03 * Feed % Solids * Feed Rate)
                                           + (6.433E-04 * Wash water * Feed Rate)


Obs     ACTUAL    PREDICTED                           STUDENT COOK'S OUTLIER
Ord      VALUE      VALUE      RESIDUAL     LEVER      RESID   DIST      t

  1      96.55      96.56        -0.01      1.000     -1.000 640.752   0.000
  3      99.87      99.82         0.05      0.997      1.000  31.372   0.000
  5      92.40      92.37         0.03      0.999      1.000 122.169   0.000
  7      98.39      98.41        -0.02      0.999     -1.000 177.336   0.000
  9      95.81      95.16         0.65      0.494      1.000   0.098   0.000
 10      94.78      95.41        -0.63      0.515     -1.000   0.106   0.000
 11      95.45      95.47        -0.02      1.000     -1.000 204.641   0.000
  2      90.30      90.28         0.02      1.000      1.000 218.746   0.000
  4      98.06      98.08        -0.02      0.999     -1.000 137.479   0.000
  6      90.21      90.26        -0.05      0.997     -1.000  38.354   0.000
  8      97.01      97.00         0.01      1.000      1.000 456.072   0.000
```



Response:
Combustible Recovery (%)

Coded variables:
A = Feed Percent Solids
B = Wash Water Rate
C = Feed Rate

Response:
Combustible Recovery (%)

Response:
Combustible Recovery (%)

Response:
Combustible Recovery (%)

Lamella thickener sedimentation separation of coagula formed using Elkhorn No. 3 (50% Ash) seam coal

## STATISTICAL DATA ANALYSIS

Description: Lamella Thickener

Coal Sample: Elkhorn No. 3 (50% Ash)

Response: Separation Efficiency (%)

**Design Summary**

| FAC | FACTOR | UNITS | -1 LEVEL | +1 LEVEL |
|---|---|---|---|---|
| A | Feed % Solids | (%) | 2.000 | 6.000 |
| B | Wash water | (ml/min) | 0.000 | 40.000 |
| C | Feed Rate | (ml/min) | 50.000 | 150.000 |

**Analysis Summary**

Sequential Model Sum of Squares

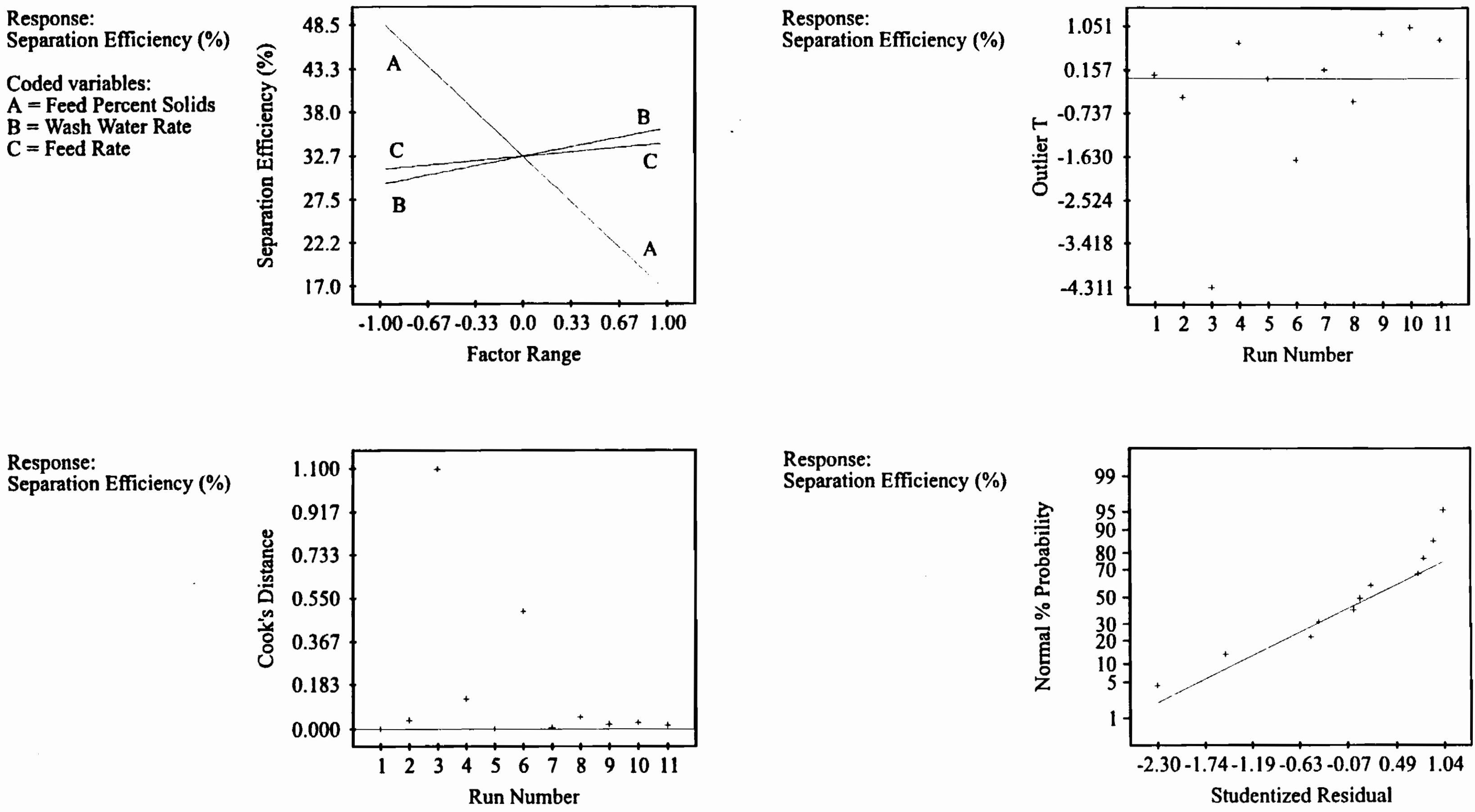
| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROB > F |
|---|---|---|---|---|---|
| MEAN | 12931.1 | 1 | 12931.1 | | |
| Linear | 1955.4 | 3 | 651.8 | 13.95 | 0.0024 |
| Quadratic | 326.0 | 6 | 54.3 | 55.82 | 0.1021 |
| Cubic | 1.0 | 1 | 1.0 | | |
| RESIDUAL | 0.0 | 0 | | | |
| TOTAL | 15213.4 | 11 | | | |

ANOVA Summary Statistics of Models Fit

| SOURCE | UNALIASED TERMS | RESID DF | ROOT MSE | R-SQR | ADJ R-SQR | PRESS |
|---|---|---|---|---|---|---|
| Linear | 4 | 7 | 6.83 | 0.8567 | 0.7954 | 876.71 |
| Quadratic | 10 | 1 | 0.99 | 0.9996 | 0.9957 | 19740.06 |
| Cubic | 11 | 0 | | | | |

```
ANOVA for Linear Model (Separation Efficiency/Lamella/Elkhorn)

                      SUM OF                     MEAN          F
        SOURCE       SQUARES       DF           SQUARE       VALUE      PROB > F

         MODEL        1955.4        3           651.79       13.95       0.0024
       RESIDUAL        326.9        7            46.71
      COR TOTAL       2282.3       10

       ROOT MSE         6.83               R-SQUARED        0.8567
       DEP MEAN        34.29           ADJ R-SQUARED        0.7954
           C.V.        19.93%

Predicted Residual Sum of Squares (PRESS) = 876.7

 INDEPENDENT   COEFFICIENT                STANDARD     t FOR H0
  VARIABLE      ESTIMATE       DF          ERROR    COEFFICIENT=0   PROB > |t|

  Intercept       32.73         1           2.08        15.74
  A              -16.44         1           2.65       -6.215        0.0004
  B                3.40         1           2.42        1.405        0.2027
  C                1.60         1           2.43       0.6595        0.5307

Final Equation in Terms of Coded Factors:

    Separation Efficiency = 32.73 - (16.44 * A) + (3.40 * B) + (1.60 * C)

Final Equation in Terms of Actual Factors:

     Separation Efficiency = 59.02 - (8.2214 * Feed % Solids)
                                 + (0.16985 * Wash water)
                                 + (3.201E-02 * Feed Rate)

Obs       ACTUAL     PREDICTED                        STUDENT COOK'S OUTLIER
Ord        VALUE       VALUE       RESIDUAL     LEVER   RESID    DIST       t

  1        44.60       44.18          0.42     0.462   0.084   0.002   0.078
  3         2.14       13.76        -11.62     0.454  -2.300   1.100  -4.311
  5        50.99       50.97          0.02     0.448   0.004   0.000   0.004
  7        23.25       22.20          1.05     0.454   0.209   0.009   0.194
  9        40.48       34.38          6.10     0.091   0.937   0.022   0.928
 10        39.81       33.02          6.79     0.093   1.043   0.028   1.051
 11        40.20       34.85          5.35     0.096   0.824   0.018   0.803
  2        45.40       47.38         -1.98     0.481  -0.402   0.037  -0.376
  4        19.78       16.07          3.71     0.479   0.752   0.130   0.726
  6        47.54       54.96         -7.42     0.471  -1.494   0.497  -1.675
  8        22.96       25.40         -2.44     0.471  -0.490   0.054  -0.462
```

```
ANOVA for Quadratic Model (Separation Efficiency/Lamella/Elkhorn)

                   SUM OF                   MEAN         F
    SOURCE         SQUARES       DF        SQUARE      VALUE      PROB > F

     MODEL         2281.3         9        253.48      260.4       0.0481
  RESIDUAL            1.0         1          0.97
 COR TOTAL         2282.3        10

  ROOT MSE           0.99               R-SQUARED     0.9996
  DEP MEAN          34.29           ADJ R-SQUARED     0.9957
      C.V.           2.88%

Predicted Residual Sum of Squares (PRESS) = 19740.1

 INDEPENDENT   COEFFICIENT              STANDARD     t FOR H0
  VARIABLE      ESTIMATE       DF        ERROR    COEFFICIENT=0  PROB > |t|

  Intercept         39.99       1          0.64         62.18
  A                 -7.28       1          4.09        -1.778        0.3262
  B                  6.38       1          1.03         6.217        0.1015
  C                  0.49       1          0.50        0.9856        0.5046
  A2                46.77       1         19.94         2.346        0.2565
  B2                -8.52       1         36.63       -0.2327        0.8545
  C2               -39.98       1         24.22        -1.651        0.3467
  AB                 5.86       1          1.34         4.363        0.1434
  AC                 2.77       1          0.40         6.853        0.0922
  BC                -2.69       1          0.37        -7.343        0.0862

Final Equation in Terms of Coded Factors:

    Separation Efficiency = 39.99 - (7.28 * A) + (6.38 * B) + (0.49 * C)
                                  + (46.77 * A2) - (8.52 * B2) - (39.98 * C2)
                                  + (5.86 * AB) + (2.77 * AC) - (2.69 * BC)

Final Equation in Terms of Actual Factors:

     Separation Efficiency = 83.20 - (102.87 * Feed % Solids)
                                 + (0.85486 * Wash water)
                                 + (3.1517 * Feed Rate)
                                 + (11.693 * Feed % Solids^2)
                                 - (2.130E-02 * Wash water^2)
                                 - (1.599E-02 * Feed Rate^2)
                                 + (0.14638 * Feed % Solids * Wash water)
                                 + (2.768E-02 * Feed % Solids * Feed Rate)
                                 - (2.694E-03 * Wash water * Feed Rate)

Obs       ACTUAL    PREDICTED                         STUDENT COOK'S OUTLIER
Ord        VALUE       VALUE     RESIDUAL    LEVER     RESID    DIST      t

  1        44.60       44.59         0.01    1.000     1.000 640.752   0.000
  3         2.14        2.20        -0.06    0.997    -1.000  31.372   0.000
  5        50.99       51.02        -0.03    0.999    -1.000 122.169   0.000
  7        23.25       23.23         0.02    0.999     1.000 177.336   0.000
  9        40.48       41.18        -0.70    0.494    -1.000   0.098   0.000
 10        39.81       39.12         0.69    0.515     1.000   0.106   0.000
 11        40.20       40.18         0.02    1.000     1.000 204.641   0.000
  2        45.40       45.42        -0.02    1.000    -1.000 218.746   0.000
  4        19.78       19.75         0.03    0.999     1.000 137.479   0.000
  6        47.54       47.49         0.05    0.997     1.000  38.354   0.000
  8        22.96       22.97        -0.01    1.000    -1.000 456.072   0.000
```



Lamella thickener sedimentation separation of coagula formed using Pittsburgh No. 8 seam coal

**Lamella thickener parametric test data using Pittsburgh No. 8 seam coal**

| Test Number | Flow Rates | | | | | % Solids | | | Yield | Combustible Recovery | Rejection | | Separation Efficiency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wash Water | Feed | | Product | Tailings | Feed | Product | Tails | | | Ash | Sulphur | |
| | (ml/min) | (ml/min) | (lb/hr) | (ml/min) | (ml/min) | (%) | (%) | (%) | (%) | (%) | (%) | (%) | (%) |
| 1 | 20 | 50 | 0.12 | 7 | 63 | 1.99 | 10.52 | 0.01 | 97.64 | 99.23 | 10.13 | 0.00 | 9.36 |
| 2 | 100 | 50 | 0.12 | 140 | 10 | 2.12 | 9.44 | 0.09 | 85.71 | 88.94 | 29.59 | 21.53 | 18.53 |
| 3 | 20 | 50 | 0.35 | 30 | 40 | 5.81 | 8.66 | nes | 102.07 | 102.49 | 0.00 | 0.00 | 2.49 |
| 4 | 100 | 50 | 0.37 | 30 | 120 | 5.99 | 8.48 | 0.04 | 96.55 | 97.42 | 7.56 | 5.98 | 4.98 |
| 5 | 20 | 94 | 0.23 | 23 | 88 | 1.99 | 7.52 | 0.02 | 99.60 | 99.90 | 2.07 | 1.44 | 1.97 |
| 6 | 100 | 96 | 0.23 | 20 | 174 | 1.99 | 7.81 | 0.08 | 88.65 | 93.32 | 36.93 | 23.07 | 30.25 |
| 7* | 20 | 100 | 0.72 | 90 | 30 | 6.02 | 5.86 | nes | 99.65 | 99.58 | 0.00 | 0.00 | -0.42 |
| 8* | 100 | 100 | 0.72 | 102 | 98 | 6.02 | 5.51 | 0.02 | 99.45 | 99.70 | 1.76 | 0.00 | 1.46 |
| 9 | 60 | 75 | 0.36 | 42 | 90 | 3.98 | 6.48 | 0.02 | 99.70 | 99.86 | 1.05 | 0.51 | 0.91 |
| 10 | 61 | 75 | 0.36 | 42 | 90 | 3.99 | 7.01 | 0.02 | 100.15 | 100.07 | -0.56 | 0.00 | -0.49 |
| 11 | 62 | 75 | 0.38 | 43 | 94 | 4.05 | 6.37 | 0.02 | 99.18 | 99.60 | 2.77 | 1.10 | 2.37 |

* - uncontrollable mudline

'nes' - Not Enough Sample

**Lamella thickener parametric test data using Pittsburgh No. 8 seam coal**

| Test Number | % Ash (adjusted) | | | % Combustible (adj.) | | | % Sulfur (adjusted) | | | Superficial Velocity | | Throughput | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) | Overflow (mm/min) | Plate (mm/min) | Eff. Area (lb/hr/sq.in.) | Actual Area (lb/hr/sq.in.) | Volume (lb/hr/litre) |
| 1 | 16.95 | 15.60 | 72.92 | 83.05 | 84.40 | 27.08 | 3.98 | 3.82 | nes | 3.97 | 7.38 | 0.0007 | 0.0028 | 0.0106 |
| 2 | 17.42 | 14.31 | 36.08 | 82.58 | 85.69 | 63.92 | 4.26 | 3.90 | 6.42 | 19.87 | 36.91 | 0.0007 | 0.0028 | 0.0106 |
| 3 | 16.76 | 16.42 | nes | 83.24 | 83.58 | 100.00 | 4.27 | 4.24 | nes | 3.97 | 7.38 | 0.0021 | 0.0084 | 0.0319 |
| 4 | 17.37 | 16.63 | 38.10 | 82.63 | 83.37 | 61.90 | 4.30 | 4.20 | 6.87 | 19.87 | 36.91 | 0.0022 | 0.0088 | 0.0335 |
| 5 | 15.53 | 15.27 | 79.50 | 84.47 | 84.73 | 20.50 | 3.55 | 3.52 | 8.49 | 3.97 | 7.38 | 0.0013 | 0.0054 | 0.0208 |
| 6 | 15.42 | 10.97 | 50.18 | 84.58 | 89.03 | 49.82 | 3.57 | 3.10 | 7.22 | 19.87 | 36.91 | 0.0013 | 0.0054 | 0.0208 |
| 7* | 17.25 | 17.31 | nes | 82.75 | 82.69 | 100.00 | 3.69 | 3.67 | nes | 3.97 | 7.38 | 0.0043 | 0.0172 | 0.0658 |
| 8* | 17.25 | 17.04 | 55.11 | 82.75 | 82.96 | 44.89 | 3.69 | 3.62 | nes | 19.87 | 36.91 | 0.0043 | 0.0172 | 0.0658 |
| 9 | 17.32 | 17.19 | 60.55 | 82.68 | 82.81 | 39.45 | 4.04 | 4.03 | 7.76 | 11.92 | 22.14 | 0.0021 | 0.0087 | 0.0330 |
| 10 | 17.38 | 17.45 | 63.59 | 82.62 | 82.55 | 36.41 | 4.03 | 4.03 | 7.21 | 12.12 | 22.51 | 0.0021 | 0.0087 | 0.0330 |
| 11 | 17.84 | 17.49 | 60.08 | 82.16 | 82.51 | 39.92 | 3.80 | 3.78 | 7.26 | 12.32 | 22.88 | 0.0022 | 0.0090 | 0.0342 |

* - uncontrollable mudline

'nes' - Not Enough Sample

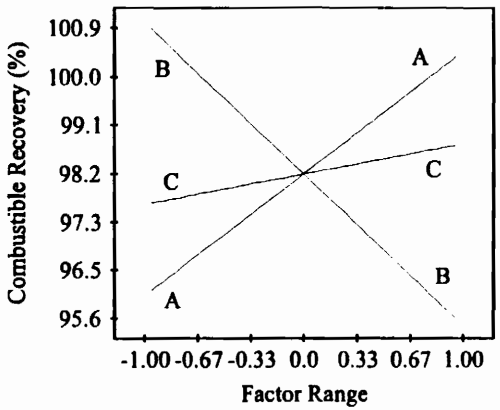
```
                           STATISTICAL DATA ANALYSIS

Description:          Lamella Thickener

Coal Sample:          Pittsburgh No. 8

Response:             Combustible Recovery (%)

Design Summary

FAC     FACTOR              UNITS                   -1 LEVEL       +1 LEVEL
 A      Feed % Solids       (%)                        2.000          6.000
 B      Wash Water          (ml/min)                  20.000        100.000
 C      Feed Rate           (ml/min)                  50.000        100.000

Analysis Summary

 Sequential Model Sum of Squares

                        SUM OF                 MEAN          F
   SOURCE              SQUARES      DF        SQUARE       VALUE      PROB > F

     MEAN             106058.0       1      106058.0
   Linear                100.3       3          33.4       5.246       0.0328
Quadratic                 44.6       6           7.4       162.1       0.0601
    Cubic                  0.0       1           0.0
 RESIDUAL                  0.0       0
    TOTAL             106202.9      11


 ANOVA Summary Statistics of Models Fit

                     UNALIASED  RESID     ROOT                  ADJ
   SOURCE              TERMS     DF       MSE      R-SQR       R-SQR       PRESS

   Linear                4       7       2.52     0.6922      0.5602      139.79
Quadratic               10       1       0.21     0.9997      0.9968
    Cubic               11       0
```

```
ANOVA for Linear Model (Combustible Recovery/Lamella/Pittsburgh)

                    SUM OF                   MEAN         F
    SOURCE         SQUARES       DF         SQUARE      VALUE      PROB > F

     MODEL          100.3         3          33.43       5.246      0.0328
  RESIDUAL           44.6         7           6.37
 COR TOTAL          144.9        10

  ROOT MSE           2.52                 R-SQUARED    0.6922
  DEP MEAN          98.19             ADJ R-SQUARED    0.5602
      C.V.           2.57%

Predicted Residual Sum of Squares (PRESS) = 139.8

 INDEPENDENT   COEFFICIENT               STANDARD     t FOR H0
  VARIABLE      ESTIMATE      DF         ERROR    COEFFICIENT=0  PROB > |t|

  Intercept         98.23      1          0.76         128.9
  A                  2.22      1          0.91         2.441        0.0447
  B                 -2.76      1          0.89        -3.092        0.0175
  C                  0.55      1          0.94        0.5892        0.5742

Final Equation in Terms of Coded Factors:

     Combustible Recovery = 98.23 + (2.22 * A) - (2.76 * B) + (0.55 * C)

Final Equation in Terms of Actual Factors:

     Combustible Recovery = 96.27 + (1.1115 * Feed % Solids)
                                  - (6.900E-02 * Wash Water)
                                  + (2.211E-02 * Feed Rate)

Obs       ACTUAL    PREDICTED                     STUDENT COOK'S OUTLIER
Ord        VALUE      VALUE     RESIDUAL   LEVER   RESID    DIST     t

  1        99.23      98.22        1.01    0.453   0.544   0.061   0.514
  3       102.49     102.44        0.05    0.467   0.028   0.000   0.026
  2        88.94      92.81       -3.87    0.452  -2.069   0.884  -3.074
  4        97.42      97.14        0.28    0.486   0.154   0.006   0.143
  9        99.86      98.23        1.63    0.091   0.677   0.011   0.648
 10       100.07      98.16        1.91    0.091   0.793   0.016   0.770
 11        99.60      98.20        1.40    0.092   0.580   0.008   0.551
  5        99.90      99.19        0.71    0.445   0.379   0.029   0.354
  7        99.58     103.77       -4.19    0.487  -2.315   1.272  -4.430
  6        93.32      93.71       -0.39    0.467  -0.213   0.010  -0.198
  8        99.70      98.25        1.45    0.469   0.790   0.138   0.766
```

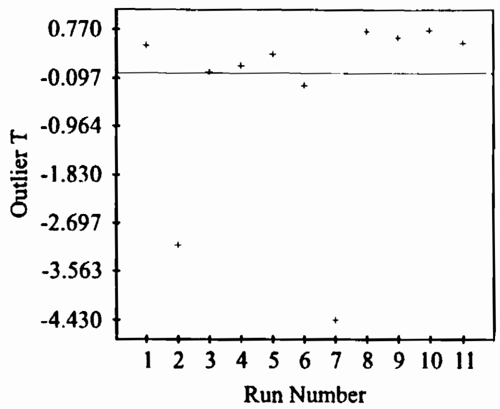
```
ANOVA for Quadratic Model (Combustible Recovery/Lamella/Pittsburgh)

                  SUM OF                    MEAN         F
     SOURCE      SQUARES       DF         SQUARE       VALUE      PROB > F

      MODEL        144.8        9          16.09       351.3       0.0414
   RESIDUAL          0.0        1           0.05
  COR TOTAL        144.9       10

   ROOT MSE         0.21               R-SQUARED      0.9997
   DEP MEAN        98.19           ADJ R-SQUARED      0.9968
       C.V.         0.22%

 Case(s) with leverage of 1.0000:  PRESS statistic not defined.

 INDEPENDENT   COEFFICIENT              STANDARD    t FOR H0
  VARIABLE      ESTIMATE       DF         ERROR   COEFFICIENT=0  PROB > |t|

  Intercept        100.01       1          0.16        637.1
  A                 -2.62       1          3.54      -0.7395        0.5946
  B                 -3.27       1          0.43       -7.512        0.0843
  C                  6.12       1          3.97        1.542        0.3662
  A2               -26.80       1         17.25       -1.554        0.3641
  B2               -16.73       1         13.50       -1.240        0.4322
  C2                44.64       1         33.04        1.351        0.4057
  AB                 3.33       1          1.29        2.580        0.2354
  AC                -4.98       1          3.11       -1.601        0.3555
  BC                 0.00       1          0.86     1.29E-03        0.9992

Final Equation in Terms of Coded Factors:

    Combustible Recovery = 100.01 - (2.62 * A) - (3.27 * B) + (6.12 * C)
                                - (26.80 * A2) - (16.73 * B2) + (44.64 * C2)
                                + (3.33 * AB) - (4.98 * AC) + (0.00 * BC)

Final Equation in Terms of Actual Factors:

    Combustible Recovery = 328.80 + (57.256 * Feed % Solids)
                                + (1.0067 * Wash Water)
                                - (10.070 * Feed Rate)
                                - (6.6989 * Feed % Solids^2)
                                - (1.046E-02 * Wash Water^2)
                                + (7.142E-02 * Feed Rate^2)
                                + (4.157E-02 * Feed % Solids * Wash Water)
                                - (0.09956 * Feed % Solids * Feed Rate)
                                + (1.107E-06 * Wash Water * Feed Rate)


Obs       ACTUAL    PREDICTED                      STUDENT COOK'S OUTLIER
Ord        VALUE      VALUE      RESIDUAL   LEVER   RESID    DIST      t

  1        99.23      99.23          0.00   1.000
  3       102.49     102.49    -7.254E-07   1.000
  2        88.94      88.94         -0.00   1.000
  4        97.42      97.42          0.00   1.000
  9        99.86     100.01         -0.15   0.538  -1.000   0.116    0.000
 10       100.07      99.91          0.16   0.465   1.000   0.087    0.000
 11        99.60      99.61         -0.01   0.997  -1.000  38.004    0.000
  5        99.90      99.90         -0.00   1.000
  7        99.58      99.58          0.00   1.000
  6        93.32      93.32         -0.00   1.000
  8        99.70      99.70         -0.00   1.000
```

Response:
Combustible Recovery (%)

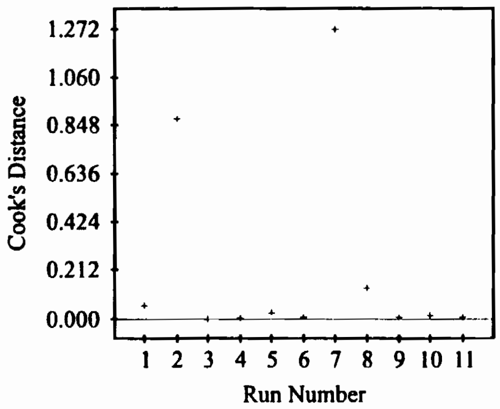
Coded variables:
A = Feed Percent Solids
B = Wash Water Rate
C = Feed Rate



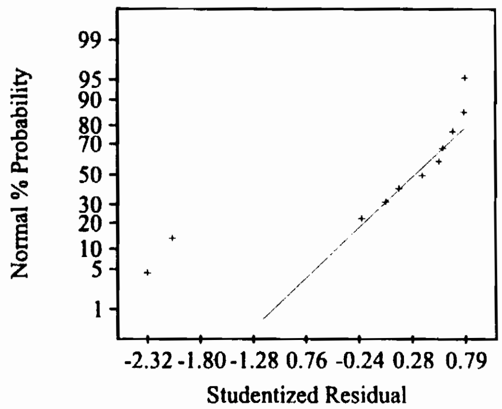
Response:
Combustible Recovery (%)



Response:
Combustible Recovery (%)



Response:
Combustible Recovery (%)



Lamella thickener sedimentation separation of coagula formed using Pittsburgh No. 8 seam coal

## STATISTICAL DATA ANALYSIS

Description: Lamella Thickener

Coal Sample: Pittsburgh No. 8

Response: Separation Efficiency (%)

**Design Summary**

| FAC | FACTOR | UNITS | -1 LEVEL | +1 LEVEL |
|---|---|---|---|---|
| A | Feed % Solids | (%) | 2.000 | 6.000 |
| B | Wash Water | (ml/min) | 20.000 | 100.000 |
| C | Feed Rate | (ml/min) | 50.000 | 100.000 |

**Analysis Summary**

Sequential Model Sum of Squares

| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROB > F |
|---|---|---|---|---|---|
| MEAN | 463.6 | 1 | 463.6 | | |
| Linear | 560.4 | 3 | 186.8 | 3.574 | 0.0750 |
| Quadratic | 364.5 | 6 | 60.8 | 45.33 | 0.1132 |
| Cubic | 1.3 | 1 | 1.3 | | |
| RESIDUAL | 0.0 | 0 | | | |
| TOTAL | 1389.9 | 11 | | | |

ANOVA Summary Statistics of Models Fit

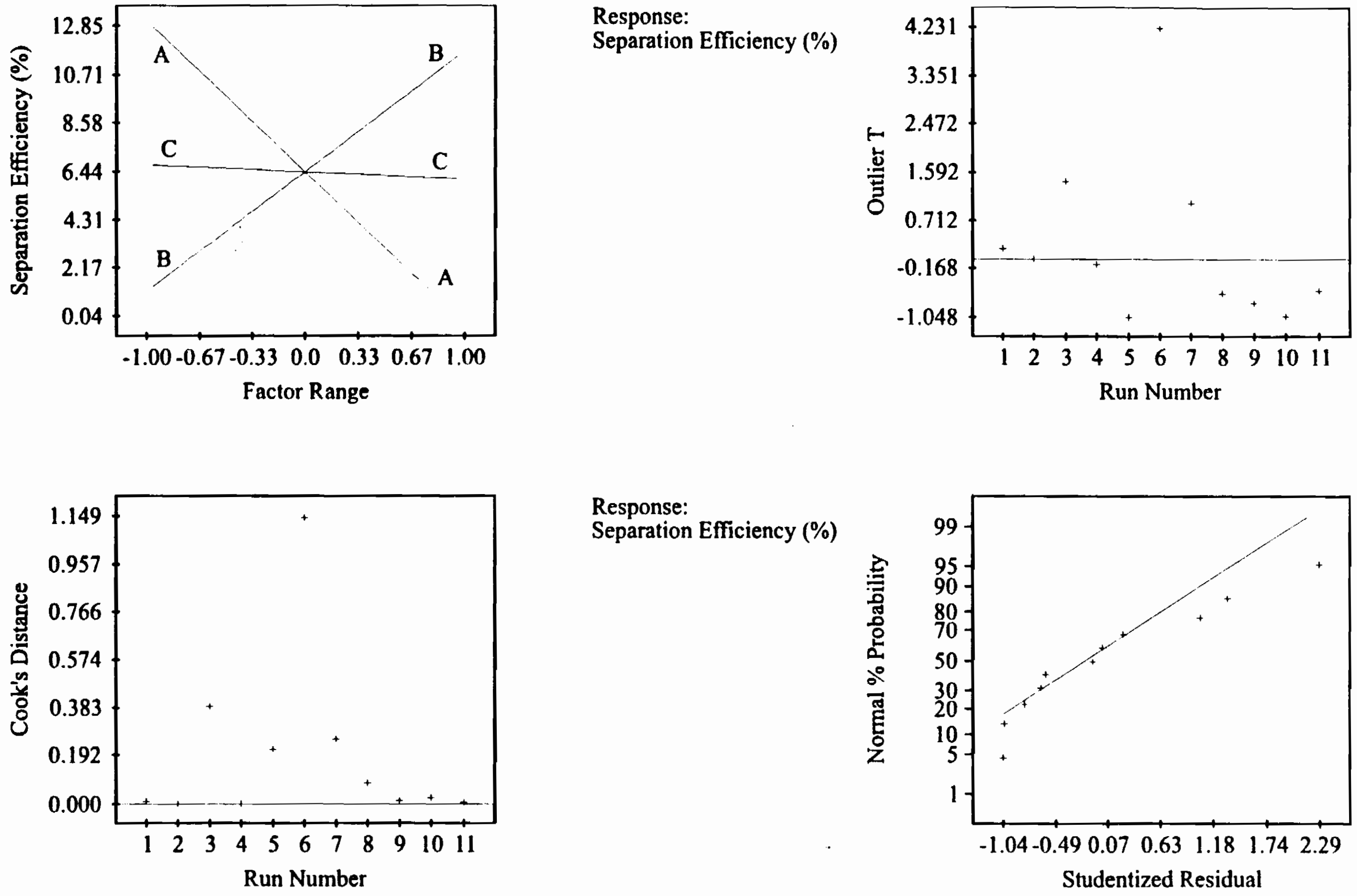
| SOURCE | UNALIASED TERMS | RESID DF | ROOT MSE | R-SQR | ADJ R-SQR | PRESS |
|---|---|---|---|---|---|---|
| Linear | 4 | 7 | 7.23 | 0.6050 | 0.4357 | 1064.68 |
| Quadratic | 10 | 1 | 1.16 | 0.9986 | 0.9855 | |
| Cubic | 11 | 0 | | | | |

