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Technical Progress Report

Fourth Quarter

DOE/PC/89909--T3

(July 1, 1990 - September 30, 1990)