```
ANOVA for Linear Model (Separation Efficiency/Lamella/Pittsburgh)

                  SUM OF                    MEAN          F
     SOURCE       SQUARES      DF          SQUARE       VALUE      PROB > F

      MODEL        560.4        3          186.81       3.574       0.0750
   RESIDUAL        365.9        7           52.27
  COR TOTAL        926.3       10

   ROOT MSE         7.23                R-SQUARED      0.6050
   DEP MEAN         6.49            ADJ R-SQUARED      0.4357
       C.V.       111.37%

Predicted Residual Sum of Squares (PRESS) = 1064.7


 INDEPENDENT  COEFFICIENT               STANDARD    t FOR H0
  VARIABLE     ESTIMATE       DF         ERROR    COEFFICIENT=0  PROB > |t|

  Intercept         6.44       1          2.18         2.953
  A                -6.67       1          2.61        -2.558        0.0377
  B                 5.31       1          2.56         2.077        0.0765
  C                -0.31       1          2.69        -0.1154       0.9114

Final Equation in Terms of Coded Factors:

     Separation Efficiency = 6.44 - (6.67 * A) + (5.31 * B) - (0.31 * C)

Final Equation in Terms of Actual Factors:

     Separation Efficiency = 12.76 - (3.3360 * Feed % Solids)
                                  + (0.13271 * Wash Water)
                                  - (1.240E-02 * Feed Rate)

Obs      ACTUAL    PREDICTED                       STUDENT COOK'S OUTLIER
Ord       VALUE      VALUE     RESIDUAL   LEVER     RESID   DIST      t

  1        9.36        8.12       1.24    0.453     0.232   0.011   0.216
  3        2.49       -4.56       7.05    0.467     1.336   0.391   1.432
  2       18.53       18.40       0.13    0.452     0.024   0.000   0.022
  4        4.98        5.39      -0.41    0.486    -0.079   0.001  -0.073
  9        0.91        6.44      -5.53    0.091    -0.803   0.016  -0.780
 10       -0.49        6.58      -7.07    0.091    -1.025   0.026  -1.030
 11        2.37        6.38      -4.01    0.092    -0.581   0.009  -0.552
  5        1.97        7.57      -5.60    0.445    -1.040   0.217  -1.048
  7       -0.42       -5.85       5.43    0.487     1.048   0.260   1.056
  6       30.25       18.16      12.09    0.467     2.290   1.149   4.231
  8        1.46        4.77      -3.31    0.469    -0.628   0.087  -0.599
```

```
ANOVA for Quadratic Model (Separation Efficiency/Lamella/Pittsburgh)

                    SUM OF                    MEAN         F
    SOURCE         SQUARES       DF          SQUARE       VALUE      PROB > F

     MODEL           925.0        9          102.78       76.69       0.0884
  RESIDUAL             1.3        1            1.34
 COR TOTAL           926.3       10

  ROOT MSE            1.16                R-SQUARED      0.9986
  DEP MEAN            6.49            ADJ R-SQUARED      0.9855
      C.V.           17.83%

 INDEPENDENT   COEFFICIENT               STANDARD     t FOR H0
  VARIABLE      ESTIMATE       DF          ERROR   COEFFICIENT=0  PROB > |t|

  Intercept          0.12       1          0.85        0.1448
  A                 23.48       1         19.13         1.228       0.4352
  B                  8.12       1          2.35         3.455       0.1794
  C                -35.56       1         21.45        -1.658       0.3456
  A2               211.19       1         93.29         2.264       0.2648
  B2                49.30       1         73.00        0.6753       0.6219
  C2              -271.49       1        178.72        -1.519       0.3706
  AB               -17.50       1          6.97        -2.511       0.2413
  AC                23.49       1         16.82         1.396       0.3957
  BC                10.31       1          4.65         2.216       0.2698

Final Equation in Terms of Coded Factors:

    Separation Efficiency = 0.12 + (23.48 * A) + (8.12 * B) - (35.56 * C)
                                + (211.19 * A2) + (49.30 * B2)
                                - (271.49 * C2) - (17.50 * AB)
                                + (23.49 * AC) + (10.31 * BC)

Final Equation in Terms of Actual Factors:

     Separation Efficiency = - 1305.31 - (32.73 * Feed % Solids)
                                - (3.3926 * Wash Water)
                                + (61.238 * Feed Rate)
                                + (52.797 * Feed % Solids^2)
                                + (3.081E-02 * Wash Water^2)
                                - (0.43439 * Feed Rate^2)
                                - (0.21878 * Feed % Solids * Wash Water)
                                + (0.46970 * Feed % Solids * Feed Rate)
                                + (1.031E-02 * Wash Water * Feed Rate)


Obs       ACTUAL     PREDICTED                          STUDENT COOK'S OUTLIER
Ord        VALUE        VALUE       RESIDUAL    LEVER    RESID    DIST      t

  1         9.36         9.36          -0.00    1.000
  3         2.49         2.49           0.00    1.000
  2        18.53        18.52           0.01    1.000
  4         4.98         4.98          -0.00    1.000
  9         0.91         0.12           0.79    0.538    1.000   0.116    0.000
 10        -0.49         0.36          -0.85    0.465   -1.000   0.087    0.000
 11         2.37         2.31           0.06    0.997    1.000  38.004    0.000
  5         1.97         1.97           0.00    1.000
  7        -0.42        -0.41          -0.01    1.000
  6        30.25        30.25           0.00    1.000
  8         1.46         1.46           0.00    1.000
```

Response:
Separation Efficiency (%)

Coded variables:
A = Feed Percent Solids
B = Wash Water Rate
C = Feed Rate



Response:
Separation Efficiency (%)

Response:
Separation Efficiency (%)

Response:
Separation Efficiency (%)

Lamella thickener sedimentation separation of coagula formed using Pittsburgh No. 8 seam coal

# APPENDIX D - ROTOR CENTRIFUGE DATA

**Rotor centrifuge preliminary test data using Elkhorn No. 3 seam coal**

| Test Number | pH | RPM's | Effective G's | % Solids | | Yield (%) | Combustible Recovery (%) | Ash Rejection (%) | Separation Efficiency (%) | % Ash | | | % Combustible | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Feed (%) | Tails (%) | | | | | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) |
| 1 | 7.5 | 500 | 0.99 | 4.99 | *nm | 31.47 | 36.08 | 73.16 | 9.24 | 49.95 | 42.61 | 53.32 | 50.05 | 57.39 | 46.68 |
| 2 | 7.5 | 750 | 2.24 | 5.01 | 2.20 | 52.72 | 61.61 | 56.17 | 17.78 | 49.98 | 41.55 | 59.38 | 50.02 | 58.45 | 40.62 |
| 3 | 7.5 | 1000 | 3.98 | 4.99 | *nm | 81.18 | 93.10 | 30.77 | 23.87 | 49.95 | 42.60 | 81.65 | 50.05 | 57.40 | 18.35 |
| 4 | 7.5 | 1250 | 6.21 | 5.01 | 0.05 | 88.77 | 98.08 | 20.56 | 18.64 | 49.98 | 44.73 | 91.47 | 50.02 | 55.27 | 8.53 |
| 5 | 7.5 | 1500 | 8.95 | 4.99 | *nm | 87.28 | 98.08 | 23.53 | 21.61 | 49.95 | 43.76 | 92.43 | 50.05 | 56.24 | 7.57 |
| 6 | 7.5 | 500 | 0.99 | 10.29 | 9.40 | 10.65 | 11.16 | 89.84 | 1.00 | 50.93 | 48.58 | 51.21 | 49.07 | 51.42 | 48.79 |
| 7 | 7.5 | 750 | 2.24 | 10.29 | 6.23 | 45.58 | 47.81 | 56.57 | 4.38 | 50.93 | 48.53 | 52.94 | 49.07 | 51.47 | 47.06 |
| 8 | 7.5 | 1000 | 3.98 | 10.29 | 3.69 | 70.86 | 75.31 | 33.42 | 8.73 | 50.93 | 47.85 | 58.42 | 49.07 | 52.15 | 41.58 |
| 9 | 7.5 | 1250 | 6.21 | 10.29 | 2.59 | 78.78 | 83.60 | 25.86 | 9.46 | 50.93 | 47.93 | 62.07 | 49.07 | 52.07 | 37.93 |
| 10 | 7.5 | 1500 | 8.95 | 10.29 | 0.42 | 93.69 | 99.03 | 11.46 | 10.50 | 50.93 | 48.13 | 92.48 | 49.07 | 51.87 | 7.52 |
| 11 | 7.5 | 500 | 0.99 | 13.55 | 12.48 | 11.83 | 12.03 | 88.36 | 0.39 | 50.78 | 49.96 | 50.89 | 49.22 | 50.04 | 49.11 |
| 12 | 7.5 | 800 | 2.55 | 13.55 | 9.72 | 15.00 | 14.95 | 84.95 | -0.10 | 50.78 | 50.95 | 50.75 | 49.22 | 49.05 | 49.25 |
| 13 | 7.5 | 1000 | 3.98 | 13.55 | 8.79 | 76.92 | 76.97 | 23.12 | 0.09 | 50.78 | 50.75 | 50.88 | 49.22 | 49.25 | 49.12 |
| 14 | 7.5 | 1250 | 6.21 | 13.55 | 3.06 | 83.95 | 85.06 | 17.12 | 2.18 | 50.78 | 50.13 | 54.18 | 49.22 | 49.87 | 45.82 |
| 15 | 7.5 | 1500 | 8.95 | 13.55 | 0.00 | 98.33 | 99.63 | 2.93 | 2.56 | 50.78 | 50.13 | 89.12 | 49.22 | 49.87 | 10.88 |
| 16 | 10.0 | 500 | 0.99 | 5.01 | 3.74 | 17.56 | 18.70 | 83.57 | 2.28 | 50.26 | 47.02 | 50.95 | 49.74 | 52.98 | 49.05 |
| 17 | 10.0 | 1000 | 3.98 | 5.01 | 1.06 | 75.09 | 84.36 | 34.08 | 18.44 | 50.26 | 44.12 | 68.77 | 49.74 | 55.88 | 31.23 |
| 18 | 10.0 | 1500 | 8.95 | 5.01 | 0.49 | 83.16 | 90.94 | 24.53 | 15.47 | 50.26 | 45.61 | 73.23 | 49.74 | 54.39 | 26.77 |
| 19 | 10.0 | 2000 | 15.91 | 5.01 | 0.02 | 87.92 | 94.35 | 18.45 | 12.80 | 50.26 | 46.62 | 76.74 | 49.74 | 53.38 | 23.26 |
| 20 | 7.5 | 550 | 1.20 | 2.87 | 1.87 | 32.71 | 39.64 | 73.93 | 13.57 | 51.09 | 40.72 | 56.13 | 48.91 | 59.28 | 43.87 |
| 21 | 7.5 | 750 | 2.24 | 2.88 | 0.70 | 77.04 | 90.33 | 35.72 | 26.05 | 51.04 | 42.59 | 79.39 | 48.96 | 57.41 | 20.61 |
| 22 | 7.5 | 1000 | 3.98 | 2.89 | 0.51 | 83.34 | 96.20 | 29.01 | 25.21 | 51.00 | 43.44 | 88.83 | 49.00 | 56.56 | 11.17 |
| 23 | 7.5 | 1200 | 5.73 | 2.89 | 0.31 | 87.71 | 98.23 | 22.49 | 20.72 | 50.78 | 44.88 | 92.92 | 49.22 | 55.13 | 7.08 |
| 24 | 7.5 | 1500 | 8.95 | 2.89 | 0.23 | 91.19 | 98.70 | 16.04 | 14.74 | 50.98 | 46.94 | 92.79 | 49.02 | 53.06 | 7.21 |
| 25 | 10.0 | 500 | 0.99 | 2.87 | 1.62 | 36.36 | 42.40 | 69.32 | 11.72 | 51.51 | 43.46 | 56.11 | 48.49 | 56.54 | 43.89 |
| 26 | 10.0 | 1000 | 3.98 | 2.92 | 0.51 | 71.16 | 79.19 | 36.53 | 15.72 | 51.11 | 45.59 | 64.73 | 48.89 | 54.41 | 35.27 |
| 27 | 10.0 | 1500 | 8.95 | 2.90 | 0.43 | 79.75 | 87.88 | 27.98 | 15.86 | 51.27 | 46.30 | 70.84 | 48.73 | 53.70 | 29.16 |

*nm - not measured

**Rotor centrifuge preliminary test data using Pittsburgh No. 8 seam coal**

| Test Number | pH | RPM's | Effective G's | % Solids | | Yield (%) | Combustible Recovery (%) | Ash Rejection (%) | Separation Efficiency (%) | % Ash | | | % Combustible | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Feed (%) | Tails (%) | | | | | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) |
| 1 | 7.6 | 500 | 0.99 | 4.48 | 3.86 | 54.39 | 54.22 | 44.78 | -1.00 | 16.97 | 17.23 | 16.66 | 83.03 | 82.77 | 83.34 |
| 2 | 7.6 | 750 | 2.24 | 4.50 | 1.52 | 32.39 | 32.77 | 69.45 | 2.22 | 16.88 | 15.92 | 17.34 | 83.12 | 84.08 | 82.66 |
| 3 | 7.6 | 1000 | 3.98 | 4.48 | 0.22 | 90.42 | 90.77 | 11.30 | 2.06 | 16.86 | 16.54 | 19.88 | 83.14 | 83.46 | 80.12 |
| 4 | 7.6 | 1250 | 6.21 | 4.47 | 0.00 | 99.81 | 100.00 | 1.14 | 1.14 | 16.89 | 16.73 | 100.00 | 83.11 | 83.27 | 0.00 |
| 5 | 10.0 | 500 | 0.99 | 4.51 | 3.50 | 40.10 | 38.27 | 51.34 | -10.39 | 17.56 | 21.31 | 15.05 | 82.44 | 78.69 | 84.95 |
| 6 | 10.0 | 1000 | 3.98 | 4.51 | 0.47 | 88.32 | 86.20 | 1.89 | -11.91 | 17.77 | 19.74 | 2.88 | 82.23 | 80.26 | 97.12 |
| 7 | 10.0 | 1500 | 8.95 | 4.49 | 0.00 | 109.19 | 110.95 | -1.11 | 9.83 | 17.84 | 16.52 | 2.16 | 82.16 | 83.48 | 97.84 |
| 8 | 10.0 | 2000 | 15.91 | 4.52 | 0.00 | 97.80 | 97.39 | 0.26 | -2.35 | 17.70 | 18.05 | 2.12 | 82.30 | 81.95 | 97.88 |

**Rotor centrifuge parametric test data using Elkhorn No. 3 seam coal**

| Test Number | pH | Spin Time (min) | RPM's | Effective G's | Feed Solids (%) | Yield (%) | Comb. Rec. (%) | Rejection |  | Separation Efficiency (%) | % Ash (Adjusted) |  |  | % Sulphur (Adjusted) |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  |  | Ash (%) | Sulphur (%) |  | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) |
| 1 | 7.6 | 6 | 1050 | 4.38 | 1.07 | 96.38 | 98.78 | 5.93 | 0.00 | 4.71 | 51.00 | 49.78 | 83.46 | 0.40 | 0.40 | 0.40 |
| 2 | 7.6 | 6 | 1100 | 4.81 | 4.71 | 78.97 | 79.75 | 21.79 | 0.00 | 1.55 | 50.59 | 50.10 | 52.43 | 0.41 | 0.41 | 0.41 |
| 3 | 9.5 | 6 | 1000 | 3.98 | 1.08 | 84.15 | 93.96 | 25.34 | 0.82 | 19.29 | 50.83 | 45.10 | 81.25 | 0.39 | 0.46 | 0.02 |
| 4 | 9.6 | 6 | 1100 | 4.81 | 4.67 | 85.27 | 94.87 | 24.09 | 6.50 | 18.30 | 50.63 | 45.07 | 82.82 | 0.41 | 0.46 | 0.16 |
| 5 | 8.5 | 3 | 750 | 2.24 | 2.75 | 36.13 | 46.47 | 73.48 | 55.68 | 19.86 | 51.84 | 38.05 | 59.64 | 0.43 | 0.54 | 0.37 |
| 6 | 8.5 | 3 | 1250 | 6.21 | 2.85 | 84.90 | 97.69 | 27.19 | 4.59 | 24.88 | 51.42 | 44.10 | 92.57 | 0.43 | 0.48 | 0.13 |
| 7 | 8.5 | 9 | 750 | 2.24 | 2.76 | 66.05 | 81.67 | 48.25 | 22.48 | 29.11 | 52.22 | 40.92 | 74.20 | 0.43 | 0.50 | 0.29 |
| 8 | 8.6 | 9 | 1250 | 6.21 | 2.84 | 93.17 | 98.96 | 12.23 | 0.00 | 11.19 | 51.71 | 48.71 | 92.66 | 0.42 | 0.46 | 0.00 |
| 9 | 8.6 | 3 | 1000 | 3.98 | 0.70 | 74.64 | 94.61 | 45.25 | 16.24 | 39.86 | 50.09 | 36.74 | 89.39 | 0.39 | 0.44 | 0.25 |
| 10 | 8.5 | 3 | 1000 | 3.98 | 4.68 | 66.31 | 78.50 | 45.61 | 19.76 | 24.00 | 50.56 | 41.47 | 68.45 | 0.41 | 0.47 | 0.27 |
| 11 | 8.5 | 9 | 1000 | 3.98 | 0.70 | 87.76 | 97.51 | 21.83 | 5.53 | 19.34 | 50.40 | 44.89 | 89.92 | 0.41 | 0.44 | 0.18 |
| 12 | 8.5 | 9 | 1000 | 3.98 | 4.70 | 91.15 | 98.76 | 16.48 | 0.00 | 15.24 | 49.94 | 45.76 | 93.01 | 0.39 | 0.44 | 0.00 |
| 13 | 7.5 | 6 | 750 | 2.24 | 2.77 | 47.69 | 49.38 | 53.87 | 0.00 | 3.43 | 51.83 | 50.13 | 53.38 | 0.42 | 0.42 | 0.41 |
| 14 | 9.5 | 6 | 750 | 2.24 | 2.87 | 69.38 | 83.33 | 43.80 | 16.23 | 27.45 | 51.41 | 41.64 | 73.55 | 0.42 | 0.50 | 0.23 |
| 15 | 7.5 | 6 | 1250 | 6.21 | 2.78 | 98.91 | 100.00 | 2.10 | 1.12 | 1.95 | 51.93 | 51.40 | 100.00 | 0.43 | 0.43 | 0.31 |
| 16 | 9.5 | 6 | 1250 | 6.21 | 2.86 | 84.02 | 91.70 | 23.14 | 7.60 | 14.84 | 51.77 | 47.36 | 74.95 | 0.43 | 0.47 | 0.20 |
| 17 | 8.5 | 6 | 750 | 2.24 | 0.69 | 77.41 | 94.48 | 39.43 | 5.06 | 33.91 | 50.34 | 39.39 | 87.86 | 0.42 | 0.51 | 0.09 |
| 18 | 8.5 | 6 | 750 | 2.24 | 4.72 | 68.10 | 80.43 | 44.41 | 20.72 | 26.19 | 49.64 | 40.52 | 69.11 | 0.43 | 0.50 | 0.28 |
| 19 | 8.5 | 6 | 1250 | 6.21 | 0.70 | 86.84 | 96.84 | 22.93 | 0.00 | 19.77 | 50.59 | 44.90 | 88.14 | 0.41 | 0.49 | 0.00 |
| 20 | 8.5 | 6 | 1250 | 6.21 | 4.70 | 90.22 | 98.60 | 18.11 | 0.00 | 16.71 | 50.10 | 45.47 | 92.83 | 0.41 | 0.46 | 0.00 |
| 21 | 7.5 | 3 | 1000 | 3.98 | 2.76 | 86.67 | 86.77 | 13.43 | 0.00 | 0.91 | 51.67 | 51.61 | 52.06 | 0.43 | 0.43 | 0.44 |
| 22 | 9.5 | 3 | 1000 | 3.98 | 2.85 | 68.70 | 83.67 | 45.07 | 20.72 | 27.83 | 52.11 | 41.67 | 75.02 | 0.43 | 0.50 | 0.28 |
| 23 | 7.5 | 9 | 1000 | 3.98 | 2.76 | 78.29 | 80.06 | 23.35 | 20.53 | 3.42 | 52.00 | 50.91 | 55.93 | 0.43 | 0.44 | 0.41 |
| 24 | 9.5 | 9 | 1000 | 3.98 | 2.85 | 86.44 | 94.31 | 21.05 | 6.76 | 15.36 | 51.23 | 46.79 | 79.53 | 0.43 | 0.47 | 0.22 |
| 25 | 8.5 | 6 | 1000 | 3.98 | 2.81 | 81.28 | 95.65 | 32.12 | 7.06 | 27.77 | 51.75 | 43.22 | 88.78 | 0.43 | 0.49 | 0.16 |
| 26 | 8.6 | 6 | 1000 | 3.98 | 2.84 | 86.44 | 97.99 | 24.44 | 5.52 | 22.43 | 51.48 | 45.00 | 92.79 | 0.43 | 0.47 | 0.17 |
| 27 | 8.5 | 6 | 1000 | 3.98 | 2.80 | 80.14 | 95.60 | 34.34 | 5.94 | 29.94 | 51.65 | 42.32 | 89.29 | 0.43 | 0.50 | 0.13 |

## STATISTICAL DATA ANALYSIS

Description: Centrifugal Sedimentation

Coal Sample: Elkhorn No. 3 (50% Ash)

Response: Combustible Recovery (%)

**Design Summary**

| FAC | FACTOR | UNITS | -1 LEVEL | +1 LEVEL |
|---|---|---|---|---|
| A | % Solids | (%) | 1.000 | 5.000 |
| B | pH | | 7.500 | 9.500 |
| C | RPM's | (rpm) | 750.000 | 1250.000 |
| D | time | (min) | 3.000 | 9.000 |

**Analysis Summary**

Sequential Model Sum of Squares

| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROB > F |
|---|---|---|---|---|---|
| MEAN | 211619.5 | 1 | 211619.5 | | |
| Linear | 2518.4 | 4 | 629.6 | 5.869 | 0.0023 |
| Quadratic | 1817.1 | 10 | 181.7 | 4.017 | 0.0130 |
| Cubic | 498.0 | 8 | 62.2 | 5.541 | 0.0578 |
| RESIDUAL | 44.9 | 4 | 11.2 | | |
| TOTAL | 216497.8 | 27 | | | |

Lack of Fit Tests

| MODEL | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROB > F |
|---|---|---|---|---|---|
| Linear | 2356.3 | 20 | 117.8 | 63.17 | 0.0157 |
| Quadratic | 539.2 | 10 | 53.9 | 28.91 | 0.0339 |
| Cubic | 41.2 | 2 | 20.6 | 11.05 | 0.0830 |
| PURE ERR | 3.7 | 2 | 1.9 | | |

ANOVA Summary Statistics of Models Fit

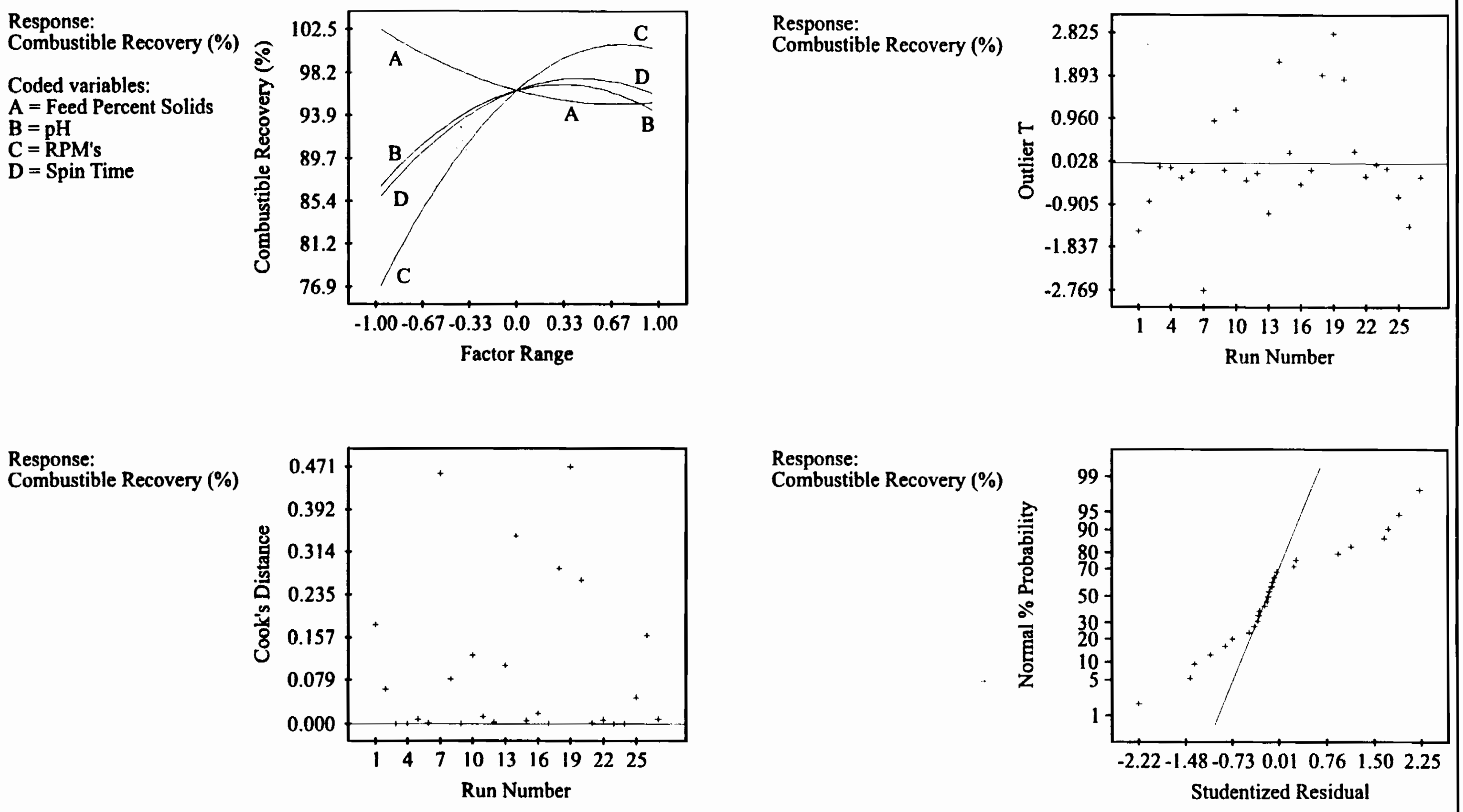
| SOURCE | UNALIASED TERMS | RESID DF | ROOT MSE | R-SQR | ADJ R-SQR | PRESS |
|---|---|---|---|---|---|---|
| Linear | 5 | 22 | 10.36 | 0.5162 | 0.4283 | 3627.06 |
| Quadratic | 15 | 12 | 6.73 | 0.8887 | 0.7589 | 3113.95 |
| Cubic | 23 | 4 | 3.35 | 0.9908 | 0.9401 | 5941.35 |

```
ANOVA for Linear Model (Combustible Recovery / Centrifuge / Elkhorn)
                     SUM OF                    MEAN          F
    SOURCE          SQUARES       DF          SQUARE       VALUE      PROB > F

     MODEL           2518.4        4          629.59        5.869       0.0023
   RESIDUAL          2360.0       22          107.27
   Lack Of Fit         2356.3     20          117.81       63.17        0.0157
    Pure Error            3.7      2            1.87
  COR TOTAL          4878.4       26

   ROOT MSE           10.36                R-SQUARED      0.5162
   DEP MEAN           88.53            ADJ R-SQUARED      0.4283
       C.V.           11.70%

Predicted Residual Sum of Squares (PRESS) = 3627.1

  INDEPENDENT   COEFFICIENT              STANDARD    t FOR H0
   VARIABLE       ESTIMATE      DF          ERROR  COEFFICIENT=0  PROB > |t|

   Intercept         88.53       1           1.99       44.42
   A                 -3.77       1           2.99       -1.262       0.2203
   B                  3.92       1           2.99        1.313       0.2028
   C                 12.34       1           2.99        4.126       0.0004
   D                  5.30       1           2.99        1.772       0.0903

Final Equation in Terms of Coded Factors:

       Combustible Recovery = 88.53 - (3.77 * A) + (3.92 * B) + (12.34 * C) + (5.30 * D)

Final Equation in Terms of Actual Factors:

       Combustible Recovery = 0.89 - (1.8862 * % Solids) + (3.9250 * pH)
                                + (4.934E-02 * RPM's) + (1.7656 * time)

Obs        ACTUAL     PREDICTED                        STUDENT COOK'S OUTLIER Run
Ord         VALUE       VALUE      RESIDUAL   LEVER     RESID   DIST      t    Ord
  1         98.78       88.38        10.40    0.204     1.125   0.065   1.133   15
  2         79.75       80.83        -1.08    0.204    -0.117   0.001  -0.115   24
  3         93.96       96.23        -2.27    0.204    -0.245   0.003  -0.240   11
  4         94.87       88.68         6.19    0.204     0.669   0.023   0.661   25
  5         46.47       70.90       -24.43    0.204    -2.643   0.357  -3.126    7
  6         97.69       95.57         2.12    0.204     0.229   0.003   0.224   23
  7         81.67       81.49         0.18    0.204     0.019   0.000   0.019   16
  8         98.96      106.16        -7.20    0.204    -0.779   0.031  -0.772   18
  9         94.61       87.01         7.60    0.204     0.823   0.035   0.816    5
 10         78.50       79.46        -0.96    0.204    -0.104   0.001  -0.102   22
 11         97.51       97.60        -0.09    0.204    -0.010   0.000  -0.010    4
 12         98.76       90.06         8.70    0.204     0.942   0.045   0.939    3
 13         49.38       72.27       -22.89    0.204    -2.477   0.314  -2.849   26
 14         83.33       80.12         3.21    0.204     0.347   0.006   0.340    6
 15        100.00       96.94         3.06    0.204     0.331   0.006   0.324   12
 16         91.70      104.79       -13.09    0.204    -1.417   0.103  -1.452    8
 17         94.48       79.97        14.51    0.204     1.570   0.126   1.628   14
 18         80.43       72.42         8.01    0.204     0.866   0.038   0.861   19
 19         96.84      104.64        -7.80    0.204    -0.844   0.036  -0.838    1
 20         98.60       97.09         1.51    0.204     0.163   0.001   0.159   13
 21         86.77       79.31         7.46    0.204     0.807   0.033   0.801   20
 22         83.67       87.16        -3.49    0.204    -0.378   0.007  -0.370   10
 23         80.06       89.90        -9.84    0.204    -1.065   0.058  -1.068   27
 24         94.31       97.75        -3.44    0.204    -0.373   0.007  -0.365    2
 25         95.65       88.53         7.12    0.037     0.700   0.004   0.692   17
 26         97.99       88.53         9.46    0.037     0.931   0.007   0.928   21
 27         95.60       88.53         7.07    0.037     0.696   0.004   0.687    9
```

```
ANOVA for Quadratic Model (Combustible Recovery / Centrifuge / Elkhorn)

                  SUM OF                  MEAN        F
    SOURCE       SQUARES      DF         SQUARE     VALUE      PROB > F

     MODEL        4335.5      14         309.68      6.845      0.0010
   RESIDUAL        542.9      12          45.24
   Lack Of Fit       539.2    10          53.92     28.91       0.0339
    Pure Error         3.7     2           1.87
  COR TOTAL       4878.4      26

   ROOT MSE          6.73              R-SQUARED    0.8887
   DEP MEAN         88.53          ADJ R-SQUARED    0.7589
       C.V.          7.60%

Predicted Residual Sum of Squares (PRESS) = 3114.0


 INDEPENDENT   COEFFICIENT               STANDARD    t FOR H0
  VARIABLE       ESTIMATE      DF          ERROR   COEFFICIENT=0  PROB > |t|

  Intercept        96.41        1           3.88       24.83
  A                -3.77        1           1.94      -1.943      0.0759
  B                 3.93        1           1.94       2.021      0.0661
  C                12.34        1           1.94       6.353      0.0001
  D                 5.30        1           1.94       2.728      0.0183
  A2                2.63        1           2.91      0.9043      0.3836
  B2               -6.18        1           2.91      -2.122      0.0553
  C2               -8.31        1           2.91      -2.853      0.0145
  D2               -5.88        1           2.91      -2.019      0.0664
  AB                4.99        1           3.36       1.482      0.1640
  AC                3.95        1           3.36       1.175      0.2627
  AD                4.34        1           3.36       1.290      0.2212
  BC              -10.56        1           3.36      -3.141      0.0085
  BD                4.34        1           3.36       1.290      0.2214
  CD               -8.48        1           3.36      -2.522      0.0268

Final Equation in Terms of Coded Factors:

       Combustible Recovery = 96.41 - (3.77 * A)  + (3.93 * B)  + (12.34 * C)
                                   + (5.30 * D)  + (2.63 * A2) - (6.18 * B2)
                                       - (8.31 * C2) - (5.88 * D2) + (4.99 * AB)
                                       + (3.95 * AC) + (4.34 * AD) - (10.56 * BC)
                                       + (4.34 * BD) - (8.48 * CD)

Final Equation in Terms of Actual Factors:

       Combustible Recovery = - 841.22 - (39.268 * % Solids) + (135.08 * pH)
                              + (0.71849 * RPM's) + (6.4560 * time)
                              + (0.65844 * % Solids^2) - (6.1800 * pH^2)
                              - (1.329E-04 * RPM's^2) - (0.65333 * time^2)
                              + (2.4925 * % Solids * pH)
                              + (7.905E-03 * % Solids * RPM's)
                              + (0.72333 * % Solids * time)
                              - (4.225E-02 * pH * RPM's) + (1.4458 * pH * time)
                              - (1.131E-02 * RPM's * time)
```

**ANOVA for Quadratic Model** (Combustible Recovery / Centrifuge / Elkhorn)

| Obs Ord | ACTUAL VALUE | PREDICTED VALUE | RESIDUAL | LEVER | STUDENT RESID | COOK'S DIST | OUTLIER t | Run Ord |
|---|---|---|---|---|---|---|---|---|
| 1 | 98.78 | 97.70 | 1.08 | 0.583 | 0.249 | 0.006 | 0.239 | 15 |
| 2 | 79.75 | 80.18 | -0.43 | 0.583 | -0.100 | 0.001 | -0.096 | 24 |
| 3 | 93.96 | 95.58 | -1.62 | 0.583 | -0.373 | 0.013 | -0.359 | 11 |
| 4 | 94.87 | 98.00 | -3.13 | 0.583 | -0.722 | 0.049 | -0.707 | 25 |
| 5 | 46.47 | 56.11 | -9.64 | 0.583 | -2.220 | 0.460 | -2.769 | 7 |
| 6 | 97.69 | 97.75 | -0.06 | 0.583 | -0.013 | 0.000 | -0.012 | 23 |
| 7 | 81.67 | 83.67 | -2.00 | 0.583 | -0.460 | 0.020 | -0.445 | 16 |
| 8 | 98.96 | 91.37 | 7.59 | 0.583 | 1.747 | 0.285 | 1.937 | 18 |
| 9 | 94.61 | 95.98 | -1.37 | 0.583 | -0.316 | 0.009 | -0.304 | 5 |
| 10 | 78.50 | 79.76 | -1.26 | 0.583 | -0.290 | 0.008 | -0.278 | 22 |
| 11 | 97.51 | 97.90 | -0.39 | 0.583 | -0.089 | 0.001 | -0.085 | 4 |
| 12 | 98.76 | 99.03 | -0.27 | 0.583 | -0.062 | 0.000 | -0.060 | 3 |
| 13 | 49.38 | 55.10 | -5.72 | 0.583 | -1.318 | 0.162 | -1.364 | 26 |
| 14 | 83.33 | 84.08 | -0.75 | 0.583 | -0.172 | 0.003 | -0.165 | 6 |
| 15 | 100.00 | 100.90 | -0.90 | 0.583 | -0.207 | 0.004 | -0.198 | 12 |
| 16 | 91.70 | 87.62 | 4.08 | 0.583 | 0.939 | 0.082 | 0.934 | 8 |
| 17 | 94.48 | 86.13 | 8.35 | 0.583 | 1.924 | 0.345 | 2.215 | 14 |
| 18 | 80.43 | 70.68 | 9.75 | 0.583 | 2.246 | 0.471 | 2.825 | 19 |
| 19 | 96.84 | 102.89 | -6.05 | 0.583 | -1.394 | 0.181 | -1.458 | 1 |
| 20 | 98.60 | 103.25 | -4.65 | 0.583 | -1.072 | 0.107 | -1.079 | 13 |
| 21 | 86.77 | 79.47 | 7.30 | 0.583 | 1.682 | 0.264 | 1.841 | 20 |
| 22 | 83.67 | 78.64 | 5.03 | 0.583 | 1.158 | 0.125 | 1.176 | 10 |
| 23 | 80.06 | 81.39 | -1.33 | 0.583 | -0.306 | 0.009 | -0.294 | 27 |
| 24 | 94.31 | 97.91 | -3.60 | 0.583 | -0.830 | 0.064 | -0.818 | 2 |
| 25 | 95.65 | 96.41 | -0.76 | 0.333 | -0.139 | 0.001 | -0.133 | 17 |
| 26 | 97.99 | 96.41 | 1.58 | 0.333 | 0.287 | 0.003 | 0.276 | 21 |
| 27 | 95.60 | 96.41 | -0.81 | 0.333 | -0.148 | 0.001 | -0.142 | 9 |



The batch centrifugal separation of coagula formed using Elkhhorn No. 3 (50% Ash) seam coal

## STATISTICAL DATA ANALYSIS

Description: Centrifugal Sedimentation

Coal Sample: Elkhorn No. 3 (50% Ash)

Response: Separation Efficiency (%)

**Design Summary**

| FAC | FACTOR | UNITS | -1 LEVEL | +1 LEVEL |
|---|---|---|---|---|
| A | % Solids | (%) | 1.000 | 5.000 |
| B | pH | | 7.500 | 9.500 |
| C | RPM's | (rpm) | 750.000 | 1250.000 |
| D | time | (min) | 3.000 | 9.000 |

**Analysis Summary**

Sequential Model Sum of Squares

| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROB > F |
|---|---|---|---|---|---|
| MEAN | 9231.1 | 1 | 9231.1 | | |
| Linear | 1429.8 | 4 | 357.4 | 5.185 | 0.0043 |
| Quadratic | 1323.2 | 10 | 132.3 | 8.205 | 0.0006 |
| Cubic | 141.5 | 8 | 17.7 | 1.359 | 0.4070 |
| RESIDUAL | 52.0 | 4 | 13.0 | | |
| TOTAL | 12177.6 | 27 | | | |

Lack of Fit Tests

| MODEL | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROB > F |
|---|---|---|---|---|---|
| Linear | 1486.8 | 20 | 74.3 | 4.977 | 0.1804 |
| Quadratic | 163.6 | 10 | 16.4 | 1.096 | 0.5676 |
| Cubic | 22.2 | 2 | 11.1 | 0.7419 | 0.5741 |
| PURE ERR | 29.9 | 2 | 14.9 | | |

ANOVA Summary Statistics of Models Fit

| SOURCE | UNALIASED TERMS | RESID DF | ROOT MSE | R-SQR | ADJ R-SQR | PRESS |
|---|---|---|---|---|---|---|
| Linear | 5 | 22 | 8.30 | 0.4853 | 0.3917 | 2275.84 |
| Quadratic | 15 | 12 | 4.02 | 0.9343 | 0.8577 | 1009.79 |
| Cubic | 23 | 4 | 3.61 | 0.9823 | 0.8852 | 3258.69 |

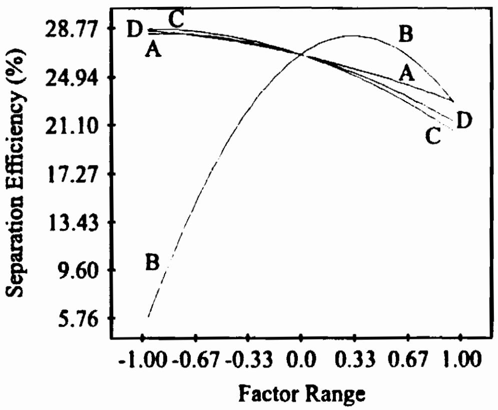
```
ANOVA for Linear Model (Separation Efficiency / Centrifuge / Elkhorn)
                   SUM OF                       MEAN          F
    SOURCE         SQUARES       DF            SQUARE        VALUE      PROB > F

     MODEL         1429.8         4            357.44        5.185       0.0043
   RESIDUAL        1516.7        22             68.94
   Lack Of Fit       1486.8      20             74.34        4.977       0.1804
    Pure Error         29.9       2             14.94
  COR TOTAL        2946.4        26

   ROOT MSE          8.30                   R-SQUARED       0.4853
   DEP MEAN         18.49               ADJ R-SQUARED       0.3917
       C.V.         44.90%

Predicted Residual Sum of Squares (PRESS) = 2275.8

  INDEPENDENT   COEFFICIENT                STANDARD     t FOR H0
   VARIABLE       ESTIMATE       DF          ERROR    COEFFICIENT=0   PROB > |t|
   Intercept        18.49         1           1.60         11.57
   A                -2.91         1           2.40         -1.213      0.2380
   B                 8.92         1           2.40          3.724      0.0012
   C                -4.22         1           2.40         -1.760      0.0924
   D                -3.64         1           2.40         -1.519      0.1431

Final Equation in Terms of Coded Factors:

       Separation Efficiency = 18.49 - (2.91 * A) + (8.92 * B)  - (4.22 * C)
                                 - (3.64 * D)

Final Equation in Terms of Actual Factors:

       Separation Efficiency = - 28.86 - (1.4537 * % Solids) + (8.9250 * pH)
                                   - (1.687E-02 * RPM's) - (1.2133 * time)

Obs       ACTUAL     PREDICTED                          STUDENT  COOK'S OUTLIER  Run
Ord        VALUE       VALUE      RESIDUAL    LEVER      RESID    DIST      t     Ord
  1         4.71       12.47         -7.76    0.204     -1.048    0.056  -1.050   15
  2         1.55        6.66         -5.11    0.204     -0.689    0.024  -0.681   24
  3        19.29       30.32        -11.03    0.204     -1.489    0.113  -1.534   11
  4        18.30       24.51         -6.21    0.204     -0.838    0.036  -0.832   25
  5        19.86       26.35         -6.49    0.204     -0.876    0.039  -0.871    7
  6        24.88       17.91          6.97    0.204      0.940    0.045   0.938   23
  7        29.11       19.07         10.04    0.204      1.355    0.094   1.383   16
  8        11.19       10.63          0.56    0.204      0.075    0.000   0.073   18
  9        39.86       25.04         14.82    0.204      2.001    0.205   2.161    5
 10        24.00       19.22          4.78    0.204      0.645    0.021   0.636   22
 11        19.34       17.76          1.58    0.204      0.214    0.002   0.209    4
 12        15.24       11.94          3.30    0.204      0.445    0.010   0.437    3
 13         3.43       13.78        -10.35    0.204     -1.397    0.100  -1.430   26
 14        27.45       31.63         -4.18    0.204     -0.565    0.016  -0.556    6
 15         1.95        5.35         -3.40    0.204     -0.459    0.011  -0.450   12
 16        14.84       23.20         -8.36    0.204     -1.128    0.065  -1.135    8
 17        33.91       25.62          8.29    0.204      1.120    0.064   1.126   14
 18        26.19       19.80          6.39    0.204      0.862    0.038   0.857   19
 19        19.77       17.18          2.59    0.204      0.350    0.006   0.342    1
 20        16.71       11.37          5.34    0.204      0.721    0.027   0.713   13
 21         0.91       13.21        -12.30    0.204     -1.659    0.141  -1.733   20
 22        27.83       31.06         -3.23    0.204     -0.435    0.010  -0.427   10
 23         3.42        5.93         -2.51    0.204     -0.338    0.006  -0.331   27
 24        15.36       23.78         -8.42    0.204     -1.136    0.066  -1.144    2
 25        27.77       18.49          9.28    0.037      1.139    0.010   1.147   17
 26        22.43       18.49          3.94    0.037      0.484    0.002   0.475   21
 27        29.94       18.49         11.45    0.037      1.405    0.015   1.439    9
```

```
ANOVA for Quadratic Model (Separation Efficiency / Centrifuge / Elkhorn)

                  SUM OF                  MEAN         F
    SOURCE        SQUARES      DF        SQUARE      VALUE      PROB > F

     MODEL         2752.9      14        196.64      12.19       0.0001
   RESIDUAL         193.5      12         16.13
   Lack Of Fit        163.6    10         16.36      1.096       0.5676
    Pure Error         29.9     2         14.94
  COR TOTAL        2946.4      26

   ROOT MSE          4.02               R-SQUARED   0.9343
   DEP MEAN         18.49           ADJ R-SQUARED   0.8577
       C.V.         21.72%

Predicted Residual Sum of Squares (PRESS) = 1009.8


  INDEPENDENT   COEFFICIENT              STANDARD    t FOR H0
   VARIABLE      ESTIMATE      DF         ERROR    COEFFICIENT=0  PROB > |t|

   Intercept        26.71       1          2.32        11.52
   A                -2.91       1          1.16       -2.508       0.0275
   B                 8.92       1          1.16        7.699       0.0001
   C                -4.22       1          1.16       -3.638       0.0034
   D                -3.64       1          1.16       -3.140       0.0085
   A2               -0.96       1          1.74      -0.5523       0.5909
   B2              -13.44       1          1.74       -7.729       0.0001
   C2               -2.16       1          1.74       -1.241       0.2383
   D2               -1.94       1          1.74       -1.118       0.2854
   AB                0.54       1          2.01       0.2702       0.7916
   AC                1.16       1          2.01       0.5802       0.5725
   AD                2.94       1          2.01        1.464       0.1688
   BC               -2.78       1          2.01       -1.386       0.1910
   BD               -3.74       1          2.01       -1.865       0.0868
   CD               -5.73       1          2.01       -2.856       0.0145

Final Equation in Terms of Coded Factors:

       Separation Efficiency = 26.71 - (2.91 * A) + (8.92 * B) - (4.22 * C)
                         - (3.64 * D)  - (0.96 * A2) - (13.44 * B2)
                                 - (2.16 * C2) - (1.94 * D2) + (0.54 * AB)
                                 + (1.16 * AC) + (2.94 * AD) - (2.78 * BC)
                                   - (3.74 * BD) - (5.73 * CD)

Final Equation in Terms of Actual Factors:

       Separation Efficiency = - 1217.51 - (7.5888 * % Solids) + (255.20 * pH)
                               + (0.18568 * RPM's) + (18.166 * time)
                               - (0.24010 * % Solids^2) - (13.439 * pH^2)
                               - (3.453E-05 * RPM's^2) - (0.21602 * time^2)
                               + (0.27125 * % Solids * pH)
                               + (2.330E-03 * % Solids * RPM's)
                               + (0.49000 * % Solids * time)
                               - (1.113E-02 * pH * RPM's)
                               - (1.2483 * pH * time)
                               - (7.647E-03 * RPM's * time)
```

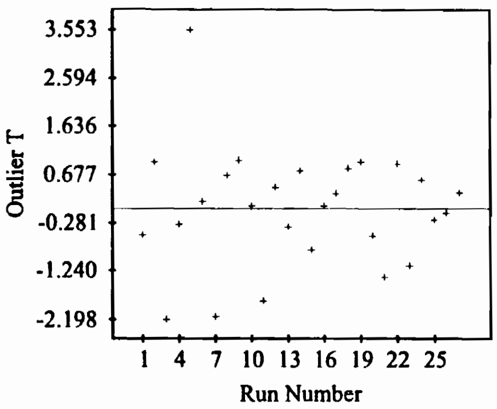
```
ANOVA for Quadratic Model (Separation Efficiency / Centrifuge / Elkhorn)

Obs        ACTUAL    PREDICTED                        STUDENT COOK'S OUTLIER Run
Ord         VALUE      VALUE       RESIDUAL    LEVER   RESID   DIST      t    Ord

  1          4.71        6.84        -2.13     0.583  -0.821   0.063  -0.809  15
  2          1.55       -0.06         1.61     0.583   0.622   0.036   0.605  24
  3         19.29       23.60        -4.31     0.583  -1.664   0.258  -1.817  11
  4         18.30       18.87        -0.57     0.583  -0.221   0.005  -0.212  25
  5         19.86       24.73        -4.87     0.583  -1.880   0.330  -2.143   7
  6         24.88       27.77        -2.89     0.583  -1.114   0.116  -1.127  23
  7         29.11       28.92         0.19     0.583   0.072   0.000   0.069  16
  8         11.19        9.02         2.17     0.583   0.838   0.065   0.826  18
  9         39.86       33.30         6.56     0.583   2.532   0.598   3.553   5
 10         24.00       21.60         2.40     0.583   0.925   0.080   0.919  22
 11         19.34       20.14        -0.80     0.583  -0.307   0.009  -0.295   4
 12         15.24       20.20        -4.96     0.583  -1.914   0.342  -2.198   3
 13          3.43        3.63        -0.20     0.583  -0.076   0.001  -0.073  26
 14         27.45       27.04         0.41     0.583   0.158   0.002   0.151   6
 15          1.95        0.76         1.19     0.583   0.461   0.020   0.445  12
 16         14.84       13.04         1.80     0.583   0.694   0.045   0.678   8
 17         33.91       31.88         2.02     0.583   0.781   0.057   0.768  14
 18         26.19       23.74         2.45     0.583   0.945   0.083   0.941  19
 19         19.77       21.12        -1.35     0.583  -0.521   0.025  -0.504   1
 20         16.71       17.63        -0.92     0.583  -0.357   0.012  -0.343  13
 21          0.91        2.30        -1.39     0.583  -0.536   0.027  -0.520  20
 22         27.83       27.64         0.19     0.583   0.073   0.001   0.070  10
 23          3.42        2.51         0.91     0.583   0.351   0.012   0.338  27
 24         15.36       12.87         2.49     0.583   0.961   0.086   0.957   2
 25         27.77       26.71         1.06     0.333   0.322   0.003   0.310  17
 26         22.43       26.71        -4.28     0.333  -1.306   0.057  -1.350  21
 27         29.94       26.71         3.23     0.333   0.984   0.032   0.983   9
```

Response:
Separation Efficiency (%)

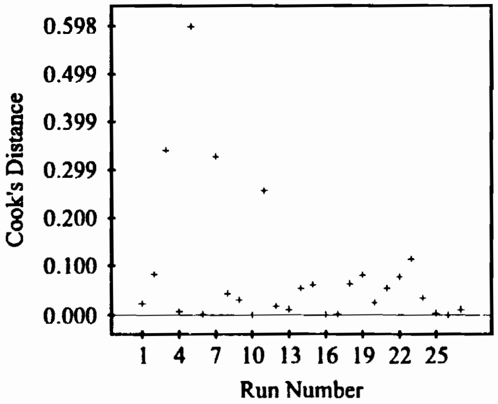
Coded variables:
A = Feed Percent Solids
B = pH
C = RPM's
D = Spin Time



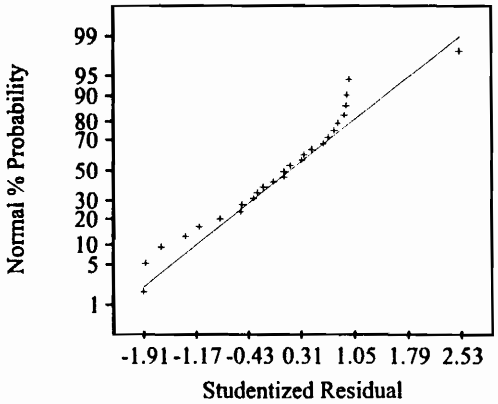
Response:
Separation Efficiency (%)



Response:
Separation Efficiency (%)



Response:
Separation Efficiency (%)



The batch centrifugal separation of coagula formed using Elkhhorn No. 3 (50% Ash) seam coal

## STATISTICAL DATA ANALYSIS

Description: Centrifugal Sedimentation

Coal Sample: Elkhorn No. 3 (50% Ash)

Response: Ash Rejection (%)

**Design Summary**

| FAC | FACTOR | UNITS | -1 LEVEL | +1 LEVEL |
|---|---|---|---|---|
| A | % Solids | (%) | 1.000 | 5.000 |
| B | pH | | 7.500 | 9.500 |
| C | RPM's | (rpm) | 750.000 | 1250.000 |
| D | time | (min) | 3.000 | 9.000 |

**Analysis Summary**

Sequential Model Sum of Squares

| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROB > F |
|---|---|---|---|---|---|
| MEAN | 24243.6 | 1 | 24243.6 | | |
| Linear | 4531.6 | 4 | 1132.9 | 11.34 | 0.0001 |
| Quadratic | 1609.3 | 10 | 160.9 | 3.277 | 0.0277 |
| Cubic | 498.2 | 8 | 62.3 | 2.735 | 0.1733 |
| RESIDUAL | 91.1 | 4 | 22.8 | | |
| TOTAL | 30973.9 | 27 | | | |

Lack of Fit Tests

| MODEL | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROB > F |
|---|---|---|---|---|---|
| Linear | 2144.7 | 20 | 107.2 | 3.974 | 0.2201 |
| Quadratic | 535.4 | 10 | 53.5 | 1.984 | 0.3814 |
| Cubic | 37.1 | 2 | 18.6 | 0.6879 | 0.5925 |
| PURE ERR | 54.0 | 2 | 27.0 | | |

ANOVA Summary Statistics of Models Fit

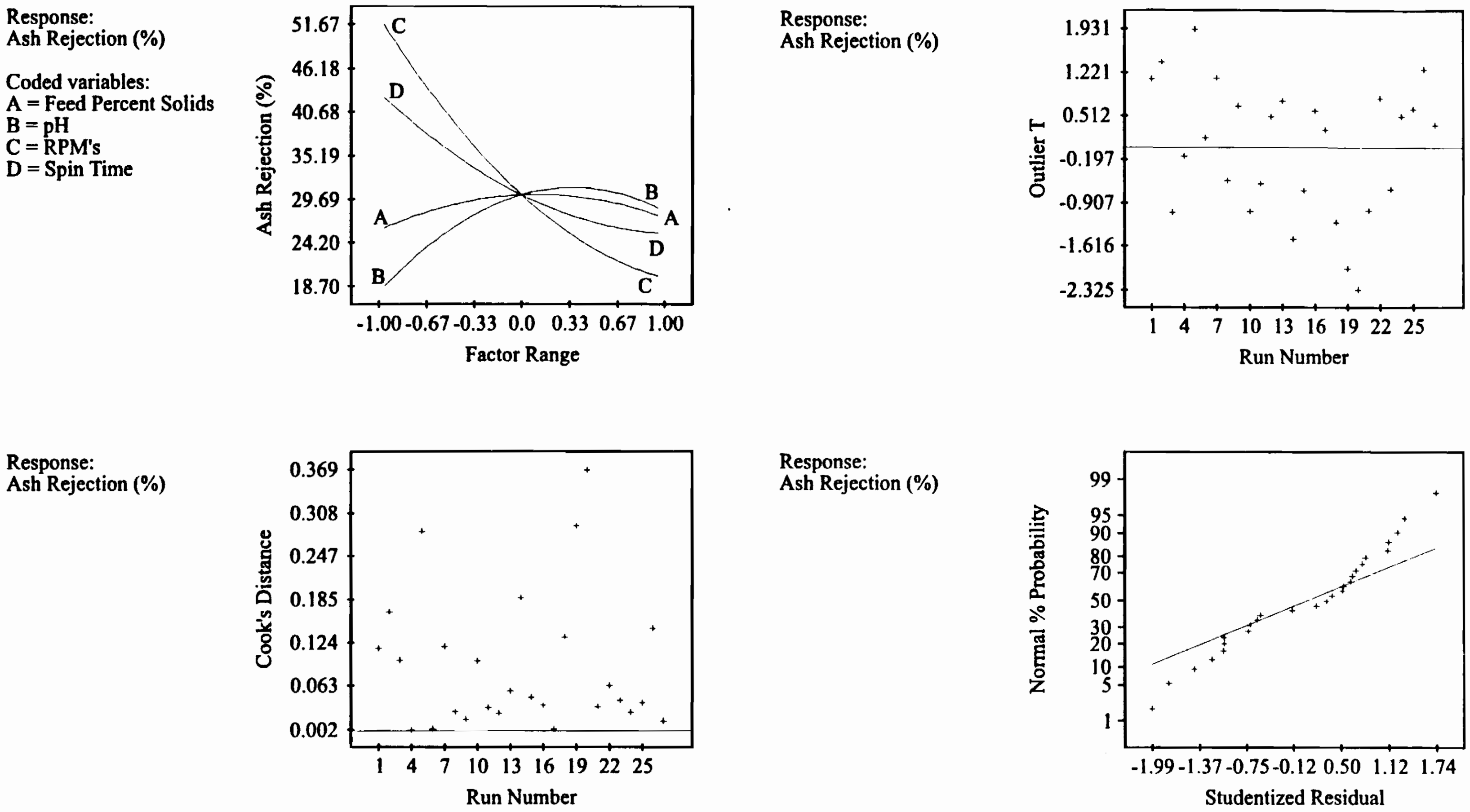
| SOURCE | UNALIASED TERMS | RESID DF | ROOT MSE | R-SQR | ADJ R-SQR | PRESS |
|---|---|---|---|---|---|---|
| Linear | 5 | 22 | 10.00 | 0.6733 | 0.6139 | 3440.37 |
| Quadratic | 15 | 12 | 7.01 | 0.9124 | 0.8103 | 3205.19 |
| Cubic | 23 | 4 | 4.77 | 0.9865 | 0.9120 | 5467.73 |

```
ANOVA for Linear Model (Ash Rejection / Centrifuge / Elkhorn)

                  SUM OF                  MEAN         F
   SOURCE        SQUARES      DF         SQUARE      VALUE      PROB > F

    MODEL         4531.6       4        1132.90      11.34       0.0001
  RESIDUAL        2198.7      22          99.94
  Lack Of Fit       2144.7    20         107.23      3.974       0.2201
   Pure Error         54.0     2          26.99
 COR TOTAL        6730.3      26

  ROOT MSE         10.00               R-SQUARED    0.6733
  DEP MEAN         29.97           ADJ R-SQUARED    0.6139
      C.V.         33.36%

Predicted Residual Sum of Squares (PRESS) = 3440.4

 INDEPENDENT   COEFFICIENT              STANDARD    t FOR H0
  VARIABLE       ESTIMATE       DF        ERROR   COEFFICIENT=0   PROB > |t|
  Intercept        29.97         1         1.92       15.58
  A                 0.82         1         2.89      0.2824        0.7803
  B                 5.17         1         2.89       1.791        0.0871
  C               -16.46         1         2.89      -5.704        0.0001
  D                -8.90         1         2.89      -3.085        0.0054

Final Equation in Terms of Coded Factors:

        Ash Rejection = 29.97 + (0.82 * A) + (5.17 * B) - (16.46 * C) - (8.90 * D)

Final Equation in Terms of Actual Factors:

        Ash Rejection = 68.47 + (0.40750 * % Solids) + (5.1683 * pH)
                            - (6.585E-02 * RPM's) - (2.9678 * time)

Obs        ACTUAL      PREDICTED                             STUDENT COOK'S OUTLIER Run
Ord         VALUE         VALUE       RESIDUAL     LEVER      RESID    DIST       t   Ord
  1          5.93         23.98         -18.05     0.204     -2.024   0.210  -2.191   15
  2         21.79         25.61          -3.82     0.204     -0.428   0.009  -0.420   24
  3         25.34         34.32          -8.98     0.204     -1.006   0.052  -1.007   11
  4         24.09         35.95         -11.86     0.204     -1.329   0.090  -1.354   25
  5         73.48         55.33          18.15     0.204      2.035   0.212   2.206    7
  6         27.19         22.41           4.78     0.204      0.536   0.015   0.527   23
  7         48.25         37.52          10.73     0.204      1.202   0.074   1.215   16
  8         12.23          4.60           7.63     0.204      0.855   0.037   0.850   18
  9         45.25         38.05           7.20     0.204      0.807   0.033   0.800    5
 10         45.61         39.68           5.93     0.204      0.664   0.023   0.656   22
 11         21.83         20.25           1.58     0.204      0.177   0.002   0.174    4
 12         16.48         21.88          -5.40     0.204     -0.605   0.019  -0.596    3
 13         53.87         41.26          12.61     0.204      1.414   0.102   1.449   26
 14         43.80         51.60          -7.80     0.204     -0.874   0.039  -0.869    6
 15          2.10          8.34          -6.24     0.204     -0.699   0.025  -0.691   12
 16         23.14         18.67           4.47     0.204      0.501   0.013   0.492    8
 17         39.43         45.61          -6.18     0.204     -0.693   0.025  -0.685   14
 18         44.41         47.24          -2.83     0.204     -0.317   0.005  -0.311   19
 19         22.93         12.69          10.24     0.204      1.148   0.067   1.157    1
 20         18.11         14.32           3.79     0.204      0.425   0.009   0.417   13
 21         13.43         33.70         -20.27     0.204     -2.272   0.264  -2.538   20
 22         45.07         44.04           1.03     0.204      0.116   0.001   0.113   10
 23         23.35         15.89           7.46     0.204      0.836   0.036   0.830   27
 24         21.05         26.23          -5.18     0.204     -0.581   0.017  -0.572    2
 25         32.12         29.97           2.15     0.037      0.220   0.000   0.215   17
 26         24.44         29.97          -5.53     0.037     -0.563   0.002  -0.554   21
 27         34.34         29.97           4.37     0.037      0.446   0.002   0.438    9
```

```
ANOVA for Quadratic Model (Ash Rejection / Centrifuge / Elkhorn)

                   SUM OF                  MEAN          F
    SOURCE         SQUARES      DF         SQUARE        VALUE      PROB > F

     MODEL         6140.9       14         438.64        8.931       0.0003
  RESIDUAL          589.3       12          49.11
  Lack Of Fit         535.4     10          53.54        1.984       0.3814
   Pure Error          54.0      2          26.99
 COR TOTAL         6730.3       26

  ROOT MSE           7.01                R-SQUARED      0.9124
  DEP MEAN          29.97            ADJ R-SQUARED      0.8103
      C.V.          23.39%

Predicted Residual Sum of Squares (PRESS) = 3205.2


 INDEPENDENT   COEFFICIENT               STANDARD     t FOR H0
  VARIABLE      ESTIMATE        DF          ERROR    COEFFICIENT=0  PROB > |t|

  Intercept        30.30         1           4.05        7.489
  A                 0.82         1           2.02        0.4029      0.6941
  B                 5.17         1           2.02         2.555      0.0252
  C               -16.46         1           2.02        -8.137      0.0001
  D                -8.90         1           2.02        -4.401      0.0009
  A2               -3.67         1           3.03        -1.210      0.2494
  B2               -7.20         1           3.03        -2.374      0.0352
  C2                6.04         1           3.03         1.992      0.0697
  D2                4.08         1           3.03         1.344      0.2037
  AB               -4.28         1           3.50        -1.221      0.2456
  AC               -2.45         1           3.50       -0.6992      0.4978
  AD               -1.43         1           3.50       -0.4074      0.6909
  BC                7.78         1           3.50         2.220      0.0465
  BD               -8.48         1           3.50        -2.422      0.0322
  CD                2.57         1           3.50        0.7327      0.4778

Final Equation in Terms of Coded Factors:

        Ash Rejection = 30.30 + (0.82 * A) + (5.17 * B) - (16.46 * C)
                             - (8.90 * D)  - (3.67 * A2) - (7.20 * B2)
                             + (6.04 * C2) + (4.08 * D2) - (4.28 * AB)
                             - (2.45 * AC) - (1.43 * AD) + (7.78 * BC)
                             - (8.48 * BD) + (2.57 * CD)

Final Equation in Terms of Actual Factors:

        Ash Rejection = -279.67 + (30.424 * % Solids) + (119.90 * pH)
               - (0.52953 * RPM's) + (12.925 * time) - (0.91833 * % Solids^2)
               - (7.2033 * pH^2) + (9.671E-05 * RPM's^2) + (0.45324 * time^2)
               - (2.1388 * % Solids * pH) - (4.900E-03 * % Solids * RPM's)
               - (0.23792 * % Solids * time) + (3.111E-02 * pH * RPM's)
               - (2.8283 * pH * time) + (3.423E-03 * RPM's * time)
```

**ANOVA for Quadratic Model** (Ash Rejection / Centrifuge / Elkhorn)

```
Obs      ACTUAL    PREDICTED                   STUDENT COOK'S OUTLIER Run
Ord       VALUE      VALUE     RESIDUAL  LEVER   RESID   DIST      t    Ord

  1        5.93        9.16      -3.23   0.583  -0.715   0.048  -0.699  15
  2       21.79       19.35       2.44   0.583   0.540   0.027   0.523  24
  3       25.34       28.05      -2.71   0.583  -0.600   0.034  -0.583  11
  4       24.09       21.13       2.96   0.583   0.655   0.040   0.638  25
  5       73.48       68.36       5.12   0.583   1.133   0.120   1.148   7
  6       27.19       30.30      -3.11   0.583  -0.687   0.044  -0.671  23
  7       48.25       45.41       2.84   0.583   0.627   0.037   0.610  16
  8       12.23       17.63      -5.40   0.583  -1.193   0.133  -1.216  18
  9       45.25       37.37       7.88   0.583   1.743   0.283   1.931   5
 10       45.61       41.85       3.76   0.583   0.831   0.064   0.819  22
 11       21.83       22.41      -0.58   0.583  -0.129   0.002  -0.124   4
 12       16.48       21.19      -4.71   0.583  -1.041   0.101  -1.045   3
 13       53.87       48.21       5.66   0.583   1.251   0.146   1.284  26
 14       43.80       42.99       0.81   0.583   0.178   0.003   0.171   6
 15        2.10       -0.27       2.37   0.583   0.523   0.026   0.507  12
 16       23.14       25.63      -2.49   0.583  -0.549   0.028  -0.533   8
 17       39.43       45.87      -6.44   0.583  -1.423   0.189  -1.494  14
 18       44.41       52.40      -7.99   0.583  -1.766   0.291  -1.965  19
 19       22.93       17.84       5.09   0.583   1.124   0.118   1.138   1
 20       18.11       14.57       3.54   0.583   0.782   0.057   0.768  13
 21       13.43       22.43      -9.00   0.583  -1.989   0.369  -2.325  20
 22       45.07       49.73      -4.66   0.583  -1.031   0.099  -1.034  10
 23       23.35       21.59       1.76   0.583   0.389   0.014   0.375  27
 24       21.05       14.96       6.09   0.583   1.347   0.169   1.400   2
 25       32.12       30.30       1.82   0.333   0.318   0.003   0.306  17
 26       24.44       30.30      -5.86   0.333  -1.024   0.035  -1.026  21
 27       34.34       30.30       4.04   0.333   0.706   0.017   0.690   9
```



Response:
Ash Rejection (%)

Coded variables:
A = Feed Percent Solids
B = pH
C = RPM's
D = Spin Time

Response:
Ash Rejection (%)

Response:
Ash Rejection (%)

Response:
Ash Rejection (%)

The batch centrifugal separation of coagula formed using Elkhhorn No. 3 (50% Ash) seam coal

# APPENDIX E - FILTER LEAF BATCH DATA

**Round I filter leaf tests using Elkhorn No. 3 seam coal**

| Test Number | Filter Medium | Cycle Time (sec) | Stage Number | pH | EDTA | % Solids | | Form | | Dry | | Wash Water | | | Dischrg Press (psi) | Total air thru cycle (CFM) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Feed (%) | Tails (%) | Time (sec) | Vacuum (mm Hg) | Time (sec) | Vacuum (mm Hg) | Time (sec) | Rate (ml/min) | Vacuum (mm Hg) | | |
| 1 | PO-801 HF | 180 | 1 | 7.5 | 0.4 | 15.0 | | 60 | 80 | | | 0 | | | | |
| 2 | NY-413 | 180 | 1 | 7.5 | 0.4 | 15.0 | | 60 | 80 | | | 0 | | | | |
| 3 | PO-801 HF | 180 | 1 | 7.5 | 0.4 | 10.0 | | 60 | 60 | 90 | | 0 | | | | |
| 4 | PO-801 RF | 180 | 1 | 7.6 | 0.4 | 10.0 | | 60 | 60 | | | 0 | | | | |
| 5 | SA-601 | 180 | 1 | 7.5 | 0.4 | 10.0 | | 60 | 70 | | | 0 | | | | |
| 6 | POPR-852 F | 180 | 1 | 7.5 | 0.4 | 9.8 | | 60 | 80 | 90 | 50 | 0 | | | | |
| | | 180 | 2 | 7.5 | 0 | | | 60 | 90 | 90 | 50 | 0 | | | | |
| 7 | PO-8-1 RF | 180 | 1 | 7.5 | 0.4 | 5.0 | | 60 | 60 | | | 0 | | | | |
| 8 | NY-413 | 180 | 1 | 7.5 | 0.4 | 10.0 | | 60 | 60 | | | 0 | | | | |
| 9 | NY-413 | 180 | 1 | 7.5 | 0.4 | 5.0 | | 60 | | 90 | | 0 | | | | |
| 10 | PO-801 HF | 180 | 1 | 7.5 | 0.4 | 5.0 | | 60 | 55 | 90 | | 0 | | | | |
| 11 | SA-601 | 180 | 1 | 7.5 | 0.4 | 5.0 | | 60 | 60 | 90 | | 0 | | | | |
| 12 | POPR-852 F | ? | 1 | 7.6 | 0.4 | 4.5 | | ? | 60 | 90 | | 0 | | | | |
| | | | | | | | | | (ml/min) | | (ml/min) | | | | | |
| 13 | POPR-852 F | | 1 | 7.5 | 0.4 | 4.7 | 4.2 | 470 | 50 | | 50 | 0 | | | | |
| 14 | POPR-852 F | | 1 | 7.7 | 0.4 | 4.7 | 4.3 | 180 | 50 | | 50 | 0 | | | | |
| 15 | POPR-852 F | | 1 | 7.6 | 0.4 | 5.0 | 4.0 | 180 | 50 | | 50 | 0 | | | | |

**Round I filter leaf tests using Elkhorn No. 3 seam coal**

| Test Number | % Ash (adjusted) | | | % Combustible (adj.) | | | % Sulfur (adjusted) | | | Yield | Combustible Recovery | Ash Rejection | Sulfur Rejection | Separation Efficiency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) | (%) | (%) | (%) | (%) | (%) |
| 1 | | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | | | |
| 6 | 47.88 | 45.85 | 47.91 | 52.12 | 54.15 | 52.09 | | | | 1.46 | 1.51 | 1.51 | | 0.12 |
| | 47.91 | 46.92 | 47.48 | 52.09 | 53.08 | 52.52 | | | | -76.79 | -78.25 | -78.25 | | -3.05 |
| 7 | | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | | |
| 11 | | | | | | | | | | | | | | |
| 12 | 47.78 | 62.46 | 49.80 | 52.22 | 37.54 | 50.20 | | | | -15.96 | -11.47 | -11.47 | | 9.39 |
| 13 | 51.39 | 66.85 | 50.58 | 48.61 | 33.15 | 49.42 | | | | 4.98 | 3.40 | 3.40 | | -3.08 |
| 14 | 51.46 | 59.22 | 50.88 | 48.54 | 40.78 | 49.12 | | | | 6.95 | 5.84 | 5.84 | | -2.16 |
| 15 | 51.60 | | 54.86 | 48.40 | | 45.14 | | | | | | | | |

**Round II filter leaf tests using Elkhorn No. 3 seam coal**

| Test Number | Filter Media | %Solids | | Yield | Combustilbe Recovery | Ash Rejection | Separation Efficiency | % Ash | | | % Combustible | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Feed (%) | Tails (%) | (%) | (%) | (%) | (%) | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) |
| 1-step | POPR-852F | 4.73 | 3.89 | 19.16 | 20.45 | 82.08 | 2.53 | 51.17 | 47.80 | 51.88 | 48.83 | 52.20 | 48.12 |
| 2 | POPR-852F | 4.65 | 0.78 | 83.56 | 85.11 | 18.16 | 3.27 | 51.04 | 46.33 | 52.27 | 48.96 | 53.67 | 47.73 |
| 3-twice | POPR-852F | 4.65 | 1.51 | 70.56 | 76.51 | 35.17 | 11.68 | 51.04 | 46.79 | 60.84 | 48.96 | 53.21 | 39.16 |
| 4 | PO 801 RF | | 4.67 | | 0.00 | 100.00 | 0.00 | | | | | | |
| 5 | SA 601 | | 4.77 | | 0.00 | 100.00 | 0.00 | | | | | | |
| 6 | NY 413 | | 4.72 | | 0.00 | 100.00 | 0.00 | | | | | | |
| 7 | PO 801 HF | | 4.57 | | 0.00 | 100.00 | 0.00 | | | | | | |
| 8 | P 851 | 4.69 | 4.03 | 8.47 | 9.30 | 92.37 | 1.68 | 49.23 | 44.38 | 49.78 | 50.77 | 55.62 | 50.22 |
| 9 | P 854 F | 4.69 | 2.28 | 51.68 | 52.63 | 49.30 | 1.93 | 49.23 | 48.18 | 50.11 | 50.77 | 51.82 | 49.89 |
| 10 | P 858 | 4.59 | 3.42 | 22.05 | 23.91 | 79.88 | 3.78 | 49.17 | 44.80 | 50.30 | 50.83 | 55.20 | 49.70 |
| 11 | P 859 | 4.59 | | | | | | 49.17 | | | 50.83 | | |

**Round II filter leaf tests using Pittsburgh No. 8 seam coal**

| Test Number | Filter Media | %Solids | | Yield | Combustilbe Recovery | Ash Rejection | Separation Efficiency | % Ash | | | % Combustible | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Feed (%) | Tails (%) | (%) | (%) | (%) | (%) | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) |
| 1 | POPR-852F | | 1.01 | 81.65 | 81.71 | 18.65 | 0.36 | 17.60 | 17.54 | 17.89 | 82.40 | 82.46 | 82.11 |
| 2 | P 851 | 5.13 | 3.30 | 36.45 | 36.39 | 63.30 | -0.31 | 17.48 | 17.60 | 17.41 | 82.52 | 82.40 | 82.59 |
| 3 | SA 601 | | 4.88 | 0.00 | 0.00 | 100.00 | 0.00 | 17.51 | 0.00 | 17.51 | 82.49 | 0.00 | 82.49 |
| 4 | P 859 | | 4.65 | 2.55 | 2.54 | 97.44 | -0.02 | 17.57 | 17.69 | 17.57 | 82.43 | 82.31 | 82.43 |
| 5 | P 854 F | | 0.01 | 99.79 | 99.80 | 0.27 | 0.07 | 17.59 | 17.58 | 22.22 | 82.41 | 82.42 | 77.78 |
| 6 | P 858 | 5.07 | 1.53 | 70.82 | 70.78 | 29.00 | -0.21 | 17.56 | 17.60 | 17.45 | 82.44 | 82.40 | 82.55 |
| 7 | PO 801 HF | | 2.42 | 55.31 | 55.30 | 44.65 | -0.05 | 17.65 | 17.66 | 17.63 | 82.35 | 82.34 | 82.37 |
| 8 | PO 801 RF | 5.17 | 4.46 | 10.38 | 10.23 | 88.89 | -0.89 | 17.59 | 18.83 | 17.45 | 82.41 | 81.17 | 82.55 |
| 9 | NY 413 | | 4.97 | 0.00 | 0.00 | 100.00 | 0.00 | 17.54 | 0.00 | 17.54 | 82.46 | 0.00 | 82.46 |

# APPENDIX F - COLUMN FLOTATION DATA

**Column flotation parametric test data using Elkhorn No. 3 seam coal**

| Test No. | Flow Rates Wash Water (ml/min) | Feed (ml/min) | Aeration (cc/min) | Frother (ml/min) | Tailings (ml/min) | Bias Factor | Bias Rate (cm/sec) | % Solids Feed (%) | Tails (%) | Mass Flow Rates Feed (g/min) | Product (g/min) | Tails (g/min) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 600 | 150 | 1000 | 15 | 740 | 0.983 | 0.485 | 3.70 | 0.66 | 5.55 | 0.43 | 4.63 |
| 2 | 200 | 150 | 2000 | 38 | 280 | 0.650 | 0.107 | 10.00 | 3.95 | 15.00 | 4.04 | 10.00 |
| 3 | 200 | 250 | 1000 | 25 | 350 | 0.500 | 0.082 | 3.70 | 1.51 | 9.25 | 2.53 | 4.55 |
| 4 | 600 | 250 | 2000 | 25 | 710 | 0.767 | 0.378 | 3.70 | 0.96 | 9.25 | 1.67 | 6.45 |
| 5 | 600 | 250 | 2000 | 63 | 830 | 0.967 | 0.477 | 10.00 | 2.72 | 25.00 | 2.13 | 22.00 |
| 6 | 400 | 200 | 1500 | 35 | 600 | 1.000 | 0.329 | 6.75 | 1.86 | 13.81 | 1.18 | 10.52 |
| 7 | 200 | 250 | 2000 | 63 | 440 | 0.950 | 0.156 | 10.00 | 4.71 | 25.00 | 3.34 | 19.52 |
| 8 | 200 | 150 | 1000 | 15 | 340 | 0.950 | 0.156 | 3.70 | 1.17 | 8.62 | 1.54 | 3.58 |
| 9 | 200 | 250 | 1000 | 63 | 400 | 0.750 | 0.123 | 9.47 | 5.15 | 23.68 | 4.92 | 19.16 |
| 10 | 400 | 200 | 1500 | 35 | 590 | 0.975 | 0.321 | 6.73 | 2.27 | 13.81 | 1.18 | 12.49 |
| 11 | 600 | 250 | 1000 | 63 | 840 | 0.983 | 0.485 | 9.47 | 2.80 | 23.68 | 1.24 | 23.04 |
| 12 | 400 | 200 | 1500 | 35 | 590 | 0.975 | 0.321 | 6.75 | 1.87 | 13.81 | 1.14 | 10.39 |
| 13 | 200 | 150 | 1000 | 38 | 210 | 0.300 | 0.049 | 9.40 | 4.32 | 14.30 | 4.26 | 9.84 |
| 14 | 600 | 250 | 1000 | 25 | 750 | 0.833 | 0.411 | 3.70 | 0.91 | 9.25 | 0.80 | 6.57 |
| 15 | 400 | 200 | 1500 | 35 | 580 | 0.950 | 0.312 | 6.75 | 1.86 | 13.81 | 1.31 | 10.27 |
| 16 | 600 | 150 | 2000 | 15 | 680 | 0.883 | 0.436 | 3.70 | 0.66 | 8.62 | 0.85 | 4.26 |
| 17 | 600 | 150 | 1000 | 38 | 710 | 0.933 | 0.461 | 9.47 | 2.05 | 14.66 | 0.99 | 13.69 |
| 18 | 200 | 250 | 2000 | 25 | 460 | 1.050 | 0.173 | 3.65 | nm | 9.44 | 1.33 | 8.09 |
| 19 | 600 | 150 | 2000 | 38 | 650 | 0.833 | 0.411 | 9.40 | 2.10 | 14.30 | 1.32 | 13.35 |
| 20 | 200 | 150 | 2000 | 15 | 320 | 0.850 | 0.140 | 3.70 | 1.15 | 8.62 | 1.83 | 3.35 |

'nm' - Not Measured

**Column flotation parametric test data using Elkhorn No. 3 seam coal**

| Test No. | % Ash (Adjusted) Feed (%) | Product (%) | Tails (%) | % Combustible (Adjusted) Feed (%) | Product (%) | Tails (%) | % Sulfur (Adjusted) Feed (%) | Product (%) | Tails (%) | Yield (%) | Combustib Recovery (%) | Rejection Ash (%) | Sulfur (%) | Separation Efficiency (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 49.04 | 7.11 | 54.99 | 50.96 | 92.89 | 45.01 | 0.34 | 0.52 | 0.32 | 12.43 | 22.65 | 98.20 | 84.71 | 20.85 |
| 2 | 50.43 | 12.04 | 69.37 | 49.57 | 87.96 | 30.63 | 0.35 | 0.54 | 0.26 | 33.04 | 58.62 | 92.11 | 50.41 | 50.74 |
| 3 | 50.06 | 10.90 | 83.73 | 49.94 | 89.10 | 16.27 | 0.35 | 0.53 | 0.19 | 46.23 | 82.48 | 89.93 | 28.74 | 72.42 |
| 4 | 50.26 | 8.86 | 60.04 | 49.74 | 91.14 | 39.96 | 0.35 | 0.56 | 0.30 | 19.11 | 35.01 | 96.63 | 69.23 | 31.65 |
| 5 | 51.08 | 9.06 | 52.85 | 48.92 | 90.94 | 47.15 | 0.36 | 0.57 | 0.35 | 4.04 | 7.51 | 99.28 | 92.80 | 6.80 |
| 6 | 50.66 | 8.94 | 54.70 | 49.34 | 91.06 | 45.30 | 0.36 | 0.56 | 0.34 | 8.83 | 16.29 | 98.44 | 85.86 | 14.74 |
| 7 | 49.63 | 12.99 | 56.65 | 50.37 | 87.01 | 43.35 | 0.35 | 0.54 | 0.31 | 16.08 | 27.77 | 95.79 | 73.17 | 23.57 |
| 8 | 50.57 | 9.39 | 64.22 | 49.43 | 90.61 | 35.78 | 0.35 | 0.55 | 0.29 | 24.90 | 45.64 | 95.38 | 63.74 | 41.01 |
| 9 | 49.87 | 14.17 | 58.22 | 50.13 | 85.83 | 41.78 | 0.41 | 0.59 | 0.36 | 18.96 | 32.46 | 94.61 | 68.72 | 27.07 |
| 10 | 50.18 | 9.02 | 53.45 | 49.82 | 90.98 | 46.55 | 0.35 | 0.57 | 0.34 | 7.36 | 13.44 | 98.68 | 92.92 | 12.12 |
| 11 | 49.13 | 9.90 | 52.14 | 50.87 | 90.10 | 47.86 | 0.40 | 0.61 | 0.38 | 7.13 | 12.62 | 98.56 | 86.74 | 11.19 |
| 12 | 50.26 | 9.00 | 55.22 | 49.74 | 91.00 | 44.78 | 0.35 | 0.56 | 0.33 | 10.73 | 19.63 | 98.08 | 86.09 | 17.71 |
| 13 | 50.50 | 13.35 | 64.37 | 49.50 | 86.65 | 35.63 | 0.36 | 0.56 | 0.28 | 27.19 | 47.59 | 92.81 | 55.56 | 40.40 |
| 14 | 49.71 | 8.23 | 57.96 | 50.29 | 91.77 | 42.04 | 0.34 | 0.56 | 0.30 | 16.59 | 30.27 | 97.25 | 74.66 | 27.53 |
| 15 | 50.13 | 9.15 | 55.28 | 49.87 | 90.85 | 44.72 | 0.35 | 0.55 | 0.33 | 11.16 | 20.34 | 97.96 | 85.71 | 18.30 |
| 16 | 50.79 | 8.06 | 57.49 | 49.21 | 91.94 | 42.51 | 0.35 | 0.58 | 0.32 | 13.55 | 25.32 | 97.85 | 80.88 | 23.17 |
| 17 | 49.61 | 9.19 | 52.60 | 50.39 | 90.81 | 47.40 | 0.40 | 0.58 | 0.39 | 6.89 | 12.41 | 98.72 | 92.37 | 11.14 |
| 18 | 49.60 | 9.25 | 55.54 | 50.40 | 90.75 | 44.46 | 0.37 | 0.56 | 0.34 | 12.83 | 23.11 | 97.61 | 79.36 | 20.71 |
| 19 | 50.65 | 8.65 | 53.88 | 49.35 | 91.35 | 46.12 | 0.36 | 0.57 | 0.34 | 7.14 | 13.22 | 98.78 | 86.23 | 12.00 |
| 20 | 50.74 | 10.03 | 69.18 | 49.26 | 89.97 | 30.82 | 0.35 | 0.56 | 0.26 | 31.17 | 56.94 | 93.84 | 52.00 | 50.78 |

**Column flotation parametric test data using Pittsburgh No. 8 seam coal**

| Test No. | Flow Rates | | | | | | Bias Factor | Bias Rate (cm/sec) | % Solids | | Mass Flow Rates | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wash Water (ml/min) | Feed (ml/min) | Aeration (cc/min) | Frother (lb/ton) | Frother (ml/min) | Tailings (ml/min) | | | Feed (%) | Tails (%) | Feed (g/min) | Product (g/min) | Tails (g/min) |
| 1 | 600 | 250 | 1000 | 5 | 31 | 680 | 0.72 | 0.35 | 3.61 | 0.76 | 9.00 | 4.00 | 5.33 |
| 2 | 200 | 256 | 2000 | 4 | 63 | 0 | -1.28 | -0.21 | 9.75 | 0.00 | 25.13 | 23.42 | 0.00 |
| 3 | 600 | 150 | 1000 | 5 | 47 | 690 | 0.90 | 0.44 | 9.97 | 1.94 | 15.00 | 4.00 | 13.13 |
| 4 | 600 | 250 | 1000 | 5 | 78 | 800 | 0.92 | 0.45 | 9.97 | 2.92 | 26.77 | 4.81 | 22.37 |
| 5 | 200 | 158 | 2000 | 4 | 38 | 0 | -0.79 | -0.13 | 9.80 | 0.00 | 15.77 | 15.06 | 0.00 |
| 6 | 200 | 250 | 1000 | 5 | 78 | 380 | 0.65 | 0.11 | 9.97 | 5.71 | 25.00 | 6.01 | 19.72 |
| 7 | 600 | 150 | 2000 | 5 | 47 | 520 | 0.62 | 0.30 | 10.00 | 2.16 | 15.00 | 6.43 | 10.88 |
| 8 | 200 | 250 | 1000 | 5 | 31 | 150 | -0.50 | -0.08 | 3.61 | 0.41 | 9.02 | 9.24 | 0.29 |
| 9 | 600 | 250 | 2000 | 5 | 78 | 540 | 0.48 | 0.24 | 10.00 | 3.66 | 25.00 | 7.63 | 19.71 |
| 10 | 600 | 150 | 1000 | 5 | 19 | 700 | 0.92 | 0.45 | 3.61 | 0.51 | 6.24 | 2.36 | 3.55 |
| 11 | 400 | 200 | 1500 | 5 | 44 | 480 | 0.70 | 0.23 | 6.81 | 2.10 | 14.47 | 6.56 | 9.20 |
| 12 | 200 | 250 | 2000 | 4 | 25 | 0 | -1.25 | -0.21 | 3.93 | 0.00 | 10.09 | 11.16 | 0.00 |
| 13 | 400 | 200 | 1500 | 5 | 44 | 440 | 0.60 | 0.20 | 6.81 | 2.13 | 14.47 | 5.24 | 9.33 |
| 14 | 400 | 200 | 1500 | 5 | 44 | 490 | 0.73 | 0.24 | 6.81 | 2.11 | 14.47 | 5.29 | 9.18 |
| 15 | 200 | 150 | 1000 | 5 | 47 | 250 | 0.50 | 0.08 | 9.97 | 4.18 | 15.00 | 5.62 | 10.29 |
| 16 | 600 | 250 | 2000 | 4 | 25 | 760 | 0.85 | 0.42 | 3.93 | 0.87 | 10.09 | 3.35 | 6.53 |
| 17 | 200 | 150 | 1000 | 5 | 19 | 150 | 0.00 | 0.00 | 3.61 | 0.42 | 6.24 | 6.96 | 0.48 |
| 18 | 400 | 200 | 1500 | 5 | 44 | 460 | 0.65 | 0.21 | 6.81 | 2.10 | 14.47 | 5.34 | 9.10 |
| 19 | 600 | 158 | 2000 | 4 | 15 | 720 | 0.94 | 0.46 | 3.93 | 0.54 | 6.44 | 2.50 | 3.81 |
| 20 | 200 | 168 | 2000 | 4 | 15 | 260 | 0.46 | 0.08 | 3.93 | 0.93 | 6.68 | 4.16 | 2.29 |

**Column flotation parametric test data using Pittsburgh No. 8 seam coal**

| Test No. | % Ash (Adjusted) | | | % Combustible (Adjusted) | | | % Sulfur (Adjusted) | | | Yield (%) | Combustible Recovery (%) | Rejection | | Separation Efficiency (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) | | | Ash (%) | Sulfur (%) | |
| 1 | 14.70 | 3.34 | 23.96 | 85.30 | 96.66 | 76.04 | 3.51 | 2.30 | 4.50 | 44.91 | 50.89 | 89.80 | 70.51 | 40.68 |
| 2 | 16.81 | 16.26 | 0.00 | 83.19 | 83.74 | 0.00 | 4.01 | 3.87 | 0.00 | 99.34 | 100.00 | 0.00 | 0.00 | 0.00 |
| 3 | 16.67 | 3.37 | 20.10 | 83.33 | 96.63 | 79.90 | 3.54 | 2.29 | 3.86 | 20.50 | 23.77 | 95.86 | 86.81 | 19.63 |
| 4 | 16.72 | 3.44 | 18.93 | 83.28 | 96.56 | 81.07 | 3.57 | 2.31 | 3.78 | 14.27 | 16.54 | 97.06 | 90.76 | 13.61 |
| 5 | 16.78 | 16.14 | 0.00 | 83.22 | 83.86 | 0.00 | 4.04 | 3.89 | 0.00 | 99.24 | 100.00 | 0.00 | 0.00 | 0.00 |
| 6 | 16.64 | 4.88 | 19.76 | 83.36 | 95.12 | 80.24 | 3.59 | 2.54 | 3.87 | 20.97 | 23.93 | 93.85 | 85.10 | 17.78 |
| 7 | 16.00 | 3.45 | 21.88 | 84.00 | 96.55 | 78.12 | 3.62 | 2.36 | 4.22 | 31.90 | 36.67 | 93.12 | 78.97 | 29.79 |
| 8 | 14.58 | 10.81 | 78.77 | 85.42 | 89.19 | 21.23 | 3.54 | 3.20 | 9.25 | 94.45 | 98.62 | 29.97 | 14.68 | 28.59 |
| 9 | 15.98 | 4.06 | 19.36 | 84.02 | 95.94 | 80.64 | 3.63 | 2.44 | 3.97 | 22.09 | 25.23 | 94.39 | 85.06 | 19.61 |
| 10 | 14.62 | 3.00 | 23.84 | 85.38 | 97.00 | 76.16 | 3.53 | 2.25 | 4.55 | 44.24 | 50.26 | 90.92 | 71.73 | 41.18 |
| 11 | 16.80 | 3.64 | 23.58 | 83.20 | 96.36 | 76.42 | 3.73 | 2.42 | 4.40 | 34.00 | 39.38 | 92.63 | 78.05 | 32.01 |
| 12 | 16.11 | 13.17 | 0.00 | 83.89 | 86.83 | 0.00 | 4.22 | 3.45 | 0.00 | 96.61 | 100.00 | 0.00 | 0.00 | 0.00 |
| 13 | 16.62 | 3.80 | 23.94 | 83.38 | 96.20 | 76.06 | 3.77 | 2.43 | 4.54 | 36.35 | 41.93 | 91.69 | 76.48 | 33.62 |
| 14 | 16.73 | 3.87 | 24.10 | 83.27 | 96.13 | 75.90 | 3.75 | 2.42 | 4.51 | 36.43 | 42.06 | 91.57 | 76.53 | 33.63 |
| 15 | 16.64 | 4.45 | 21.96 | 83.36 | 95.55 | 78.04 | 3.59 | 2.38 | 4.12 | 30.38 | 34.83 | 91.87 | 79.81 | 26.70 |
| 16 | 16.68 | 3.41 | 23.62 | 83.32 | 96.59 | 76.38 | 4.09 | 2.37 | 5.00 | 34.34 | 39.81 | 92.98 | 79.95 | 32.79 |
| 17 | 14.57 | 6.58 | 50.72 | 85.43 | 93.42 | 49.28 | 3.54 | 2.76 | 7.10 | 81.90 | 89.56 | 63.01 | 36.05 | 52.57 |
| 18 | 16.75 | 3.86 | 24.03 | 83.25 | 96.14 | 75.97 | 3.74 | 2.40 | 4.50 | 36.09 | 41.68 | 91.68 | 76.78 | 33.36 |
| 19 | 16.56 | 3.38 | 24.93 | 83.44 | 96.62 | 75.07 | 4.03 | 2.31 | 5.11 | 38.84 | 44.97 | 92.07 | 77.89 | 37.05 |
| 20 | 16.50 | 4.47 | 37.09 | 83.50 | 95.53 | 62.91 | 4.01 | 2.59 | 6.43 | 63.12 | 72.21 | 82.90 | 59.30 | 55.11 |

## STATISTICAL DATA ANALYSIS

**Description:** Froth Flotation

**Coal Sample:** Elkhorn No. 3

**Response:** Combustible Recovery

### Design Summary

| FAC | FACTOR | UNITS | -1 LEVEL | +1 LEVEL |
|---|---|---|---|---|
| A | Water | ml/min | 200.000 | 600.000 |
| B | Feed | ml/min | 150.000 | 250.000 |
| C | Solids | % | 4.000 | 10.000 |
| D | Air | ml/min | 1000.000 | 2000.000 |

### Analysis Summary

#### Sequential Model Sum of Squares

| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROB > F |
|---|---|---|---|---|---|
| MEAN | 18199.8 | 1 | 18199.8 | | |
| Linear | 3804.7 | 4 | 951.2 | 4.364 | 0.0154 |
| Quadratic | 2111.5 | 7 | 301.6 | 2.084 | 0.1625 |
| Cubic | 879.7 | 4 | 219.9 | 3.163 | 0.1454 |
| RESIDUAL | 278.1 | 4 | 69.5 | | |
| TOTAL | 25273.7 | 20 | | | |

#### Lack of Fit Tests

| MODEL | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROB > F |
|---|---|---|---|---|---|
| Linear | 3238.8 | 12 | 269.9 | 26.52 | 0.0103 |
| Quadratic | 1127.3 | 5 | 225.5 | 22.16 | 0.0142 |
| Cubic | 247.6 | 1 | 247.6 | 24.33 | 0.0160 |
| PURE ERR | 30.5 | 3 | 10.2 | | |

#### ANOVA Summary Statistics of Models Fit

| SOURCE | UNALIASED TERMS | RESID DF | ROOT MSE | R-SQR | ADJ R-SQR | PRESS |
|---|---|---|---|---|---|---|
| Linear | 5 | 15 | 14.76 | 0.5378 | 0.4146 | 6037.87 |
| Quadratic | 12 | 8 | 12.03 | 0.8363 | 0.6113 | 11597.81 |
| Cubic | 16 | 4 | 8.34 | 0.9607 | 0.8133 | 63437.37 |

```
ANOVA for Linear Model

                 SUM OF                     MEAN          F
   SOURCE        SQUARES        DF          SQUARE        VALUE       PROB > F

    MODEL         3804.7         4          951.17        4.364       0.0154
  RESIDUAL        3269.3        15          217.95
  Lack Of Fit     3238.8        12          269.90        26.52       0.0103
  Pure Error        30.5         3           10.18
  COR TOTAL       7074.0        19

  ROOT MSE        14.76                  R-SQUARED      0.5378
  DEP MEAN        30.17              ADJ R-SQUARED      0.4146
      C.V.        48.94%

 Predicted Residual Sum of Squares (PRESS) = 6037.9

 INDEPENDENT   COEFFICIENT               STANDARD    t FOR H0
  VARIABLE      ESTIMATE        DF         ERROR    COEFFICIENT=0   PROB > |t|

  Intercept        30.17         1          3.30        9.138
  A               -13.48         1          3.69       -3.651        0.0024
  B                -1.95         1          3.69      -0.5277        0.6055
  C                -6.83         1          3.69       -1.850        0.0842
  D                -2.41         1          3.69      -0.6540        0.5230

 Final Equation in Terms of Coded Factors:

        Recovery = 30.17 - 13.48 * A - 1.95 * B - 6.83 * C - 2.41 * D

 Final Equation in Terms of Actual Factors:

        Recovery = 88.08 - 6.738E-02 * Water - 3.895E-02 * Feed
                          - 2.2754 * Solids - 4.828E-03 * Air

Obs        ACTUAL     PREDICTED                     STUDENT COOK'S OUTLIER Run
Ord         VALUE       VALUE       RESIDUAL  LEVER   RESID   DIST      t   Ord

  1         45.64       54.83         -9.19   0.300  -0.744   0.047  -0.732   8
  2         22.65       27.88         -5.23   0.300  -0.423   0.015  -0.411   1
  3         82.48       50.93         31.55   0.300   2.554   0.559   3.282   3
  4         30.27       23.98          6.29   0.300   0.509   0.022   0.496  14
  5         47.59       41.18          6.41   0.300   0.519   0.023   0.506  13
  6         12.41       14.23         -1.82   0.300  -0.147   0.002  -0.142  17
  7         32.46       37.28         -4.82   0.300  -0.390   0.013  -0.379   9
  8         12.62       10.33          2.29   0.300   0.185   0.003   0.179  11
  9         56.94       50.00          6.94   0.300   0.562   0.027   0.549  20
 10         25.32       23.05          2.27   0.300   0.184   0.003   0.178  16
 11         23.11       46.11        -23.00   0.300  -1.862   0.297  -2.051  18
 12         35.01       19.16         15.85   0.300   1.284   0.141   1.314   4
 13         58.62       36.35         22.27   0.300   1.803   0.279   1.968   2
 14         13.22        9.40          3.82   0.300   0.309   0.008   0.300  19
 15         27.77       32.45         -4.68   0.300  -0.379   0.012  -0.368   7
 16          7.51        5.50          2.01   0.300   0.162   0.002   0.157   5
 17         16.29       30.17        -13.88   0.050  -0.964   0.010  -0.962   6
 18         13.44       30.17        -16.73   0.050  -1.162   0.014  -1.177  10
 19         19.63       30.17        -10.54   0.050  -0.732   0.006  -0.720  12
 20         20.34       30.17         -9.83   0.050  -0.683   0.005  -0.670  15
```

```
ANOVA for Quadratic Model

                     SUM OF                      MEAN           F
   SOURCE           SQUARES        DF           SQUARE        VALUE      PROB > F

    MODEL            5916.1        11           537.83        3.716       0.0365
  RESIDUAL           1157.8         8           144.73
  Lack Of Fit        1127.3         5           225.46        22.16       0.0142
  Pure Error           30.5         3            10.18
  COR TOTAL          7074.0        19

  ROOT MSE            12.03                  R-SQUARED      0.8363
  DEP MEAN            30.17              ADJ R-SQUARED      0.6113
      C.V.            39.88%

 Predicted Residual Sum of Squares (PRESS) = 11597.8

 INDEPENDENT   COEFFICIENT                 STANDARD    t FOR HO
  VARIABLE      ESTIMATE        DF          ERROR    COEFFICIENT=0  PROB > |t|

  Intercept        17.43         1           6.02        2.897
  A               -13.48         1           3.01       -4.480       0.0021
  B                -1.95         1           3.01       -0.6475      0.5354
  C                -6.83         1           3.01       -2.270       0.0529
  D                -2.41         1           3.01       -0.8026      0.4454
  A2               15.93         1           6.73        2.368       0.0454
  B2             ALIASED         0
  C2             ALIASED         0
  D2             ALIASED         0
  AB                3.42         1           3.01        1.138       0.2879
  AC               -1.61         1           3.01       -0.5353      0.6070
  AD                2.80         1           3.01        0.9318      0.3787
  BC               -4.49         1           3.01       -1.492       0.1740
  BD               -5.64         1           3.01       -1.875       0.0976
  CD                2.67         1           3.01        0.8873      0.4008

 Final Equation in Terms of Coded Factors:

        Recovery = 17.43 - 13.48 * A  - 1.95 * B  - 6.83 * C  - 2.41 * D
                         + 15.93 * A2 + 0.00 * B2 + 0.00 * C2 + 0.00 * D2
                         +  3.42 * AB - 1.61 * AC + 2.80 * AD - 4.49 * BC
                         -  5.64 * BD + 2.67 * CD

 Final Equation in Terms of Actual Factors:

        Not available for ALIASED models.
```

| Obs Ord | ACTUAL VALUE | PREDICTED VALUE | RESIDUAL | LEVER | STUDENT RESID | COOK'S DIST | OUTLIER t | Run Ord |
|---|---|---|---|---|---|---|---|---|
| 1 | 45.64 | 55.17 | -9.53 | 0.687 | -1.417 | 0.368 | -1.532 | 8 |
| 2 | 22.65 | 18.99 | 3.66 | 0.687 | 0.544 | 0.054 | 0.519 | 1 |
| 3 | 82.48 | 64.68 | 17.80 | 0.687 | 2.646 | 1.284 | 7.010 | 3 |
| 4 | 30.27 | 42.20 | -11.93 | 0.687 | -1.773 | 0.577 | -2.129 | 14 |
| 5 | 47.59 | 48.38 | -0.79 | 0.687 | -0.117 | 0.003 | -0.109 | 13 |
| 6 | 12.41 | 5.75 | 6.66 | 0.687 | 0.990 | 0.180 | 0.988 | 17 |
| 7 | 32.46 | 39.94 | -7.48 | 0.687 | -1.112 | 0.227 | -1.131 | 9 |
| 8 | 12.62 | 11.01 | 1.61 | 0.687 | 0.239 | 0.010 | 0.225 | 11 |
| 9 | 56.94 | 50.68 | 6.26 | 0.687 | 0.931 | 0.159 | 0.922 | 20 |
| 10 | 25.32 | 25.71 | -0.39 | 0.687 | -0.058 | 0.001 | -0.054 | 16 |
| 11 | 23.11 | 37.63 | -14.52 | 0.687 | -2.160 | 0.855 | -3.128 | 18 |
| 12 | 35.01 | 26.36 | 8.65 | 0.687 | 1.287 | 0.304 | 1.352 | 4 |
| 13 | 58.62 | 54.56 | 4.06 | 0.687 | 0.604 | 0.067 | 0.578 | 2 |
| 14 | 13.22 | 23.15 | -9.93 | 0.687 | -1.476 | 0.400 | -1.619 | 19 |
| 15 | 27.77 | 23.56 | 4.21 | 0.687 | 0.625 | 0.072 | 0.600 | 7 |
| 16 | 7.51 | 5.85 | 1.66 | 0.687 | 0.247 | 0.011 | 0.232 | 5 |
| 17 | 16.29 | 17.43 | -1.14 | 0.250 | -0.109 | 0.000 | -0.102 | 6 |
| 18 | 13.44 | 17.43 | -3.99 | 0.250 | -0.382 | 0.004 | -0.361 | 10 |
| 19 | 19.63 | 17.43 | 2.20 | 0.250 | 0.212 | 0.001 | 0.199 | 12 |
| 20 | 20.34 | 17.43 | 2.91 | 0.250 | 0.280 | 0.002 | 0.263 | 15 |

## STATISTICAL DATA ANALYSIS

**Description:** Froth Flotation

**Coal Sample:** Elkhorn No. 3

**Response:** Concentrate Ash

### Design Summary

| FAC | FACTOR | UNITS | -1 LEVEL | +1 LEVEL |
|---|---|---|---|---|
| A | Water | ml/min | 200.000 | 600.000 |
| B | Feed | ml/min | 150.000 | 250.000 |
| C | Solids | % | 4.000 | 10.000 |
| D | Air | ml/min | 1000.000 | 2000.000 |

### Analysis Summary

#### Sequential Model Sum of Squares

| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROB > F |
|---|---|---|---|---|---|
| MEAN | 1946.56 | 1 | 1946.56 | | |
| Linear | 55.05 | 4 | 13.76 | 17.48 | 0.0001 |
| Quadratic | 10.56 | 7 | 1.51 | 9.603 | 0.0024 |
| Cubic | 0.87 | 4 | 0.22 | 2.276 | 0.2227 |
| RESIDUAL | 0.38 | 4 | 0.10 | | |
| TOTAL | 2013.43 | 20 | | | |

#### Lack of Fit Tests

| MODEL | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROB > F |
|---|---|---|---|---|---|
| Linear | 11.79 | 12 | 0.98 | 125.5 | 0.0010 |
| Quadratic | 1.23 | 5 | 0.25 | 31.51 | 0.0085 |
| Cubic | 0.36 | 1 | 0.36 | 46.01 | 0.0066 |
| PURE ERR | 0.02 | 3 | 0.01 | | |

#### ANOVA Summary Statistics of Models Fit

| SOURCE | UNALIASED TERMS | RESID DF | ROOT MSE | R-SQR | ADJ R-SQR | PRESS |
|---|---|---|---|---|---|---|
| Linear | 5 | 15 | 0.887 | 0.8234 | 0.7763 | 21.462 |
| Quadratic | 12 | 8 | 0.396 | 0.9812 | 0.9554 | 12.665 |
| Cubic | 16 | 4 | 0.310 | 0.9943 | 0.9728 | 92.202 |

```
ANOVA for Linear Model

                   SUM OF                  MEAN          F
   SOURCE          SQUARES      DF        SQUARE       VALUE       PROB > F

    MODEL          55.05         4        13.764       17.48        0.0001
  RESIDUAL         11.81        15         0.787
  Lack Of Fit      11.79        12         0.982       125.5        0.0010
  Pure Error        0.02         3         0.008
  COR TOTAL        66.87        19

  ROOT MSE         0.887               R-SQUARED      0.8234
  DEP MEAN         9.865           ADJ R-SQUARED      0.7763
      C.V.          8.99%

 Predicted Residual Sum of Squares (PRESS) = 21.46

 INDEPENDENT   COEFFICIENT              STANDARD     t FOR HO
  VARIABLE      ESTIMATE        DF       ERROR     COEFFICIENT=0   PROB > |t|

  Intercept        9.865         1       0.198         49.72
  A               -1.443         1       0.222        -6.502        0.0001
  B                0.345         1       0.222         1.555        0.1407
  C                1.095         1       0.222         4.936        0.0002
  D               -0.205         1       0.222       -0.9241        0.3701

 Final Equation in Terms of Coded Factors:

          Ash = 9.865 - 1.443 * A + 0.345 * B + 1.095 * C - 0.205 * D

 Final Equation in Terms of Actual Factors:

          Ash = 9.431 - 7.213E-03 * Water + 6.900E-03 * Feed
                          + 0.36500 * Solids - 4.100E-04 * Air

Obs        ACTUAL     PREDICTED                          STUDENT  COOK'S OUTLIER  Run
Ord         VALUE       VALUE      RESIDUAL    LEVER      RESID    DIST      t    Ord

  1         9.390      10.073      -0.683      0.300     -0.920    0.073   -0.915    8
  2         7.110       7.188      -0.078      0.300     -0.105    0.001   -0.102    1
  3        10.900      10.763       0.137      0.300      0.185    0.003    0.178    3
  4         8.230       7.878       0.352      0.300      0.474    0.019    0.462   14
  5        13.350      12.263       1.087      0.300      1.464    0.184    1.528   13
  6         9.190       9.378      -0.188      0.300     -0.253    0.005   -0.245   17
  7        14.170      12.953       1.217      0.300      1.639    0.230    1.748    9
  8         9.900      10.068      -0.168      0.300     -0.226    0.004   -0.219   11
  9        10.040       9.663       0.377      0.300      0.508    0.022    0.495   20
 10         8.060       6.778       1.282      0.300      1.727    0.256    1.864   16
 11         9.250      10.353      -1.103      0.300     -1.486    0.189   -1.554   18
 12         8.860       7.468       1.392      0.300      1.875    0.301    2.070    4
 13        12.050      11.853       0.197      0.300      0.265    0.006    0.257    2
 14         8.650       8.968      -0.318      0.300     -0.428    0.016   -0.416   19
 15        12.990      12.543       0.447      0.300      0.602    0.031    0.589    7
 16         9.060       9.658      -0.598      0.300     -0.805    0.056   -0.796    5
 17         8.940       9.865      -0.925      0.050     -1.070    0.012   -1.076    6
 18         9.020       9.865      -0.845      0.050     -0.978    0.010   -0.976   10
 19         9.000       9.865      -0.865      0.050     -1.001    0.011   -1.001   12
 20         9.150       9.865      -0.716      0.050     -0.827    0.007   -0.818   15
```

```
ANOVA for Quadratic Model

                    SUM OF                       MEAN           F
     SOURCE         SQUARES       DF             SQUARE        VALUE        PROB > F

      MODEL          65.61        11             5.964         37.98         0.0001
   RESIDUAL           1.26         8             0.157
   Lack Of Fit        1.23         5             0.247         31.51         0.0085
   Pure Error         0.02         3             0.008
   COR TOTAL         66.87        19

   ROOT MSE          0.396                  R-SQUARED        0.9812
   DEP MEAN          9.865              ADJ R-SQUARED        0.9554
       C.V.           4.02%

  Predicted Residual Sum of Squares (PRESS) = 12.66

  INDEPENDENT    COEFFICIENT                 STANDARD    t FOR HO
   VARIABLE       ESTIMATE        DF           ERROR    COEFFICIENT=0   PROB > |t|

   Intercept        9.027          1           0.198        45.56
   A               -1.443          1           0.099       -14.56        0.0001
   B                0.345          1           0.099        3.483        0.0083
   C                1.095          1           0.099        11.05        0.0001
   D               -0.205          1           0.099       -2.069        0.0723
   A2               1.047          1           0.222        4.729        0.0015
   B2             ALIASED          0
   C2             ALIASED          0
   D2             ALIASED          0
   AB               0.035          1           0.099       0.3533        0.7330
   AC              -0.528          1           0.099       -5.325        0.0007
   AD               0.230          1           0.099        2.322        0.0488
   BC               0.015          1           0.099       0.1514        0.8834
   BD              -0.175          1           0.099       -1.767        0.1153
   CD              -0.277          1           0.099       -2.801        0.0232

  Final Equation in Terms of Coded Factors:

            Ash = 9.027 - 1.443 * A + 0.345 * B + 1.095 * C - 0.205 * D
                        + 1.047 * A2 + 0.000 * B2 + 0.000 * C2 + 0.000 * D2
                        + 0.035 * AB - 0.528 * AC + 0.230 * AD + 0.015 * BC
                        - 0.175 * BD - 0.277 * CD

  Final Equation in Terms of Actual Factors:

             Not available for ALIASED models.
```

```
Obs       ACTUAL    PREDICTED                          STUDENT COOK'S OUTLIER Run
Ord        VALUE      VALUE       RESIDUAL    LEVER    RESID    DIST     t    Ord

  1        9.390      9.582        -0.192    0.687   -0.869   0.138  -0.854    8
  2        7.110      7.223        -0.113    0.687   -0.508   0.047  -0.483    1
  3       10.900     10.522         0.377    0.687    1.704   0.532   1.997    3
  4        8.230      8.302        -0.073    0.687   -0.327   0.020  -0.308   14
  5       13.350     13.353        -0.003    0.687   -0.011   0.000  -0.011   13
  6        9.190      8.883         0.307    0.687    1.388   0.353   1.490   17
  7       14.170     14.352        -0.183    0.687   -0.824   0.124  -0.806    9
  8        9.900     10.022        -0.122    0.687   -0.553   0.056  -0.527   11
  9       10.040      9.617         0.422    0.687    1.907   0.667   2.416   20
 10        8.060      8.177        -0.117    0.687   -0.530   0.052  -0.505   16
 11        9.250      9.857        -0.607    0.687   -2.742   1.379 -10.485   18
 12        8.860      8.557         0.302    0.687    1.366   0.342   1.459    4
 13       12.050     12.278        -0.228    0.687   -1.027   0.193  -1.031    2
 14        8.650      8.727        -0.078    0.687   -0.350   0.022  -0.330   19
 15       12.990     12.578         0.412    0.687    1.862   0.636   2.314    7
 16        9.060      9.167        -0.108    0.687   -0.485   0.043  -0.461    5
 17        8.940      9.027        -0.087    0.250   -0.255   0.002  -0.239    6
 18        9.020      9.027        -0.007    0.250   -0.022   0.000  -0.020   10
 19        9.000      9.027        -0.028    0.250   -0.080   0.000  -0.075   12
 20        9.150      9.027         0.122    0.250    0.357   0.004   0.337   15
```

## STATISTICAL DATA ANALYSIS

**Description:** Froth Flotation

**Coal Sample:** Elkhorn No. 3

**Response:** Concentrate Sulfur

### Design Summary

| FAC | FACTOR | UNITS | -1 LEVEL | +1 LEVEL |
|---|---|---|---|---|
| A | Water | ml/min | 200.000 | 600.000 |
| B | Feed | ml/min | 150.000 | 250.000 |
| C | Solids | % | 4.000 | 10.000 |
| D | Air | ml/min | 1000.000 | 2000.000 |

### Sequential Model Sum of Squares

| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROB > F |
|---|---|---|---|---|---|
| MEAN | 6.316880 | 1 | 6.316880 | | |
| Linear | 0.001750 | 4 | 0.000437 | 1.030 | 0.4237 |
| Quadratic | 0.005220 | 7 | 0.000746 | 5.188 | 0.0169 |
| Cubic | 0.000550 | 4 | 0.000138 | 0.9167 | 0.5326 |
| RESIDUAL | 0.000600 | 4 | 0.000150 | | |
| TOTAL | 6.325000 | 20 | | | |

### Lack of Fit Tests

| MODEL | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROB > F |
|---|---|---|---|---|---|
| Linear | 0.006170 | 12 | 0.000514 | 7.713 | 0.0594 |
| Quadratic | 0.000950 | 5 | 0.000190 | 2.850 | 0.2089 |
| Cubic | 0.000400 | 1 | 0.000400 | 6.000 | 0.0917 |
| PURE ERR | 0.000200 | 3 | 0.000067 | | |

### ANOVA Summary Statistics of Models Fit

| SOURCE | UNALIASED TERMS | RESID DF | ROOT MSE | R-SQR | ADJ R-SQR | PRESS |
|---|---|---|---|---|---|---|
| Linear | 5 | 15 | 0.02061 | 0.2155 | 0.0063 | 0.01280 |
| Quadratic | 12 | 8 | 0.01199 | 0.8584 | 0.6636 | 0.01008 |
| Cubic | 16 | 4 | 0.01225 | 0.9261 | 0.6490 | 0.10276 |

```
ANOVA for Linear Model

                    SUM OF                   MEAN          F
   SOURCE          SQUARES        DF        SQUARE       VALUE        PROB > F

    MODEL         0.001750         4       0.00044       1.030         0.4237
  RESIDUAL        0.006370        15       0.00042
  Lack Of Fit     0.006170        12       0.00051       7.713         0.0594
  Pure Error      0.000200         3       0.00007
  COR TOTAL       0.008120        19

  ROOT MSE         0.02061                R-SQUARED     0.2155
  DEP MEAN         0.56200            ADJ R-SQUARED     0.0063
      C.V.           3.67%

 Predicted Residual Sum of Squares (PRESS) = 0.012799

 INDEPENDENT    COEFFICIENT               STANDARD     t FOR H0
  VARIABLE       ESTIMATE       DF          ERROR    COEFFICIENT=0   PROB > |t|

  Intercept       0.56200        1         0.00461       122.0
  A               0.00625        1         0.00515       1.213        0.2438
  B               0.00375        1         0.00515       0.7279       0.4779
  C               0.00750        1         0.00515       1.456        0.1661
  D            -1.164E-13        1         0.00515     -2.26E-11      1.0000

 Final Equation in Terms of Coded Factors:

         Sulfur = 0.56200 + 0.00625 * A + 0.00375 * B
                                  + 0.00750 * C - 1.164E-13 * D

 Final Equation in Terms of Actual Factors:

         Sulfur = 0.51700 + 3.125E-05 * Water + 7.500E-05 * Feed
                                   + 2.500E-03 * Solids - 2.327E-16 * Air

Obs       ACTUAL       PREDICTED                            STUDENT  COOK'S  OUTLIER  Run
Ord        VALUE         VALUE       RESIDUAL     LEVER      RESID    DIST      t     Ord

  1      0.55000       0.54450       0.00550      0.300      0.319    0.009    0.309    8
  2      0.52000       0.55700      -0.03700      0.300     -2.146    0.395   -2.490    1
  3      0.53000       0.55200      -0.02200      0.300     -1.276    0.140   -1.306    3
  4      0.56000       0.56450      -0.00450      0.300     -0.261    0.006   -0.253   14
  5      0.56000       0.55950       0.00050      0.300      0.029    0.000    0.028   13
  6      0.58000       0.57200       0.00800      0.300      0.464    0.018    0.452   17
  7      0.59000       0.56700       0.02300      0.300      1.334    0.153    1.373    9
  8      0.61000       0.57950       0.03050      0.300      1.769    0.268    1.921   11
  9      0.57000       0.54450       0.02550      0.300      1.479    0.187    1.546   20
 10      0.58000       0.55700       0.02300      0.300      1.334    0.153    1.373   16
 11      0.57000       0.55200       0.01800      0.300      1.044    0.093    1.047   18
 12      0.56000       0.56450      -0.00450      0.300     -0.261    0.006   -0.253    4
 13      0.54000       0.55950      -0.01950      0.300     -1.131    0.110   -1.142    2
 14      0.57000       0.57200      -0.00200      0.300     -0.116    0.001   -0.112   19
 15      0.54000       0.56700      -0.02700      0.300     -1.566    0.210   -1.654    7
 16      0.57000       0.57950      -0.00950      0.300     -0.551    0.026   -0.538    5
 17      0.56000       0.56200      -0.00200      0.050     -0.100    0.000   -0.096    6
 18      0.57000       0.56200       0.00800      0.050      0.398    0.002    0.387   10
 19      0.56000       0.56200      -0.00200      0.050     -0.100    0.000   -0.096   12
 20      0.55000       0.56200      -0.01200      0.050     -0.597    0.004   -0.584   15
```

```
ANOVA for Quadratic Model

                     SUM OF                        MEAN          F
   SOURCE           SQUARES         DF            SQUARE       VALUE      PROB > F

    MODEL          0.006970         11           0.00063       4.408      0.0224
 RESIDUAL          0.001150          8           0.00014
 Lack Of Fit       0.000950          5           0.00019       2.850      0.2089
 Pure Error        0.000200          3           0.00007
 COR TOTAL         0.008120         19

 ROOT MSE           0.01199                    R-SQUARED      0.8584
 DEP MEAN           0.56200                ADJ R-SQUARED      0.6636
     C.V.             2.13%

Predicted Residual Sum of Squares (PRESS) = 0.010084


 INDEPENDENT   COEFFICIENT                   STANDARD    t FOR H0
  VARIABLE      ESTIMATE        DF             ERROR    COEFFICIENT=0   PROB > |t|

  Intercept      0.56000         1            0.00599      93.41
  A              0.00625         1            0.00300      2.085         0.0705
  B              0.00375         1            0.00300      1.251         0.2462
  C              0.00750         1            0.00300      2.502         0.0368
  D           -1.389E-13         1            0.00300   -4.63E-11        1.0000
  A2             0.00250         1            0.00670     0.3730         0.7188
  B2             ALIASED         0
  C2             ALIASED         0
  D2             ALIASED         0
  AB             0.00250         1            0.00300     0.8341         0.4284
  AC             0.00625         1            0.00300      2.085         0.0705
  AD             0.00125         1            0.00300     0.4170         0.6876
  BC             0.00375         1            0.00300      1.251         0.2462
  BD            -0.00625         1            0.00300     -2.085         0.0705
  CD            -0.01500         1            0.00300     -5.004         0.0010

 Final Equation in Terms of Coded Factors:

          Sulfur = 0.56000 + 0.00625 * A + 0.00375 * B + 0.00750 * C
                                 - 1.389E-13 * D + 0.00250 * A2 + 0.00000 * B2
                                 + 0.00000 * C2 + 0.00000 * D2 + 0.00250 * AB
                                 + 0.00625 * AC + 0.00125 * AD + 0.00375 * BC
                                 - 0.00625 * BD - 0.01500 * CD


 Final Equation in Terms of Actual Factors:

   Not available for ALIASED models.
```

```
Obs      ACTUAL     PREDICTED                      STUDENT COOK'S OUTLIER Run
Ord       VALUE       VALUE      RESIDUAL   LEVER   RESID   DIST     t    Ord

  1     0.55000     0.53750       0.01250   0.687   1.865  0.638   2.320    8
  2     0.52000     0.53000      -0.01000   0.687  -1.492  0.408  -1.643    1
  3     0.53000     0.54500      -0.01500   0.687  -2.238  0.918  -3.424    3
  4     0.56000     0.54750       0.01250   0.687   1.865  0.638   2.320   14
  5     0.56000     0.56250      -0.00250   0.687  -0.373  0.026  -0.352   13
  6     0.58000     0.58000    -8.136E-13   0.687  -0.000  0.000  -0.000   17
  7     0.59000     0.58500       0.00500   0.687   0.746  0.102   0.723    9
  8     0.61000     0.61250      -0.00250   0.687  -0.373  0.026  -0.352   11
  9     0.57000     0.57750      -0.00750   0.687  -1.119  0.230  -1.140   20
 10     0.58000     0.57500       0.00500   0.687   0.746  0.102   0.723   16
 11     0.57000     0.56000       0.01000   0.687   1.492  0.408   1.643   18
 12     0.56000     0.56750      -0.00750   0.687  -1.119  0.230  -1.140    4
 13     0.54000     0.54250      -0.00250   0.687  -0.373  0.026  -0.352    2
 14     0.57000     0.56500       0.00500   0.687   0.746  0.102   0.723   19
 15     0.54000     0.54000    -7.638E-13   0.687  -0.000  0.000  -0.000    7
 16     0.57000     0.57250      -0.00250   0.687  -0.373  0.026  -0.352    5
 17     0.56000     0.56000    -5.613E-13   0.250  -0.000  0.000  -0.000    6
 18     0.57000     0.56000       0.01000   0.250   0.963  0.026   0.958   10
 19     0.56000     0.56000    -5.613E-13   0.250  -0.000  0.000  -0.000   12
 20     0.55000     0.56000      -0.01000   0.250  -0.963  0.026  -0.958   15
```

## STATISTICAL DATA ANALYSIS

**Description:** Froth Flotation

**Coal Sample:** Pittsburgh No. 8

**Response:** Combustible Recovery

### Design Summary

| FAC | FACTOR | UNITS | -1 LEVEL | +1 LEVEL |
|---|---|---|---|---|
| A | Water | ml/min | 200.000 | 600.000 |
| B | Feed | ml/min | 150.000 | 250.000 |
| C | Solids | % | 4.000 | 10.000 |
| D | Air | ml/min | 1000.000 | 2000.000 |

### Analysis Summary

**Sequential Model Sum of Squares**

| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROB > F |
|---|---|---|---|---|---|
| MEAN | 57495.7 | 1 | 57495.7 | | |
| Linear | 10059.6 | 4 | 2514.9 | 6.797 | 0.0025 |
| Quadratic | 4642.5 | 8 | 580.3 | 4.478 | 0.0316 |
| Cubic | 902.4 | 4 | 225.6 | 141.0 | 0.0010 |
| RESIDUAL | 4.8 | 3 | 1.6 | | |
| TOTAL | 73105.0 | 20 | | | |

**Lack of Fit Tests**

| MODEL | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROB > F |
|---|---|---|---|---|---|
| Linear | 5544.9 | 12 | 462.1 | 288.8 | 0.0003 |
| Quadratic | 902.4 | 4 | 225.6 | 141.0 | 0.0010 |
| Cubic | 0.0 | 0 | | | |
| PURE ERR | 4.8 | 3 | 1.6 | | |

**ANOVA Summary Statistics of Models Fit**

| SOURCE | UNALIASED TERMS | RESID DF | ROOT MSE | R-SQR | ADJ R-SQR | PRESS |
|---|---|---|---|---|---|---|
| Linear | 5 | 15 | 19.2 | 0.6445 | 0.5497 | 10750.4 |
| Quadratic | 13 | 7 | 11.4 | 0.9419 | 0.8422 | 15478.2 |
| Cubic | 17 | 3 | 1.3 | 0.9997 | 0.9981 | |

**Case(s) with leverage of 1.0000: PRESS statistic not defined.**

```
ANOVA for Linear Model

                     SUM OF                    MEAN          F
     SOURCE         SQUARES        DF        SQUARE        VALUE      PROB > F

      MODEL         10059.6         4        2514.9        6.797       0.0025
    RESIDUAL         5549.7        15         370.0
    Lack Of Fit      5544.9        12         462.1        288.8       0.0003
    Pure Error          4.8         3           1.6
    COR TOTAL       15609.3        19

    ROOT MSE           19.2                R-SQUARED     0.6445
    DEP MEAN           53.6            ADJ R-SQUARED     0.5497
        C.V.         35.87%

   Predicted Residual Sum of Squares (PRESS) = 10750.4

   INDEPENDENT   COEFFICIENT              STANDARD    t FOR HO
    VARIABLE       ESTIMATE        DF        ERROR    COEFFICIENT=0  PROB > |t|

    Intercept          53.6         1          4.3         12.45
    A                 -20.7         1          4.8        -4.299      0.0006
    B                   0.1         1          5.0     2.43E-02       0.9809
    C                 -11.6         1          4.8        -2.408      0.0293
    D                   8.1         1          4.8         1.692      0.1112

   Final Equation in Terms of Coded Factors:

          Recovery = 53.6 - 20.7 * A + 0.1 * B - 11.6 * C + 8.1 * D

   Final Equation in Terms of Actual Factors:

          Recovery = 97.1 - 0.10342 * Water + 2.419E-03 * Feed
                              - 3.8609 * Solids + 1.630E-02 * Air

  Obs        ACTUAL     PREDICTED                          STUDENT  COOK'S  OUTLIER  Run
  Ord        VALUE        VALUE      RESIDUAL    LEVER      RESID    DIST      t     Ord

    1         89.6         77.6         12.0     0.309     0.747    0.050    0.736   17
    2         50.3         36.2         14.0     0.301     0.872    0.065    0.864   10
    3         98.6         77.9         20.8     0.300     1.290    0.142    1.322    8
    4         50.9         36.5         14.4     0.308     0.900    0.072    0.894    1
    5         34.8         54.4        -19.6     0.305    -1.223    0.131   -1.245   15
    6         23.8         13.1         10.7     0.297     0.663    0.037    0.650    3
    7         23.9         54.7        -30.8     0.304    -1.916    0.320   -2.130    6
    8         16.5         13.3          3.2     0.312     0.202    0.004    0.195    4
    9         72.2         94.0        -21.7     0.278    -1.330    0.136   -1.368   20
   10         45.0         52.6         -7.6     0.293    -0.469    0.018   -0.457   19
   11        100.0         94.1          5.9     0.287     0.360    0.010    0.350   12
   12         39.8         52.8        -13.0     0.295    -0.803    0.054   -0.793   16
   13        100.0         70.8         29.2     0.297     1.813    0.278    1.982    5
   14         36.7         29.4          7.3     0.310     0.457    0.019    0.444    7
   15        100.0         71.0         29.0     0.306     1.810    0.289    1.978    2
   16         25.2         29.6         -4.4     0.298    -0.272    0.006   -0.264    9
   17         39.4         53.6        -14.2     0.050    -0.759    0.006   -0.748   11
   18         41.9         53.6        -11.7     0.050    -0.623    0.004   -0.610   13
   19         42.1         53.6        -11.6     0.050    -0.616    0.004   -0.603   14
   20         41.7         53.6        -11.9     0.050    -0.636    0.004   -0.623   18
```

```
ANOVA for Quadratic Model

                 SUM OF                  MEAN        F
   SOURCE        SQUARES      DF        SQUARE      VALUE      PROB > F

     MODEL       14702.1      12        1225.2      9.454       0.0032
 RESIDUAL          907.2       7         129.6
 Lack Of Fit       902.4       4         225.6      141.0       0.0010
 Pure Error          4.8       3           1.6
 COR TOTAL       15609.3      19

 ROOT MSE           11.4              R-SQUARED    0.9419
 DEP MEAN           53.6          ADJ R-SQUARED    0.8422
     C.V.          21.23%

Predicted Residual Sum of Squares (PRESS) = 15478.2

INDEPENDENT   COEFFICIENT                STANDARD   t FOR H0
 VARIABLE      ESTIMATE       DF          ERROR    COEFFICIENT=0  PROB > |t|

 Intercept         41.3        1            5.7        7.249
 A                -22.1        1            3.1       -7.138        0.0002
 B                 -5.0        1            5.0       -1.015        0.3438
 C                -14.5        1            3.7       -3.936        0.0056
 D                 11.8        1            4.1        2.908        0.0227
 A2               -36.5        1           39.1      -0.9356        0.3806
 B2                55.6        1           41.4        1.343        0.2212
 C2             ALIASED        0
 D2             ALIASED        0
 AB                 0.2        1            3.7     5.17E-02        0.9602
 AC                 1.9        1            2.9       0.6481        0.5376
 AD                -9.0        1            3.1       -2.889        0.0234
 BC                -2.3        1            3.1      -0.7215        0.4940
 BD                -4.0        1            5.0      -0.8029        0.4485
 CD                 9.2        1            3.7        2.501        0.0409

Final Equation in Terms of Coded Factors:

        Recovery = 41.3 - 22.1 * A - 5.0 * B - 14.5 * C + 11.8 * D
                        - 36.5 * A2 + 55.6 * B2 + 0.0 * C2 + 0.0 * D2
                        + 0.2 * AB + 1.9 * AC - 9.0 * AD - 2.3 * BC
                        - 4.0 * BD + 9.2 * CD

Final Equation in Terms of Actual Factors:

        Not available for ALIASED models.
```

```
Obs       ACTUAL    PREDICTED                   STUDENT COOK'S OUTLIER Run
Ord        VALUE      VALUE     RESIDUAL  LEVER   RESID   DIST      t   Ord

  1         89.6       86.4         3.2  0.835   0.686   0.184   0.657  17
  2         50.3       55.8        -5.6  0.720  -0.927   0.170  -0.916  10
  3         98.6       88.4        10.2  0.751   1.791   0.743   2.253   8
  4         50.9       58.7        -7.8  0.698  -1.242   0.275  -1.303   1
  5         34.8       39.6        -4.7  0.698  -0.759   0.102  -0.733  15
  6         23.8       16.6         7.2  0.751   1.259   0.367   1.325   3
  7         23.9       32.5        -8.6  0.720  -1.429   0.405  -1.572   6
  8         16.5       10.3         6.2  0.835   1.341   0.702   1.440   4
  9         72.2       82.1        -9.9  0.739  -1.694   0.625  -2.042  20
 10         45.0       33.6        11.4  0.685   1.785   0.533   2.238  19
 11        100.0      103.5        -3.5  0.686  -0.548   0.051  -0.519  12
 12         39.8       37.9         1.9  0.680   0.303   0.015   0.282  16
 13        100.0       89.3        10.7  0.713   1.750   0.585   2.160   5
 14         36.7       48.7       -12.1  0.817  -2.479   2.113  -6.565   7
 15        100.0       97.3         2.7  0.768   0.489   0.061   0.461   2
 16         25.2       26.5        -1.3  0.901  -0.358   0.090  -0.334   9
 17         39.4       41.3        -1.9  0.250  -0.191   0.001  -0.177  11
 18         41.9       41.3         0.7  0.250   0.068   0.000   0.063  13
 19         42.1       41.3         0.8  0.250   0.081   0.000   0.075  14
 20         41.7       41.3         0.4  0.250   0.042   0.000   0.039  18
```

## STATISTICAL DATA ANALYSIS

**Description:** Froth Flotation

**Coal Sample:** Pittsburgh No. 8

**Response:** Concentrate Ash

### Design Summary

| FAC | FACTOR | UNITS | -1 LEVEL | +1 LEVEL |
|---|---|---|---|---|
| A | Water | ml/min | 200.000 | 600.000 |
| B | Feed | ml/min | 150.000 | 250.000 |
| C | Solids | % | 4.000 | 10.000 |
| D | Air | ml/min | 1000.000 | 2000.000 |

### Analysis Summary

#### Sequential Model Sum of Squares

| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROB > F |
|---|---|---|---|---|---|
| MEAN | 705.2 | 1 | 705.2 | | |
| Linear | 200.7 | 4 | 50.2 | 4.950 | 0.0096 |
| Quadratic | 107.3 | 8 | 13.4 | 2.100 | 0.1721 |
| Cubic | 44.7 | 4 | 11.2 | 989.1 | 0.0001 |
| RESIDUAL | 0.0 | 3 | 0.0 | | |
| TOTAL | 1057.9 | 20 | | | |

#### Lack of Fit Tests

| MODEL | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROB > F |
|---|---|---|---|---|---|
| Linear | 152.0 | 12 | 12.7 | 1122 | 0.0001 |
| Quadratic | 44.7 | 4 | 11.2 | 989.1 | 0.0001 |
| Cubic | 0.0 | 0 | | | |
| PURE ERR | 0.0 | 3 | 0.0 | | |

#### ANOVA Summary Statistics of Models Fit

| SOURCE | UNALIASED TERMS | RESID DF | ROOT MSE | R-SQR | ADJ R-SQR | PRESS |
|---|---|---|---|---|---|---|
| Linear | 5 | 15 | 3.18 | 0.5689 | 0.4540 | 291.14 |
| Quadratic | 13 | 7 | 2.53 | 0.8732 | 0.6559 | 762.22 |
| Cubic | 17 | 3 | 0.11 | 0.9999 | 0.9994 | |

**Case(s) with leverage of 1.0000: PRESS statistic not defined.**

```
ANOVA for Linear Model

                 SUM OF                   MEAN          F
   SOURCE        SQUARES      DF         SQUARE       VALUE      PROB > F

    MODEL         200.7        4          50.17       4.950        0.0096
  RESIDUAL        152.0       15          10.14
  Lack Of Fit     152.0       12          12.67        1122        0.0001
  Pure Error        0.0        3           0.01
  COR TOTAL       352.7       19

  ROOT MSE         3.18                R-SQUARED     0.5689
  DEP MEAN         5.94            ADJ R-SQUARED     0.4540
      C.V.        53.61%

 Predicted Residual Sum of Squares (PRESS) = 291.1

 INDEPENDENT   COEFFICIENT             STANDARD    t FOR HO
  VARIABLE      ESTIMATE       DF        ERROR   COEFFICIENT=0  PROB > |t|

  Intercept        5.90         1         0.71       8.282
  A               -3.02         1         0.80      -3.788        0.0018
  B                0.91         1         0.82       1.102        0.2878
  C                0.53         1         0.80      0.6617        0.5182
  D                1.45         1         0.80       1.825        0.0881

 Final Equation in Terms of Coded Factors:

          Ash = 5.90 - 3.02 * A + 0.91 * B + 0.53 * C + 1.45 * D

 Final Equation in Terms of Actual Factors:

          Ash = 2.72 - 1.508E-02 * Water + 1.813E-02 * Feed
                          + 0.17557 * Solids + 2.908E-03 * Air

Obs        ACTUAL    PREDICTED                     STUDENT  COOK'S  OUTLIER  Run
Ord         VALUE        VALUE    RESIDUAL   LEVER   RESID    DIST        t  Ord

  1          6.56         6.03        0.53   0.309   0.200   0.004    0.194   17
  2          3.00        -0.00        3.00   0.301   1.128   0.109    1.139   10
  3         10.76         7.84        2.92   0.300   1.095   0.103    1.103    8
  4          3.34         1.81        1.53   0.308   0.577   0.030    0.564    1
  5          4.45         7.08       -2.63   0.305  -0.992   0.086   -0.992   15
  6          3.37         1.05        2.32   0.297   0.868   0.064    0.861    3
  7          4.88         8.90       -4.02   0.304  -1.512   0.199   -1.586    6
  8          3.44         2.86        0.58   0.312   0.218   0.004    0.211    4
  9          4.47         9.26       -4.79   0.278  -1.772   0.241   -1.925   20
 10          3.38         3.05        0.33   0.293   0.123   0.001    0.119   19
 11         12.77        10.75        2.02   0.287   0.751   0.046    0.740   12
 12          3.41         4.72       -1.31   0.295  -0.490   0.020   -0.477   16
 13         16.01        10.14        5.87   0.297   2.200   0.409    2.583    5
 14          3.45         3.96       -0.51   0.310  -0.193   0.003   -0.187    7
 15         16.24        11.91        4.33   0.306   1.632   0.235    1.738    2
 16          4.06         5.77       -1.71   0.298  -0.642   0.035   -0.629    9
 17          3.64         5.90       -2.26   0.050  -0.729   0.006   -0.717   11
 18          3.80         5.90       -2.10   0.050  -0.677   0.005   -0.665   13
 19          3.87         5.90       -2.03   0.050  -0.655   0.005   -0.642   14
 20          3.86         5.90       -2.04   0.050  -0.658   0.005   -0.645   18
```

```
ANOVA for Quadratic Model

                     SUM OF                    MEAN          F
 SOURCE             SQUARES      DF           SQUARE       VALUE       PROB > F

   MODEL             308.0       12            25.67       4.018        0.0371
 RESIDUAL             44.7        7             6.39
 Lack Of Fit          44.7        4            11.17       989.1        0.0001
 Pure Error            0.0        3             0.01
 COR TOTAL           352.7       19

 ROOT MSE             2.53                 R-SQUARED      0.8732
 DEP MEAN             5.94             ADJ R-SQUARED      0.6559
     C.V.            42.56%

Predicted Residual Sum of Squares (PRESS) = 762.2

INDEPENDENT   COEFFICIENT                STANDARD    t FOR HO
 VARIABLE      ESTIMATE        DF          ERROR   COEFFICIENT=0   PROB > |t|

 Intercept         3.79         1           1.26        3.001
 A                -3.19         1           0.69       -4.632        0.0024
 B                 0.23         1           1.10        0.2061       0.8426
 C                 0.14         1           0.82        0.1745       0.8664
 D                 1.92         1           0.90        2.132        0.0705
 A2               -4.31         1           8.67       -0.4975       0.6341
 B2                7.42         1           9.19        0.8066       0.4464
 C2             ALIASED         0
 D2             ALIASED         0
 AB               -0.32         1           0.83       -0.3848       0.7118
 AC               -0.27         1           0.65       -0.4103       0.6939
 AD               -1.50         1           0.69       -2.182        0.0654
 BC               -0.52         1           0.70       -0.7385       0.4842
 BD               -0.40         1           1.10       -0.3651       0.7258
 CD                1.08         1           0.82        1.321        0.2282

Final Equation in Terms of Coded Factors:

          Ash = 3.79 - 3.19 * A + 0.23 * B + 0.14 * C + 1.92 * D
                       - 4.31 * A2 + 7.42 * B2 + 0.00 * C2 + 0.00 * D2
                       - 0.32 * AB - 0.27 * AC - 1.50 * AD - 0.52 * BC
                       - 0.40 * BD + 1.08 * CD

Final Equation in Terms of Actual Factors:

  Not available for ALIASED models.
```

| Obs Ord | ACTUAL VALUE | PREDICTED VALUE | RESIDUAL | LEVER | STUDENT RESID | COOK'S DIST | OUTLIER t | Run Ord |
|---|---|---|---|---|---|---|---|---|
| 1 | 6.56 | 5.87 | 0.69 | 0.835 | 0.674 | 0.177 | 0.645 | 17 |
| 2 | 3.00 | 3.67 | -0.67 | 0.720 | -0.500 | 0.050 | -0.471 | 10 |
| 3 | 10.76 | 8.80 | 1.96 | 0.751 | 1.552 | 0.558 | 1.773 | 8 |
| 4 | 3.34 | 5.32 | -1.98 | 0.698 | -1.426 | 0.362 | -1.568 | 1 |
| 5 | 4.45 | 5.56 | -1.11 | 0.698 | -0.796 | 0.113 | -0.773 | 15 |
| 6 | 3.37 | 2.29 | 1.08 | 0.751 | 0.858 | 0.171 | 0.840 | 3 |
| 7 | 4.88 | 6.42 | -1.54 | 0.720 | -1.155 | 0.264 | -1.188 | 6 |
| 8 | 3.44 | 1.87 | 1.57 | 0.835 | 1.527 | 0.911 | 1.732 | 4 |
| 9 | 4.47 | 7.21 | -2.74 | 0.739 | -2.125 | 0.984 | -3.302 | 20 |
| 10 | 3.38 | 0.96 | 2.42 | 0.685 | 1.707 | 0.488 | 2.068 | 19 |
| 11 | 12.77 | 12.68 | 0.09 | 0.686 | 0.067 | 0.001 | 0.062 | 12 |
| 12 | 3.41 | 3.18 | 0.23 | 0.680 | 0.160 | 0.004 | 0.148 | 16 |
| 13 | 16.01 | 13.13 | 2.88 | 0.713 | 2.128 | 0.866 | 3.315 | 5 |
| 14 | 3.45 | 6.09 | -2.64 | 0.817 | -2.444 | 2.055 | -5.914 | 7 |
| 15 | 16.24 | 16.47 | -0.23 | 0.768 | -0.190 | 0.009 | -0.177 | 2 |
| 16 | 4.06 | 4.07 | -0.01 | 0.901 | -0.009 | 0.000 | -0.009 | 9 |
| 17 | 3.64 | 3.79 | -0.15 | 0.250 | -0.070 | 0.000 | -0.065 | 11 |
| 18 | 3.80 | 3.79 | 0.01 | 0.250 | 0.003 | 0.000 | 0.003 | 13 |
| 19 | 3.87 | 3.79 | 0.08 | 0.250 | 0.035 | 0.000 | 0.033 | 14 |
| 20 | 3.86 | 3.79 | 0.07 | 0.250 | 0.031 | 0.000 | 0.029 | 18 |

```
                          STATISTICAL DATA ANALYSIS

Description:        Froth Flotation
Coal Sample:        Pittsburgh No. 8
Response:           Combustible Sulfur


Design Summary

FAC     FACTOR              UNITS              -1 LEVEL      +1 LEVEL
 A      Water               ml/min              200.000       600.000
 B      Feed                ml/min              150.000       250.000
 C      Solids              %                     4.000        10.000
 D      Air                 ml/min             1000.000      2000.000

Analysis Summary

 Sequential Model Sum of Squares

                    SUM OF                 MEAN          F
  SOURCE           SQUARES       DF       SQUARE       VALUE      PROB > F

    MEAN           141.246        1      141.246
  Linear             3.371        4        0.843       6.067       0.0041
Quadratic            1.469        8        0.184       2.093       0.1732
   Cubic             0.614        4        0.153       969.2       0.0001
 RESIDUAL            0.000        3        0.000
   TOTAL           146.701       20

 Lack of Fit Tests

                    SUM OF                 MEAN          F
   MODEL           SQUARES       DF       SQUARE       VALUE      PROB > F

  Linear             2.083       12        0.174        1096       0.0001
Quadratic            0.614        4        0.153       969.2       0.0001
   Cubic             0.000        0
 PURE ERR            0.000        3        0.000

 ANOVA Summary Statistics of Models Fit

                 UNALIASED  RESID    ROOT                    ADJ
  SOURCE           TERMS     DF      MSE        R-SQR       R-SQR      PRESS

  Linear             5       15     0.373      0.6180      0.5162      4.013
Quadratic           13        7     0.296      0.8874      0.6943     10.396
   Cubic            17        3     0.013      0.9999      0.9994

 Case(s) with leverage of 1.0000:  PRESS statistic not defined.
```

```
ANOVA for Linear Model

                      SUM OF                        MEAN          F
      SOURCE          SQUARES       DF            SQUARE        VALUE        PROB > F

       MODEL            3.371        4             0.843        6.067         0.0041
    RESIDUAL            2.084       15             0.139
    Lack Of Fit         2.083       12             0.174         1096         0.0001
    Pure Error          0.000        3             0.000
    COR TOTAL           5.455       19

    ROOT MSE            0.373                  R-SQUARED       0.6180
    DEP MEAN            2.657              ADJ R-SQUARED       0.5162
        C.V.            14.02%

Predicted Residual Sum of Squares (PRESS) = 4.013

 INDEPENDENT    COEFFICIENT                  STANDARD    t FOR H0
  VARIABLE       ESTIMATE       DF            ERROR    COEFFICIENT=0  PROB > |t|

  Intercept         2.653        1            0.083        31.80
  A                -0.387        1            0.093       -4.148       0.0009
  B                 0.112        1            0.096        1.167       0.2614
  C                 0.048        1            0.093       0.5144       0.6145
  D                 0.206        1            0.093        2.204       0.0436

 Final Equation in Terms of Coded Factors:

         Sulfur = 2.653 - 0.387 * A + 0.112 * B + 0.048 * C + 0.206 * D


 Final Equation in Terms of Actual Factors:

         Sulfur = 2.248 - 1.933E-03 * Water + 2.247E-03 * Feed
                      + 1.598E-02 * Solids + 4.113E-04 * Air

Obs      ACTUAL      PREDICTED                       STUDENT  COOK'S  OUTLIER  Run
Ord       VALUE        VALUE     RESIDUAL   LEVER     RESID    DIST       t     Ord

  1       2.770        2.674       0.096    0.309     0.311   0.009    0.301   17
  2       2.250        1.900       0.350    0.301     1.122   0.108    1.132   10
  3       3.220        2.898       0.322    0.300     1.031   0.091    1.033    8
  4       2.300        2.125       0.175    0.308     0.564   0.028    0.551    1
  5       2.380        2.770      -0.390    0.305    -1.254   0.138   -1.280   15
  6       2.280        1.996       0.284    0.297     0.908   0.070    0.902    3
  7       2.540        2.994      -0.454    0.304    -1.461   0.186   -1.524    6
  8       2.310        2.221       0.089    0.312     0.288   0.008    0.279    4
  9       2.590        3.125      -0.535    0.278    -1.690   0.220   -1.815   20
 10       2.310        2.330      -0.020    0.293    -0.063   0.000   -0.061   19
 11       3.560        3.310       0.250    0.287     0.796   0.051    0.785   12
 12       2.370        2.536      -0.166    0.295    -0.532   0.024   -0.519   16
 13       3.920        3.199       0.721    0.297     2.308   0.450    2.777    5
 14       2.360        2.408      -0.048    0.310    -0.154   0.002   -0.149    7
 15       3.880        3.419       0.461    0.306     1.485   0.195    1.553    2
 16       2.440        2.632      -0.192    0.298    -0.616   0.032   -0.603    9
 17       2.420        2.653      -0.233    0.050    -0.641   0.004   -0.628   11
 18       2.430        2.653      -0.223    0.050    -0.614   0.004   -0.601   13
 19       2.420        2.653      -0.233    0.050    -0.641   0.004   -0.628   14
 20       2.400        2.653      -0.253    0.050    -0.697   0.005   -0.684   18
```

```
ANOVA for Quadratic Model

                   SUM OF                      MEAN          F
   SOURCE         SQUARES        DF           SQUARE       VALUE      PROB > F

    MODEL           4.840        12            0.403       4.596       0.0260
 RESIDUAL           0.614         7            0.088
 Lack Of Fit        0.614         4            0.153       969.2       0.0001
 Pure Error         0.000         3            0.000
 COR TOTAL          5.455        19

 ROOT MSE           0.296                  R-SQUARED     0.8874
 DEP MEAN           2.657              ADJ R-SQUARED     0.6943
     C.V.          11.15%

Predicted Residual Sum of Squares (PRESS) = 10.396

 INDEPENDENT   COEFFICIENT               STANDARD     t FOR H0
  VARIABLE       ESTIMATE        DF        ERROR    COEFFICIENT=0  PROB > |t|

  Intercept        2.417          1        0.148        16.32
  A               -0.406          1        0.081       -5.033       0.0015
  B                0.036          1        0.129       0.2779       0.7891
  C                0.005          1        0.096     5.29E-02       0.9593
  D                0.258          1        0.106        2.444       0.0445
  A2              -0.480          1        1.016      -0.4725       0.6509
  B2               0.827          1        1.078       0.7673       0.4680
  C2             ALIASED          0
  D2             ALIASED          0
  AB              -0.034          1        0.098      -0.3443       0.7408
  AC              -0.015          1        0.076      -0.2010       0.8464
  AD              -0.185          1        0.081       -2.293       0.0555
  BC              -0.058          1        0.082      -0.7037       0.5044
  BD              -0.050          1        0.129      -0.3892       0.7087
  CD               0.134          1        0.096        1.392       0.2065

 Final Equation in Terms of Coded Factors:

          Sulfur = 2.417 - 0.406 * A + 0.036 * B + 0.005 * C + 0.258 * D
                              - 0.480 * A2 + 0.827 * B2 + 0.000 * C2 + 0.000 *
D2
                          - 0.034 * AB - 0.015 * AC - 0.185 * AD - 0.058 * BC
                              - 0.050 * BD + 0.134 * CD

 Final Equation in Terms of Actual Factors:

           Not available for ALIASED models.
```

| Obs Ord | ACTUAL VALUE | PREDICTED VALUE | RESIDUAL | LEVER | STUDENT RESID | COOK'S DIST | OUTLIER t | Run Ord |
|---|---|---|---|---|---|---|---|---|
| 1 | 2.770 | 2.663 | 0.107 | 0.835 | 0.887 | 0.307 | 0.871 | 17 |
| 2 | 2.250 | 2.319 | -0.069 | 0.720 | -0.439 | 0.038 | -0.412 | 10 |
| 3 | 3.220 | 3.018 | 0.202 | 0.751 | 1.363 | 0.430 | 1.472 | 8 |
| 4 | 2.300 | 2.539 | -0.239 | 0.698 | -1.471 | 0.385 | -1.639 | 1 |
| 5 | 2.380 | 2.552 | -0.172 | 0.698 | -1.056 | 0.199 | -1.067 | 15 |
| 6 | 2.280 | 2.146 | 0.134 | 0.751 | 0.907 | 0.190 | 0.893 | 3 |
| 7 | 2.540 | 2.676 | -0.136 | 0.720 | -0.870 | 0.150 | -0.853 | 6 |
| 8 | 2.310 | 2.136 | 0.174 | 0.835 | 1.448 | 0.819 | 1.602 | 4 |
| 9 | 2.590 | 2.922 | -0.332 | 0.739 | -2.194 | 1.049 | -3.633 | 20 |
| 10 | 2.310 | 2.055 | 0.255 | 0.685 | 1.532 | 0.393 | 1.740 | 19 |
| 11 | 3.560 | 3.536 | 0.024 | 0.686 | 0.143 | 0.003 | 0.133 | 12 |
| 12 | 2.370 | 2.317 | 0.053 | 0.680 | 0.319 | 0.017 | 0.297 | 16 |
| 13 | 3.920 | 3.557 | 0.363 | 0.713 | 2.290 | 1.003 | 4.231 | 5 |
| 14 | 2.360 | 2.660 | -0.300 | 0.817 | -2.366 | 1.926 | -4.897 | 7 |
| 15 | 3.880 | 3.935 | -0.055 | 0.768 | -0.387 | 0.038 | -0.362 | 2 |
| 16 | 2.440 | 2.448 | -0.008 | 0.901 | -0.091 | 0.006 | -0.084 | 9 |
| 17 | 2.420 | 2.417 | 0.003 | 0.250 | 0.010 | 0.000 | 0.009 | 11 |
| 18 | 2.430 | 2.417 | 0.013 | 0.250 | 0.049 | 0.000 | 0.045 | 13 |
| 19 | 2.420 | 2.417 | 0.003 | 0.250 | 0.010 | 0.000 | 0.009 | 14 |
| 20 | 2.400 | 2.417 | -0.017 | 0.250 | -0.068 | 0.000 | -0.063 | 18 |

**Column flotation pH test data using Elkhorn No. 3 seam coal**

| Test Number | pH | Flow Rates | | | | | | Bias | | % Solids | | Mass Flow Rates | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Wash Water (ml/min) | Feed (ml/min) | Aeration (cc/min) | Frother (ml/min) | Frother (lb/ton) | Tailings (ml/min) | Factor (%) | Rate (cm/sec) | Feed (%) | Tails (%) | Feed (g/min) | Product (g/min) | Tails (g/min) |
| 1 | 4.0 | 200 | 105 | 1500 | 11 | 3.55 | 290 | 0.925 | 0.152 | 3.76 | 0.91 | 3.90 | 1.32 | 2.58 |
| 2 | 4.0 | 200 | 162 | 1500 | 15 | 3.14 | 350 | 0.940 | 0.155 | 3.80 | 1.27 | 6.29 | 1.73 | 4.26 |
| 3 | 4.0 | 200 | 242 | 1500 | 22 | 3.08 | 440 | 0.990 | 0.163 | 3.77 | 1.71 | 9.43 | 2.03 | 7.31 |
| 4 | 6.0 | 200 | 108 | 1500 | 10 | 3.14 | 295 | 0.935 | 0.154 | 3.93 | 1.13 | 4.23 | 0.82 | 3.26 |
| 5 | 6.0 | 200 | 156 | 1500 | 15 | 3.26 | 300 | 0.720 | 0.118 | 3.89 | 1.41 | 6.04 | 1.35 | 4.43 |
| 6 | 6.0 | 200 | 244 | 1500 | 24 | 3.34 | 450 | 1.030 | 0.169 | 4.07 | 1.96 | 9.61 | 0.80 | 8.71 |
| 7 | 7.5 | 196 | 106 | 1500 | 10 | 3.20 | 280 | 0.888 | 0.143 | 3.86 | 0.97 | 4.20 | 1.38 | 2.72 |
| 8 | 7.5 | 196 | 152 | 1500 | 15 | 3.35 | 340 | 0.959 | 0.155 | 3.90 | 1.27 | 5.91 | 1.47 | 4.26 |
| 9 | 7.5 | 196 | 224 | 1500 | 24 | 3.64 | 410 | 0.949 | 0.153 | 3.87 | 1.68 | 8.81 | 2.05 | 6.80 |
| 10 | 10.0 | 196 | 104 | 1500 | 10 | 3.26 | 280 | 0.898 | 0.145 | 3.83 | 0.91 | 4.01 | 1.66 | 2.51 |
| 11 | 10.0 | 196 | 158 | 1500 | 15 | 3.22 | 315 | 0.801 | 0.129 | 3.91 | 1.28 | 6.31 | 1.82 | 3.03 |
| 12 | 10.0 | 196 | 234 | 1500 | 24 | 3.48 | 360 | 0.643 | 0.104 | 3.90 | 1.65 | 9.17 | 3.23 | 5.84 |

**Column flotation pH test data using Elkhorn No. 3 seam coal**

| Test Number | % Ash (adjusted) | | | % Combustible (adjusted) | | | % Sulfur (adjusted) | | | Yield (%) | Combustible Recovery (%) | Rejection | | Separation Efficiency (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) | | | Ash (%) | Sulfur (%) | |
| 1 | 51.35 | 11.24 | 68.98 | 48.65 | 88.76 | 31.02 | 0.33 | 0.50 | 0.25 | 30.53 | 55.71 | 93.32 | 51.52 | 49.02 |
| 2 | 50.36 | 11.14 | 64.85 | 49.64 | 88.86 | 35.15 | 0.35 | 0.52 | 0.28 | 26.98 | 48.29 | 94.03 | 56.67 | 42.33 |
| 3 | 50.19 | 10.77 | 61.37 | 49.81 | 89.23 | 38.63 | 0.35 | 0.54 | 0.30 | 22.09 | 39.58 | 95.26 | 67.86 | 34.84 |
| 4 | 50.13 | 9.97 | 61.58 | 49.87 | 90.03 | 38.42 | 0.33 | 0.51 | 0.28 | 22.19 | 40.05 | 95.59 | 66.40 | 35.64 |
| 5 | 50.57 | 10.85 | 60.74 | 49.43 | 89.15 | 39.26 | 0.33 | 0.51 | 0.28 | 20.38 | 36.77 | 95.63 | 66.40 | 32.39 |
| 6 | 50.80 | 11.53 | 54.13 | 49.20 | 88.47 | 45.87 | 0.34 | 0.51 | 0.32 | 7.82 | 14.06 | 98.23 | 84.21 | 12.28 |
| 7 | 49.80 | 8.77 | 72.95 | 50.20 | 91.23 | 27.05 | 0.35 | 0.54 | 0.24 | 36.07 | 65.55 | 93.65 | 43.43 | 59.20 |
| 8 | 49.55 | 9.08 | 63.85 | 50.45 | 90.92 | 36.15 | 0.35 | 0.53 | 0.28 | 26.11 | 47.05 | 95.22 | 57.60 | 42.27 |
| 9 | 50.00 | 9.48 | 60.34 | 50.00 | 90.52 | 39.66 | 0.36 | 0.56 | 0.31 | 20.33 | 36.81 | 96.15 | 68.89 | 32.95 |
| 10 | 49.54 | 7.64 | 79.00 | 50.46 | 92.36 | 21.00 | 0.34 | 0.54 | 0.20 | 41.28 | 75.56 | 93.63 | 34.60 | 69.20 |
| 11 | 49.92 | 7.45 | 74.21 | 50.08 | 92.55 | 25.79 | 0.35 | 0.55 | 0.23 | 36.38 | 67.24 | 94.57 | 41.07 | 61.81 |
| 12 | 50.28 | 7.57 | 71.78 | 49.72 | 92.43 | 28.22 | 0.36 | 0.57 | 0.25 | 33.48 | 62.25 | 94.96 | 45.57 | 57.21 |

**Column flotation pH test data using Pittsburgh No. 8 seam coal**

| Test No. | pH | Flow Rates Wash Water (ml/min) | Flow Rates Feed (ml/min) | Flow Rates Aeration (cc/min) | Flow Rates Frother (ml/min) | Flow Rates Frother (lb/ton) | Flow Rates Tails (ml/min) | Bias Factor (%) | Bias Rate (cm/sec) | % Solids Feed (%) | % Solids Tails (%) | Mass Flow Rates Feed (g/min) | Mass Flow Rates Product (g/min) | Mass Flow Rates Tails (g/min) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4.0 | 196 | 104 | 1500 | 11 | 3.59 | 240 | 0.694 | 0.112 | 4.02 | 0.60 | 4.29 | 2.70 | 1.38 |
| 2 | 4.0 | 196 | 152 | 1500 | 15 | 3.35 | 275 | 0.628 | 0.101 | 4.02 | 1.04 | 6.31 | 3.35 | 2.86 |
| 3 | 4.0 | 196 | 232 | 1500 | 24 | 3.51 | 315 | 0.423 | 0.068 | 4.06 | 1.40 | 9.51 | 4.96 | 4.31 |
| 4 | 6.0 | 196 | 102 | 1500 | 10 | 3.33 | 248 | 0.745 | 0.120 | 4.03 | 0.49 | 4.29 | 3.09 | 1.22 |
| 5 | 6.0 | 196 | 160 | 1500 | 15 | 3.18 | 250 | 0.459 | 0.074 | 4.04 | 0.82 | 6.76 | 4.42 | 2.13 |
| 6 | 6.0 | 196 | 234 | 1500 | 24 | 3.48 | 305 | 0.362 | 0.058 | 4.03 | 1.35 | 9.55 | 5.33 | 4.19 |
| 7 | 7.5 | 196 | 106 | 1500 | 10 | 3.20 | 225 | 0.607 | 0.098 | 4.07 | 0.55 | 4.41 | 3.16 | 1.32 |
| 8 | 7.5 | 196 | 154 | 1500 | 15 | 3.30 | 255 | 0.515 | 0.083 | 4.10 | 0.92 | 6.43 | 3.89 | 2.42 |
| 9 | 7.5 | 198 | 185 | 1500 | 16 | 2.93 | 210 | 0.126 | 0.021 | 3.98 | 0.90 | 7.50 | 5.46 | 2.26 |
| 10 | 10.0 | 198 | 107 | 1500 | 10 | 3.17 | 240 | 0.672 | 0.109 | 3.88 | 0.50 | 4.15 | 2.68 | 1.23 |
| 11 | 10.0 | 198 | 154 | 1500 | 10 | 2.20 | 260 | 0.535 | 0.087 | 4.94 | 0.89 | 5.95 | 3.24 | 2.38 |
| 12 | 10.0 | 198 | 235 | 1500 | 19 | 2.74 | 185 | -0.253 | -0.041 | 3.92 | 1.31 | 9.25 | 6.16 | 2.73 |

**Column flotation pH test data using Pittsburgh No. 8 seam coal**

| Test No. | % Ash (adjusted) Feed (%) | % Ash (adjusted) Product (%) | % Ash (adjusted) Tails (%) | % Combustible (adjusted) Feed (%) | % Combustible (adjusted) Product (%) | % Combustible (adjusted) Tails (%) | % Sulfur (adjusted) Feed (%) | % Sulfur (adjusted) Product (%) | % Sulfur (adjusted) Tails (%) | Yield (%) | Combustible Recovery (%) | Rejection Ash (%) | Rejection Sulfur (%) | Separation Efficiency (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 16.53 | 5.44 | 39.33 | 83.47 | 94.56 | 60.67 | 3.67 | 2.66 | 5.75 | 67.28 | 76.21 | 77.86 | 51.21 | 54.07 |
| 2 | 16.49 | 6.56 | 27.55 | 83.51 | 93.44 | 72.45 | 3.67 | 2.74 | 4.72 | 52.69 | 58.96 | 79.04 | 60.41 | 38.00 |
| 3 | 16.60 | 7.63 | 27.00 | 83.40 | 92.37 | 73.00 | 3.55 | 2.80 | 4.43 | 53.69 | 59.47 | 75.32 | 57.42 | 34.79 |
| 4 | 17.05 | 4.11 | 51.80 | 82.95 | 95.89 | 48.20 | 3.63 | 2.44 | 6.84 | 72.87 | 84.23 | 82.44 | 50.96 | 66.67 |
| 5 | 17.27 | 4.23 | 43.53 | 82.73 | 95.77 | 56.47 | 3.75 | 2.41 | 6.45 | 66.82 | 77.35 | 83.63 | 57.05 | 60.99 |
| 6 | 17.04 | 4.37 | 32.88 | 82.96 | 95.63 | 67.12 | 3.59 | 2.44 | 5.04 | 55.56 | 64.04 | 85.75 | 62.10 | 49.80 |
| 7 | 16.40 | 3.67 | 48.54 | 83.60 | 96.33 | 51.46 | 3.65 | 2.26 | 7.16 | 71.63 | 82.54 | 83.97 | 55.65 | 66.51 |
| 8 | 16.60 | 3.41 | 40.35 | 83.40 | 96.59 | 59.65 | 3.70 | 2.23 | 6.34 | 64.29 | 74.46 | 86.79 | 61.29 | 61.25 |
| 9 | 16.12 | 3.87 | 43.77 | 83.88 | 96.13 | 56.23 | 3.51 | 2.29 | 6.28 | 69.30 | 79.42 | 83.36 | 54.71 | 62.78 |
| 10 | 15.06 | 3.39 | 44.28 | 84.94 | 96.61 | 55.72 | 3.47 | 2.16 | 6.75 | 71.46 | 81.28 | 83.91 | 55.52 | 65.19 |
| 11 | 15.08 | 3.01 | 33.67 | 84.92 | 96.99 | 66.33 | 3.57 | 2.10 | 5.82 | 60.63 | 69.25 | 87.90 | 64.42 | 57.15 |
| 12 | 15.27 | 4.84 | 33.29 | 84.73 | 95.16 | 66.71 | 3.54 | 2.35 | 5.59 | 63.34 | 71.14 | 79.92 | 58.00 | 51.06 |

# APPENDIX G - DRUM SCREEN DATA

## Drum screen test data using Elkhorn No. 3 (22% ash) seam coal

| Test Number | Flow Rates | | | | | Kerosene (lb/ton) | % Solids | | |
|---|---|---|---|---|---|---|---|---|---|
| | Feed (ml/min) | Feed (lb/hr) | Product (ml/min) | Tails (ml/min) | Wash Water (ml/min) | | Feed (%) | Product (%) | Tails (%) |
| 1 | 70 | 0.290 | 212 | 246 | 388 | 0 | 3.13 | 0.23 | 0.67 |
| 2 | 70 | 0.267 | 232 | 256 | 418 | 6 | 2.88 | 0.17 | 0.68 |
| 3 | 70 | 0.583 | 296 | 160 | 386 | 0 | 6.28 | 0.73 | 1.39 |
| 4 | 70 | 0.574 | 336 | 148 | 414 | 6 | 6.18 | 0.72 | 1.51 |
| 5 | 40 | 0.238 | 244 | 190 | 394 | 0 | 4.49 | 0.23 | 0.63 |
| 6 | 40 | 0.248 | 314 | 134 | 408 | 6 | 4.67 | 0.25 | 0.72 |
| 7 | 100 | 0.608 | 284 | 200 | 384 | 0 | 4.58 | 0.66 | 1.25 |
| 8 | 100 | 0.606 | 268 | 261 | 429 | 6 | 4.57 | 0.50 | 1.40 |
| 9 | 40 | 0.163 | 176 | 246 | 382 | 3 | 3.08 | 0.12 | 0.41 |
| 10 | 40 | 0.343 | 200 | 228 | 388 | 3 | 6.48 | 0.31 | 0.90 |
| 11 | 100 | 0.403 | 180 | 318 | 398 | 3 | 3.04 | 0.24 | 0.88 |
| 12 | 100 | 0.858 | 220 | 290 | 410 | 3 | 6.47 | 1.44 | 1.15 |
| 13 | 70 | 0.442 | 182 | 288 | 400 | 3 | 4.76 | 0.35 | 1.01 |
| 14 | 70 | 0.445 | 198 | 278 | 406 | 3 | 4.80 | 0.36 | 1.02 |
| 15 | 70 | 0.448 | 198 | 259 | 387 | 3 | 4.83 | 0.35 | 1.05 |

## Drum screen test data using Elkhorn No. 3 (22% ash) seam coal

| Test Number | Yield (%) | Comb. Rec. (%) | Ash Rej. (%) | Sep. Eff. (%) | % Ash | | |
|---|---|---|---|---|---|---|---|
| | | | | | Feed (%) | Product (%) | Tails (%) |
| 1 | 18.68 | 19.50 | 84.23 | 3.73 | 22.09 | 18.65 | 22.88 |
| 2 | 17.38 | 18.28 | 85.79 | 4.08 | 22.13 | 18.09 | 22.98 |
| 3 | 49.20 | 49.80 | 52.94 | 2.73 | 21.88 | 20.93 | 22.80 |
| 4 | 60.56 | 61.00 | 40.98 | 1.98 | 21.93 | 21.37 | 22.79 |
| 5 | 30.26 | 31.31 | 73.52 | 4.83 | 21.78 | 19.06 | 22.96 |
| 6 | 39.33 | 40.33 | 64.23 | 4.56 | 22.02 | 20.03 | 23.31 |
| 7 | 35.67 | 36.18 | 66.11 | 2.29 | 22.02 | 20.92 | 22.63 |
| 8 | 22.78 | 23.41 | 79.45 | 2.86 | 22.17 | 20.00 | 22.81 |
| 9 | 14.44 | 15.46 | 89.07 | 4.53 | 22.42 | 16.97 | 23.34 |
| 10 | 19.62 | 20.38 | 83.03 | 3.40 | 22.14 | 19.15 | 22.87 |
| 11 | 14.50 | 15.25 | 88.17 | 3.43 | 22.10 | 18.03 | 22.79 |
| 12 | 34.13 | 34.49 | 67.15 | 1.64 | 22.24 | 21.41 | 22.67 |
| 13 | 18.11 | 18.86 | 84.51 | 3.37 | 22.16 | 18.95 | 22.87 |
| 14 | 16.84 | 17.52 | 85.53 | 3.05 | 22.27 | 19.13 | 22.90 |
| 15 | 14.36 | 14.97 | 87.75 | 2.71 | 22.37 | 19.09 | 22.92 |

# APPENDIX H - PRELIMINARY OPTIMIZATION DATA

**Lamella thickener 3 cleaning stages data using Elkhorn No. 3 seam coal**

| Test Number | Flow Rates | | | | | % Solids | | | Yield | Combustible Recovery | Rejection | | Separation Efficiency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wash Water (ml/min) | Feed (ml/min) | Feed (lb/hr) | Product (ml/min) | Tails (ml/min) | Feed (%) | Product (%) | Tails (%) | (%) | (%) | Ash (%) | Sulphur (%) | (%) |
| I | 42 | 102 | 0.527 | 33 | 112 | 3.98 | 8.19 | 1.00 | 78.35 | 96.91 | 43.10 | 6.01 | 40.01 |
| II | 42 | 101 | 0.437 | 33 | 110 | 3.30 | 7.62 | 0.44 | 86.27 | 97.28 | 37.82 | 5.12 | 35.10 |
| III | 41 | 101 | 0.283 | 18 | 124 | 2.15 | 7.13 | 0.14 | 93.06 | 98.35 | 26.33 | 3.51 | 24.68 |
| I | | | | | | 3.98 | 8.19 | 1.00 | 78.35 | 96.91 | 43.10 | 6.01 | 40.01 |
| I-II | | | | | | 3.98 | 7.62 | 0.44 | 62.72 | 90.53 | 69.43 | 15.62 | 59.97 |
| I-III | | | | | | 3.98 | 7.13 | 0.14 | 54.34 | 84.14 | 80.10 | 25.97 | 64.24 |

**Lamella thickener 3 cleaning stages data using Elkhorn No. 3 seam coal**

| Test Number | % Ash (adjusted) | | | % Combustible (adj.) | | | % Sulfur (adjusted) | | | Superficial Velocity | | Throughput | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) | Overflow (mm/min) | Plate (mm/min) | Eff. Area (lb/hr/sq.in.) | Actual Area (lb/hr/sq.in.) | Volume (lb/hr/litre) |
| I | 46.39 | 33.69 | 92.35 | 53.61 | 66.31 | 7.65 | 0.46 | 0.53 | 0.15 | 22.26 | 41.33 | 0.0031 | 0.0126 | 0.0480 |
| II | 31.37 | 22.61 | 86.39 | 68.63 | 77.39 | 13.61 | 0.54 | 0.59 | 0.21 | 21.86 | 40.60 | 0.0026 | 0.0104 | 0.0398 |
| III | 21.46 | 16.99 | 81.38 | 78.54 | 83.01 | 18.62 | 0.6 | 0.63 | 0.26 | 24.64 | 45.76 | 0.0017 | 0.0067 | 0.0258 |
| I | 46.39 | 33.69 | 92.35 | 53.61 | 66.31 | 7.65 | 0.46 | 0.53 | 0.15 | | | | | |
| I-II | 46.39 | 22.61 | 86.39 | 53.61 | 77.39 | 13.61 | 0.46 | 0.59 | 0.21 | | | | | |
| I-III | 46.39 | 16.99 | 81.38 | 53.61 | 83.01 | 18.62 | 0.46 | 0.63 | 0.26 | | | | | |

**Lamella thickener and LOA data using Elkhorn No. 3 seam coal**

| Test Number | Flow Rates | | | | | Kerosene | % Solids | | | | Combustible | Rejection | | Separation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wash Water (ml/min) | Feed (ml/min) | Feed (lb/hr) | Product (ml/min) | Tails (ml/min) | (lb/ton) | Feed (%) | Product (%) | Tails (%) | Yield (%) | Recovery (%) | Ash (%) | Sulphur (%) | Efficiency (%) |
| 0 | 42 | 103 | 0.527 | 33 | 112 | 0 | 3.98 | 8.19 | 1.00 | 78.35 | 96.91 | 43.10 | 6.01 | 40.01 |
| 3 | 41 | 100 | 0.534 | 35 | 106 | 3 | 3.98 | 7.29 | 0.99 | 73.70 | 96.11 | 51.89 | 11.75 | 48.00 |
| 6 | 39 | 100 | 0.547 | 34 | 105 | 6 | 4.07 | 7.41 | 0.98 | 71.28 | 95.37 | 55.34 | 12.71 | 50.71 |
| 9 | 41 | 101 | 0.520 | 34 | 108 | 9 | 3.87 | 6.93 | 0.98 | 70.82 | 95.65 | 56.23 | 9.78 | 51.88 |
| 12 | 42 | 102 | 0.530 | 33 | 111 | 12 | 3.92 | 7.13 | 0.99 | 66.48 | 94.54 | 61.25 | 11.06 | 55.79 |
| 24 | 40 | 103 | 0.504 | 32 | 111 | 24 | 3.72 | 6.81 | 1.04 | 69.85 | 95.16 | 55.61 | 9.88 | 50.77 |
| 48 | 40 | 103 | 0.500 | 33 | 110 | 48 | 3.70 | 6.74 | 1.05 | 68.18 | 94.88 | 57.84 | 12.57 | 52.73 |

**Lamella thickener and LOA data using Elkhorn No. 3 seam coal**

| Test Number | % Ash (adjusted) | | | % Combustible (adj.) | | | % Sulfur (adjusted) | | | Superficial Velocity | | Throughput | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) | Overflow (mm/min) | Plate (mm/min) | Eff. Area (lb/hr/sq.in.) | Actual Area (lb/hr/sq.in.) | Volume (lb/hr/litre) |
| 0 | 46.39 | 33.69 | 92.35 | 53.61 | 66.31 | 7.65 | 0.46 | 0.53 | 0.15 | 22.26 | 41.33 | 0.0031 | 0.0126 | 0.0480 |
| 3 | 46.69 | 30.48 | 92.12 | 53.31 | 69.52 | 7.88 | 0.48 | 0.59 | 0.20 | 21.06 | 39.12 | 0.0031 | 0.0127 | 0.0486 |
| 6 | 47.50 | 29.76 | 91.53 | 52.50 | 70.24 | 8.47 | 0.46 | 0.58 | 0.19 | 20.87 | 38.75 | 0.0032 | 0.0130 | 0.0498 |
| 9 | 47.86 | 29.58 | 92.22 | 52.14 | 70.42 | 7.78 | 0.45 | 0.56 | 0.16 | 21.46 | 39.86 | 0.0031 | 0.0124 | 0.0473 |
| 12 | 50.30 | 29.32 | 91.91 | 49.70 | 70.68 | 8.09 | 0.41 | 0.56 | 0.13 | 22.06 | 40.97 | 0.0031 | 0.0126 | 0.0482 |
| 24 | 49.86 | 31.69 | 91.95 | 50.14 | 68.31 | 8.05 | 0.41 | 0.52 | 0.14 | 22.06 | 40.97 | 0.0030 | 0.0120 | 0.0459 |
| 48 | 50.64 | 31.31 | 92.06 | 49.36 | 68.69 | 7.94 | 0.40 | 0.51 | 0.16 | 21.86 | 40.60 | 0.0029 | 0.0119 | 0.0454 |

### Conventional thickener parametric test data using Elkhorn No. 3 seam coal

| Test Number | Flow Rates | | | | % Solids | | | Yield (%) | Combustible Recovery (%) | Ash Rejection (%) | Separation Efficiency (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feed (ml/min) | Feed (lb/hr) | Product (ml/min) | Tails (ml/min) | Feed (%) | Product (%) | Tails (%) | | | | |
| 1 | 46 | 0.197 | 10 | 36 | 3.00 | 6.78 | 0.68 | 86.29 | 97.92 | 24.61 | 22.53 |
| 2 | 50 | 0.131 | 35 | 15 | 1.98 | 1.81 | 0.29 | 104.05 | 100.68 | -7.72 | -7.05 |
| 3 | 49 | 0.269 | 37 | 12 | 3.98 | 3.34 | | 66.12 | 54.97 | 23.31 | -21.73 |
| 4 | 196 | 0.520 | 76 | 120 | 2.00 | 2.88 | 0.73 | 84.94 | 96.66 | 27.77 | 24.44 |
| 5 | 151 | 0.582 | 64 | 87 | 2.94 | 5.01 | 1.16 | 78.52 | 95.43 | 38.75 | 34.18 |
| 6 | 100 | 0.264 | 46 | 54 | 1.99 | 4.46 | 0.63 | 83.90 | 97.07 | 30.54 | 27.61 |
| 7 | 100 | 0.400 | 34 | 66 | 2.98 | 4.10 | 1.11 | 84.82 | 96.98 | 26.68 | 23.67 |
| 8 | 100 | 0.523 | 60 | 40 | 3.94 | 6.18 | | 88.59 | 98.46 | 22.16 | 20.63 |
| 9 | 152 | 0.794 | 124 | 28 | | 5.54 | 1.12 | 86.82 | 98.19 | 24.73 | 22.92 |

### Conventional thickener parametric test data using Elkhorn No. 3 seam coal

| Test Number | % Ash | | | % Combustible | | | Superficial Velocity (mm/min) | Throughput | |
|---|---|---|---|---|---|---|---|---|---|
| | Feed (%) | Product (%) | Tails (%) | Feed (%) | Product (%) | Tails (%) | | Area (lb/hr/sq.in.) | Volume (lb/hr/litre) |
| 1 | 51.64 | 45.12 | 92.67 | 48.36 | 54.88 | 7.33 | 6.44 | 0.0023 | 0.0188 |
| 2 | 47.92 | 49.61 | 91.32 | 52.08 | 50.39 | 8.68 | 2.68 | 0.0015 | 0.0125 |
| 3 | 51.32 | 59.53 | 35.30 | 48.68 | 40.47 | 64.70 | 2.15 | 0.0031 | 0.0256 |
| 4 | 47.97 | 40.79 | 88.47 | 52.03 | 59.21 | 11.53 | 21.47 | 0.0060 | 0.0495 |
| 5 | 49.46 | 38.58 | 89.24 | 50.54 | 61.42 | 10.76 | 15.56 | 0.0067 | 0.0554 |
| 6 | 47.71 | 39.50 | 90.48 | 52.29 | 60.50 | 9.52 | 9.66 | 0.0030 | 0.0252 |
| 7 | 51.40 | 44.43 | 90.34 | 48.60 | 55.57 | 9.66 | 11.81 | 0.0046 | 0.0381 |
| 8 | 47.87 | 42.06 | 92.97 | 52.13 | 57.94 | 7.03 | 7.16 | 0.0060 | 0.0498 |
| 9 | 49.60 | 43.00 | 93.07 | 50.40 | 57.00 | 6.93 | 5.01 | 0.0091 | 0.0756 |

## STATISTICAL DATA ANALYSIS

Description: Conventional Thickener
Coal Sample: Elkhorn No. 3 (50% Ash)
Response: Combustible Recovery (%)

**Design Summary**

| FAC | FACTOR | UNITS | -1 LEVEL | +1 LEVEL |
|---|---|---|---|---|
| A | Feed Rate | (ml/min) | 50.000 | 150.000 |
| B | Feed % Solids | (%) | 2.000 | 4.000 |

**Analysis Summary**

Sequential Model Sum of Squares

| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROB > F |
|---|---|---|---|---|---|
| MEAN | 77722.0 | 1 | 77722.0 | | |
| Linear | 439.3 | 2 | 219.6 | 1.100 | 0.3919 |
| Quadratic | 677.6 | 3 | 225.9 | 1.301 | 0.4170 |
| Cubic | 521.0 | 3 | 173.7 | | |
| RESIDUAL | 0.0 | 0 | | | |
| TOTAL | 79359.9 | 9 | | | |

ANOVA Summary Statistics of Models Fit

| SOURCE | UNALIASED TERMS | RESID DF | ROOT MSE | R-SQR | ADJ R-SQR | PRESS |
|---|---|---|---|---|---|---|
| Linear | 3 | 6 | 14.13 | 0.2682 | 0.0243 | 3331.51 |
| Quadratic | 6 | 3 | 13.18 | 0.6819 | 0.1518 | 10547.20 |
| Cubic | 9 | 0 | | | | |

```
ANOVA for Linear Model (Combustible Recovery / Conventional / Elkhorn)

                  SUM OF                    MEAN          F
   SOURCE        SQUARES     DF            SQUARE       VALUE     PROB > F

    MODEL          439.3      2            219.65       1.100      0.3919
  RESIDUAL        1198.6      6            199.76
 COR TOTAL        1637.9      8

  ROOT MSE         14.13                R-SQUARED     0.2682
  DEP MEAN         92.93            ADJ R-SQUARED     0.0243
      C.V.         15.21%

Predicted Residual Sum of Squares (PRESS) = 3331.5


 INDEPENDENT   COEFFICIENT             STANDARD    t FOR H0
  VARIABLE      ESTIMATE       DF       ERROR    COEFFICIENT=0   PROB > |t|

  Intercept        92.55        1        4.73        19.55
  A                 3.91        1        4.77       0.8194           0.4439
  B                -6.55        1        5.81       -1.126           0.3032

Final Equation in Terms of Coded Factors:

       Combustible Recovery = 92.55 + (3.91 * A) - (6.55 * B)

Final Equation in Terms of Actual Factors:

       Combustible Recovery = 104.37 + (7.811E-02 * Feed Rate)
                                     - (6.5459 * Feed % Solids)

Obs         ACTUAL     PREDICTED                          STUDENT  COOK'S  OUTLIER
Ord          VALUE        VALUE     RESIDUAL     LEVER     RESID    DIST      t

  2         100.68        95.19         5.49     0.455     0.526   0.077    0.492
  6          97.07        99.09        -2.02     0.285    -0.169   0.004   -0.155
  4          96.66       106.59        -9.93     0.596    -1.105   0.600   -1.130
  1          97.92        88.33         9.59     0.269     0.794   0.077    0.766
  7          96.98        92.55         4.43     0.112     0.333   0.005    0.307
  5          95.43        96.53        -1.10     0.208    -0.087   0.001   -0.080
  3          54.97        82.02       -27.05     0.384    -2.439   1.237  -23.877
  8          98.46        86.00        12.46     0.278     1.037   0.138    1.045
  9          98.19        90.06         8.13     0.413     0.751   0.132    0.720
```

**ANOVA for Quadratic Model** (Combustible Rec. / Conventional / Elkhorn)

```
                     SUM OF                       MEAN            F
       SOURCE       SQUARES       DF             SQUARE         VALUE      PROB > F

        MODEL        1116.9        5             223.39         1.286       0.4451
     RESIDUAL         521.0        3             173.65
    COR TOTAL        1637.9        8

     ROOT MSE         13.18                   R-SQUARED        0.6819
     DEP MEAN         92.93               ADJ R-SQUARED        0.1518
         C.V.         14.18%

Predicted Residual Sum of Squares (PRESS) = 10547.2


  INDEPENDENT    COEFFICIENT               STANDARD    t FOR H0
   VARIABLE       ESTIMATE        DF        ERROR    COEFFICIENT=0    PROB > |t|

   Intercept         97.31         1         8.89         10.94
   A                  6.98         1         5.21         1.340         0.2728
   B                 -7.83         1         5.73        -1.366         0.2652
   A2                -0.53         1         6.19     -8.63E-02         0.9367
   B2                -5.34         1         9.49       -0.5623         0.6132
   AB                 9.69         1         6.48         1.496         0.2316

Final Equation in Terms of Coded Factors:

     Combustible Recovery = 97.31 + (6.98 * A) - (7.83 * B)
                          - (0.53 * A2) - (5.34 * B2) + (9.69 * AB)

Final Equation in Terms of Actual Factors:

     Combustible Recovery = 114.79 - (0.39896 * Feed Rate)
                          + (4.8218 * Feed % Solids)
                          - (2.137E-04 * Feed Rate^2)
                          - (5.3379 * Feed % Solids^2)
                          + (0.19374 * Feed Rate * Feed % Solids)

Obs        ACTUAL     PREDICTED                          STUDENT  COOK'S  OUTLIER
Ord         VALUE       VALUE       RESIDUAL    LEVER      RESID    DIST        t

  2        100.68      101.98          -1.30    0.785     -0.213   0.028   -0.175
  6         97.07       99.80          -2.73    0.711     -0.385   0.061   -0.323
  4         96.66       92.63           4.03    0.951      1.380   6.149    1.866
  1         97.92       89.15           8.77    0.624      1.086   0.326    1.138
  7         96.98       97.31          -0.33    0.455     -0.034   0.000   -0.028
  5         95.43      103.87          -8.44    0.471     -0.881   0.115   -0.835
  3         54.97       66.59         -11.62    0.740     -1.730   1.421  -26.767
  8         98.46       84.14          14.32    0.444      1.458   0.283    2.204
  9         98.19      100.89          -2.70    0.818     -0.481   0.173   -0.409
```

## STATISTICAL DATA ANALYSIS

| | |
|---|---|
| Description: | Conventional Thickener |
| Coal Sample: | Elkhorn No. 3 (50% Ash) |
| Response: | Combustible Recovery (%)(Minus Test Number 3) |

**Design Summary**

| FAC | FACTOR | UNITS | -1 LEVEL | +1 LEVEL |
|---|---|---|---|---|
| A | Feed Rate | (ml/min) | 50.000 | 150.000 |
| B | Feed % Solids | (%) | 2.000 | 4.000 |

**Analysis Summary** (Minus Test Number 3)

Sequential Model Sum of Squares

| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROB > F |
|---|---|---|---|---|---|
| MEAN | 76321.29 | 1 | 76321.29 | | |
| Linear | 6.47 | 2 | 3.24 | 1.552 | 0.2990 |
| Quadratic | 8.97 | 3 | 2.99 | 4.124 | 0.2013 |
| Cubic | 1.45 | 2 | 0.73 | | |
| RESIDUAL | 0.00 | 0 | | | |
| TOTAL | 76338.18 | 8 | | | |

ANOVA Summary Statistics of Models Fit

| SOURCE | UNALIASED TERMS | RESID DF | ROOT MSE | R-SQR | ADJ R-SQR | PRESS |
|---|---|---|---|---|---|---|
| Linear | 3 | 5 | 1.444 | 0.3831 | 0.1363 | 30.289 |
| Quadratic | 6 | 2 | 0.852 | 0.9141 | 0.6995 | 72.457 |
| Cubic | 8 | 0 | | | | |

**ANOVA for Linear Model** (Combustible Recovery / Conventional / Elkhorn)
**Minus Test Number 3**

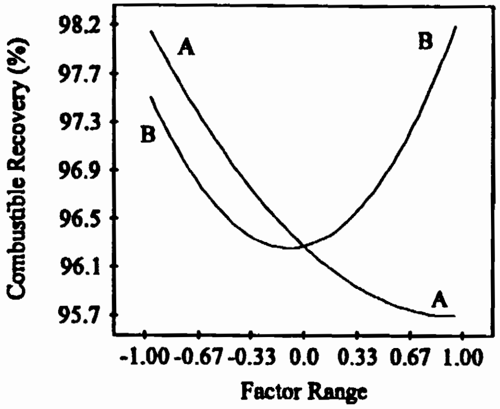
```
                     SUM OF                    MEAN           F
    SOURCE          SQUARES      DF           SQUARE        VALUE     PROB > F

     MODEL            6.47        2            3.235        1.552       0.2990
  RESIDUAL           10.42        5            2.084
 COR TOTAL           16.89        7

  ROOT MSE           1.444                 R-SQUARED      0.3831
  DEP MEAN          97.674             ADJ R-SQUARED      0.1363
      C.V.            1.48%

Predicted Residual Sum of Squares (PRESS) = 30.29


 INDEPENDENT    COEFFICIENT              STANDARD     t FOR H0
  VARIABLE        ESTIMATE       DF       ERROR    COEFFICIENT=0   PROB > |t|

  Intercept        97.901         1       0.533        183.7
  A                -0.929         1       0.527       -1.762          0.1384
  B                 0.050         1       0.655     7.70E-02          0.9416

Final Equation in Terms of Coded Factors:

     Combustible Recovery = 97.901 - (0.929 * A) + (0.050 * B)

Final Equation in Terms of Actual Factors:

     Combustible Recovery = 99.607 - (1.858E-02 * Feed Rate)
                          + (5.042E-02 * Feed % Solids)

Obs       ACTUAL     PREDICTED                            STUDENT COOK'S OUTLIER
Ord        VALUE       VALUE      RESIDUAL     LEVER       RESID    DIST       t

  2      100.680      98.779       1.901     0.466     1.801    0.943    2.719
  6       97.070      97.850      -0.780     0.286    -0.640    0.055   -0.597
  4       96.660      96.067       0.593     0.689     0.737    0.401    0.698
  1       97.920      98.904      -0.984     0.363    -0.854    0.138   -0.826
  7       96.980      97.901      -0.921     0.136    -0.686    0.025   -0.645
  5       95.430      96.953      -1.523     0.208    -1.186    0.123   -1.251
  8       98.460      97.951       0.509     0.398     0.454    0.046    0.415
  9       98.190      96.985       1.205     0.454     1.129    0.353    1.170
```

**ANOVA for Quadratic Model** (Combustible Rec. / Conventional / Elkhorn)
**Minus Test Number 3**

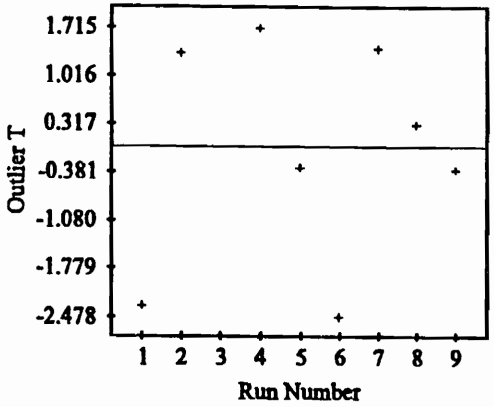
```
                      SUM OF                    MEAN          F
     SOURCE          SQUARES        DF         SQUARE       VALUE      PROB > F

      MODEL           15.44         5           3.088       4.259        0.2010
   RESIDUAL            1.45         2           0.725
  COR TOTAL           16.89         7

   ROOT MSE           0.852                 R-SQUARED      0.9141
   DEP MEAN          97.674             ADJ R-SQUARED      0.6995
       C.V.            0.87%

Predicted Residual Sum of Squares (PRESS) = 72.46


  INDEPENDENT    COEFFICIENT               STANDARD     t FOR H0
   VARIABLE        ESTIMATE        DF       ERROR    COEFFICIENT=0   PROB > |t|

   Intercept         96.253        1       0.576         167.1
   A                 -1.281        1       0.457        -2.807         0.1069
   B                  0.322        1       0.479        0.6710         0.5714
   A2                 0.677        1       0.403         1.680         0.2349
   B2                 1.730        1       0.668         2.590         0.1223
   AB                 0.616        1       0.538         1.144         0.3710

Final Equation in Terms of Coded Factors:

     Combustible Recovery = 96.253 - (1.281 * A) + (0.322 * B)
                          + (0.677 * A2) + (1.730 * B2) + (0.616 * AB)

Final Equation in Terms of Actual Factors:

     Combustible Recovery = 119.825 - (0.11673 * Feed Rate)
                          - (11.291 * Feed % Solids)
                          + (2.707E-04 * Feed Rate^2)
                          + (1.7300 * Feed % Solids^2)
                          + (1.232E-02 * Feed Rate * Feed % Solids)

Obs         ACTUAL      PREDICTED                           STUDENT  COOK'S  OUTLIER
Ord          VALUE        VALUE        RESIDUAL    LEVER     RESID    DIST       t

  2        100.680      100.236         0.444     0.791     1.142    0.823    1.368
  6         97.070       97.662        -0.592     0.719    -1.311    0.735   -2.478
  4         96.660       96.513         0.147     0.980     1.222   12.141    1.715
  1         97.920       98.426        -0.506     0.790    -1.298    1.055   -2.308
  7         96.980       96.253         0.727     0.457     1.159    0.189    1.429
  5         95.430       95.650        -0.220     0.601    -0.409    0.042   -0.303
  8         98.460       98.305         0.155     0.831     0.442    0.160    0.329
  9         98.190       98.345        -0.155     0.831    -0.442    0.160   -0.329
```

Response:
Combustible Recovery (%)

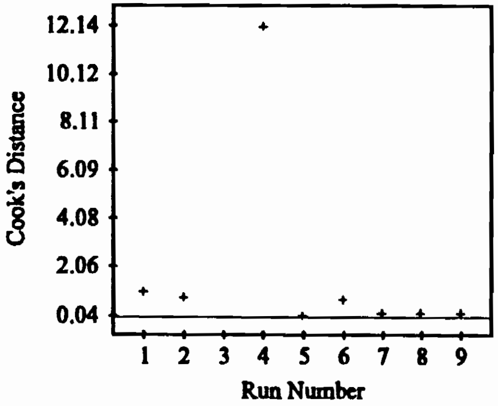
Coded variables:
A = Feed Rate
B = Feed Percent Solids



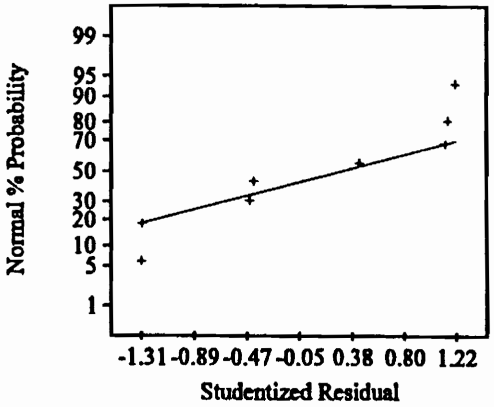
Response:
Combustible Recovery (%)



Response:
Combustible Recovery (%)



Response:
Combustible Recovery (%)



## STATISTICAL DATA ANALYSIS

| | |
|---|---|
| Description: | Conventional Thickener |
| Coal Sample: | Elkhorn No. 3 (50% Ash) |
| Response: | Separation Efficiency (%) (Minus Tests Number 3) |

**Design Summary**

| FAC | FACTOR | UNITS | -1 LEVEL | +1 LEVEL |
|---|---|---|---|---|
| A | Feed Rate | (ml/min) | 50.000 | 150.000 |
| B | Feed % Solids | (%) | 2.000 | 4.000 |

**Analysis Summary** (Minus Test Number 3)

Sequential Model Sum of Squares

| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROB > F |
|---|---|---|---|---|---|
| MEAN | 3567.2 | 1 | 3567.2 | | |
| Linear | 371.2 | 2 | 185.6 | 1.410 | 0.3268 |
| Quadratic | 423.8 | 3 | 141.3 | 1.206 | 0.4832 |
| Cubic | 234.2 | 2 | 117.1 | | |
| RESIDUAL | 0.0 | 0 | | | |
| TOTAL | 4596.4 | 8 | | | |

ANOVA Summary Statistics of Models Fit

| SOURCE | UNALIASED TERMS | RESID DF | ROOT MSE | R-SQR | ADJ R-SQR | PRESS |
|---|---|---|---|---|---|---|
| Linear | 3 | 5 | 11.47 | 0.3607 | 0.1049 | 1982.21 |
| Quadratic | 6 | 2 | 10.82 | 0.7724 | 0.2035 | 9963.13 |
| Cubic | 8 | 0 | | | | |

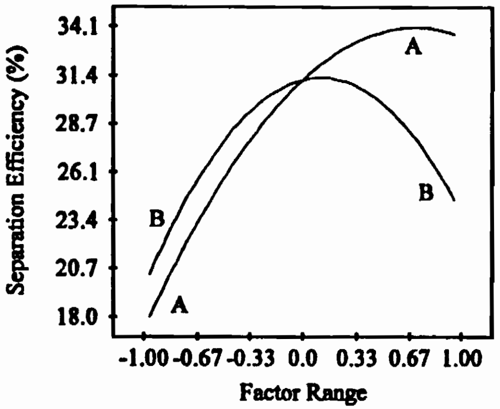
```
ANOVA for Linear Model (Separation Efficiency / Conventional / Elkhorn)
Minus Test Number 3

                    SUM OF                     MEAN          F
   SOURCE          SQUARES        DF          SQUARE        VALUE     PROB > F

    MODEL           371.2          2          185.61        1.410      0.3268
  RESIDUAL          658.0          5          131.60
 COR TOTAL         1029.2          7

  ROOT MSE          11.47                   R-SQUARED      0.3607
  DEP MEAN          21.12               ADJ R-SQUARED      0.1049
      C.V.          54.33%

Predicted Residual Sum of Squares (PRESS) = 1982.2

 INDEPENDENT   COEFFICIENT                STANDARD     t FOR H0
  VARIABLE       ESTIMATE         DF       ERROR    COEFFICIENT=0   PROB > |t|

  Intercept         20.08          1        4.24          4.741
  A                  6.24          1        4.19          1.489          0.1966
  B                  3.58          1        5.20          0.6872         0.5225

Final Equation in Terms of Coded Factors:

     Separation Efficiency = 20.08 + (6.24 * A) + (3.58 * B)

Final Equation in Terms of Actual Factors:

     Separation Efficiency = - 3.13 + (0.12479 * Feed Rate)
                             + (3.5765 * Feed % Solids)

Obs         ACTUAL       PREDICTED                         STUDENT COOK'S OUTLIER
Ord          VALUE         VALUE        RESIDUAL    LEVER    RESID    DIST       t

  2          -7.05         10.27         -17.32    0.466   -2.065    1.239   -4.813
  6          27.61         16.50          11.11    0.286    1.146    0.175    1.193
  4          24.44         28.48          -4.04    0.689   -0.632    0.295   -0.590
  1          22.53         13.34           9.19    0.363    1.003    0.191    1.004
  7          23.67         20.08           3.59    0.136    0.337    0.006    0.305
  5          34.18         26.45           7.73    0.208    0.758    0.050    0.720
  8          20.63         23.66          -3.03    0.398   -0.340    0.026   -0.308
  9          22.92         30.15          -7.23    0.454   -0.852    0.201   -0.825
```

**ANOVA for Quadratic Model** (Separation Eff. / Conventional / Elkhorn)
**Minus Test Number 3**

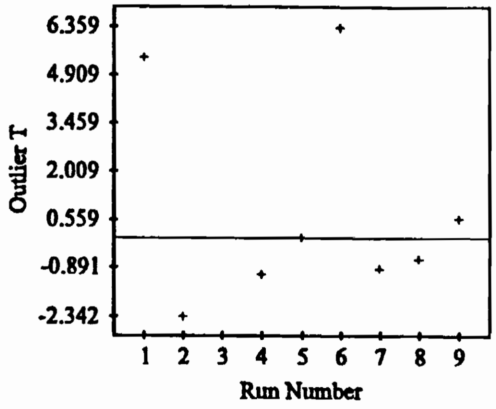
```
                   SUM OF                      MEAN           F
    SOURCE        SQUARES       DF            SQUARE        VALUE      PROB > F

     MODEL          795.0        5            159.00        1.358        0.4756
  RESIDUAL          234.2        2            117.11
 COR TOTAL         1029.2        7

  ROOT MSE          10.82                   R-SQUARED      0.7724
  DEP MEAN          21.12               ADJ R-SQUARED      0.2035
      C.V.          51.25%

Predicted Residual Sum of Squares (PRESS) = 9963.1


 INDEPENDENT   COEFFICIENT                STANDARD     t FOR H0
  VARIABLE       ESTIMATE       DF        ERROR    COEFFICIENT=0   PROB > |t|

  Intercept         31.21        1          7.32         4.264
  A                  8.18        1          5.80         1.410        0.2939
  B                  2.15        1          6.09        0.3527        0.7580
  A2                -5.78        1          5.12        -1.129        0.3760
  B2                -9.46        1          8.49        -1.114        0.3811
  AB                -6.26        1          6.84       -0.9144        0.4571

Final Equation in Terms of Coded Factors:

     Separation Efficiency = 31.21 + (8.18 * A) + (2.15 * B)
                             - (5.78 * A2) - (9.46 * B2) - (6.26 * AB)

Final Equation in Terms of Actual Factors:

     Separation Efficiency = - 137.40 + (1.0015 * Feed Rate)
                             + (71.415 * Feed % Solids)
                             - (2.312E-03 * Feed Rate^2)
                             - (9.4585 * Feed % Solids^2)
                             - (0.12515 * Feed Rate * Feed % Solids)

Obs       ACTUAL     PREDICTED                         STUDENT COOK'S OUTLIER
Ord        VALUE        VALUE     RESIDUAL    LEVER     RESID   DIST       t
  2        -7.05        -0.62        -6.43    0.791    -1.301   1.068  -2.342
  6        27.61        19.60         8.01    0.719     1.397   0.834   6.359
  4        24.44        26.02        -1.58    0.980    -1.029   8.620  -1.061
  1        22.53        15.63         6.90    0.790     1.391   1.213   5.460
  7        23.67        31.21        -7.54    0.457    -0.946   0.126  -0.899
  5        34.18        33.54         0.64    0.601     0.093   0.002   0.066
  8        20.63        23.90        -3.27    0.831    -0.734   0.440  -0.607
  9        22.92        19.65         3.27    0.831     0.734   0.440   0.607
```

**Response:**
**Separation Efficiency (%)**

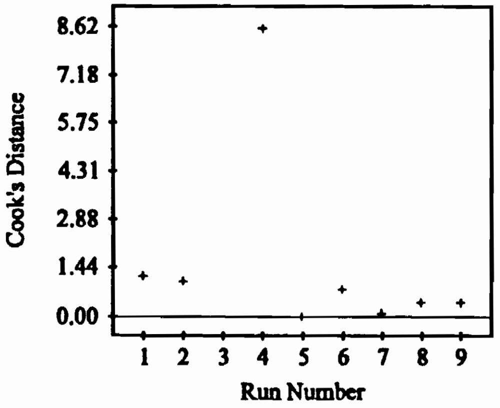
**Coded variables:**
**A = Feed Rate**
**B = Feed Percent Solids**



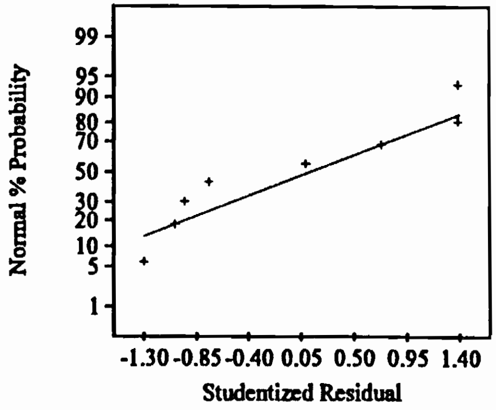
**Response:**
**Separation Efficiency (%)**



**Response:**
**Separation Efficiency (%)**



**Response:**
**Separation Efficiency (%)**



## STATISTICAL DATA ANALYSIS

Description: Conventional Thickener
Coal Sample: Elkhorn No. 3 (50% Ash)
Response: Ash Rejection (%) (Minus Test Number 3)

**Design Summary**

| FAC | FACTOR | UNITS | -1 LEVEL | +1 LEVEL |
|---|---|---|---|---|
| A | Feed Rate | (ml/min) | 50.000 | 150.000 |
| B | Feed % Solids | (%) | 2.000 | 4.000 |

**Analysis Summary** (Minus Test Number 3)

Sequential Model Sum of Squares

| SOURCE | SUM OF SQUARES | DF | MEAN SQUARE | F VALUE | PROB > F |
|---|---|---|---|---|---|
| MEAN | 4395.5 | 1 | 4395.5 | | |
| Linear | 464.8 | 2 | 232.4 | 1.409 | 0.3271 |
| Quadratic | 553.1 | 3 | 184.4 | 1.357 | 0.4509 |
| Cubic | 271.7 | 2 | 135.9 | | |
| RESIDUAL | 0.0 | 0 | | | |
| TOTAL | 5685.1 | 8 | | | |

ANOVA Summary Statistics of Models Fit

| SOURCE | UNALIASED TERMS | RESID DF | ROOT MSE | R-SQR | ADJ R-SQR | PRESS |
|---|---|---|---|---|---|---|
| Linear | 3 | 5 | 12.84 | 0.3604 | 0.1046 | 2483.71 |
| Quadratic | 6 | 2 | 11.66 | 0.7893 | 0.2626 | 11717.66 |
| Cubic | 8 | 0 | | | | |

**ANOVA for Linear Model** (Ash Rejection / Conventional / Elkhorn)
**Minus Test Number 3**

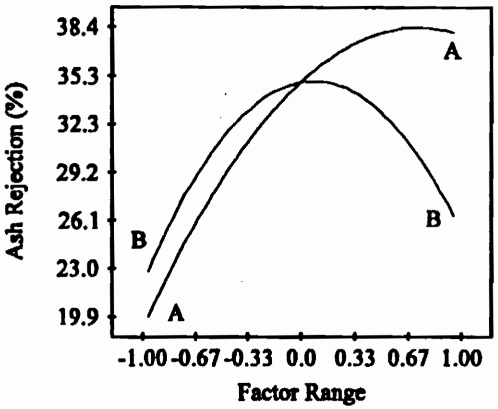
```
                        SUM OF                      MEAN          F
       SOURCE          SQUARES          DF         SQUARE       VALUE       PROB > F

        MODEL            464.8           2          232.42       1.409        0.3271
     RESIDUAL            824.8           5          164.96
    COR TOTAL           1289.7           7

     ROOT MSE            12.84                   R-SQUARED      0.3604
     DEP MEAN            23.44               ADJ R-SQUARED      0.1046
         C.V.            54.79%

Predicted Residual Sum of Squares (PRESS) = 2483.7


 INDEPENDENT    COEFFICIENT                STANDARD     t FOR H0
  VARIABLE        ESTIMATE          DF      ERROR    COEFFICIENT=0   PROB > |t|

  Intercept          22.18           1       4.74        4.677
  A                   7.17           1       4.69        1.528         0.1872
  B                   3.52           1       5.83        0.6047        0.5718

Final Equation in Terms of Coded Factors:

    Ash Rejection = 22.18 + (7.17 * A) + (3.52 * B)

Final Equation in Terms of Actual Factors:

    Ash Rejection = - 2.72 + (0.14330 * Feed Rate)
                  + (3.5238 * Feed % Solids)

Obs          ACTUAL     PREDICTED                       STUDENT  COOK'S  OUTLIER
Ord          VALUE        VALUE       RESIDUAL   LEVER    RESID    DIST       t
  2          -7.72        11.49        -19.21    0.466   -2.046   1.216   -4.537
  6          30.54        18.65         11.89    0.286    1.095   0.160    1.124
  4          27.77        32.41         -4.64    0.689   -0.648   0.310   -0.606
  1          24.61        14.44         10.17    0.363    0.992   0.187    0.990
  7          26.68        22.18          4.50    0.136    0.377   0.007    0.342
  5          38.75        29.49          9.26    0.208    0.810   0.057    0.778
  8          22.16        25.70         -3.54    0.398   -0.356   0.028   -0.322
  9          24.73        33.15         -8.42    0.454   -0.887   0.218   -0.865
```

**ANOVA for Quadratic Model** (Ash Rejection / Conventional / Elkhorn)
**Minus Test Number 3**

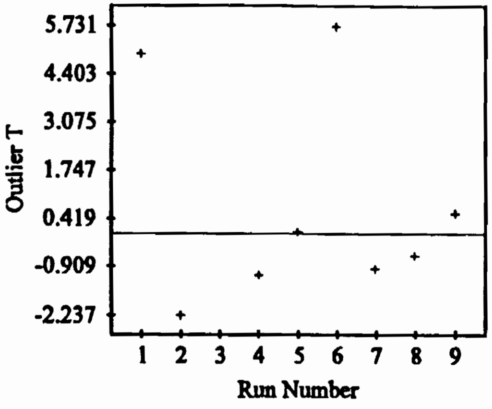
```
                    SUM OF                      MEAN          F
     SOURCE        SQUARES       DF            SQUARE        VALUE      PROB > F

      MODEL         1018.0        5            203.59        1.499        0.4465
   RESIDUAL          271.7        2            135.86
  COR TOTAL         1289.7        7

   ROOT MSE          11.66                 R-SQUARED        0.7893
   DEP MEAN          23.44             ADJ R-SQUARED        0.2626
       C.V.          49.73%

Predicted Residual Sum of Squares (PRESS) = 11717.7


  INDEPENDENT   COEFFICIENT               STANDARD     t FOR H0
   VARIABLE       ESTIMATE       DF        ERROR    COEFFICIENT=0   PROB > |t|

   Intercept          34.95       1          7.88          4.433
   A                   9.46       1          6.25          1.514        0.2691
   B                   1.82       1          6.56         0.2778        0.8073
   A2                 -6.45       1          5.51         -1.171        0.3623
   B2                -11.19       1          9.14         -1.224        0.3456
   AB                 -6.86       1          7.37        -0.9313        0.4500

Final Equation in Terms of Coded Factors:

     Ash Rejection = 34.95 + (9.46 * A) + (1.82 * B) - (6.45 * A2)
                     - (11.19 * B2) - (6.86 * AB)

Final Equation in Terms of Actual Factors:

     Ash Rejection = - 157.15 + (1.1174 * Feed Rate)
                     + (82.688 * Feed % Solids)
                     - (2.581E-03 * Feed Rate^2)
                     - (11.189 * Feed % Solids^2)
                     - (0.13729 * Feed Rate * Feed % Solids)

Obs       ACTUAL     PREDICTED                         STUDENT COOK'S OUTLIER
Ord        VALUE       VALUE       RESIDUAL    LEVER    RESID    DIST       t
  2        -7.72       -0.84          -6.88    0.791   -1.291   1.053  -2.237
  6        30.54       21.94           8.60    0.719    1.393   0.829   5.731
  4        27.77       29.50          -1.73    0.980   -1.045   8.892  -1.098
  1        24.61       17.20           7.41    0.790    1.387   1.205   4.987
  7        26.68       34.95          -8.27    0.457   -0.963   0.130  -0.930
  5        38.75       37.89           0.86    0.601    0.117   0.003   0.083
  8        22.16       25.58          -3.42    0.831   -0.714   0.416  -0.584
  9        24.73       21.31           3.42    0.831    0.714   0.416   0.584
```

**Response:**
**Ash Rejection (%)**

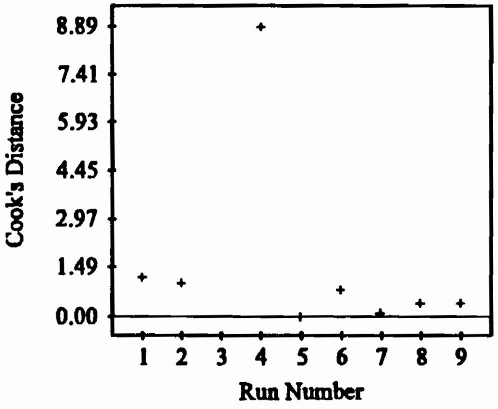
**Coded variables:**
**A = Feed Rate**
**B = Feed Percent Solids**



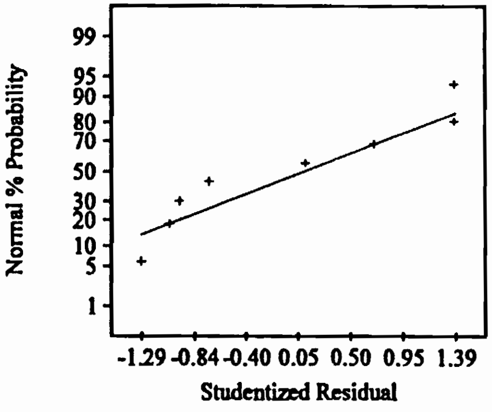
**Response:**
**Ash Rejection (%)**



**Response:**
**Ash Rejection (%)**



**Response:**
**Ash Rejection (%)**



# VITA

Jason R. Pyecha was born during 1968 in Charleston, South Carolina. One year later his family moved to Raleigh, North Carolina, where his father began his graduate studies at North Carolina State University in Nuclear Engineering. In September of 1978 the family move to Lynchburg, Virginia. While in Lynchburg, Jason was graduated from Brookville High School in the top 10% of his class. He was accepted and enrolled at Virginia Polytechnic Institute and State University in 1986. After being in *General Engineering* for two years, he enrolled in the Mining and Minerals Engineering Department. He was graduated from Virginia Tech in 1991 with a B.S. degree in Mining and Minerals Engineering and a minor in Geology. After obtaining his B.S. degree, Jason entered the graduate program in the Department of Mining and Minerals Engineering at Virginia Tech. Upon completion of his M.S. thesis, he plans to begin his professional career working for Cominco Alaska at the Red Dog Mine Site.

Jason R. Pyecha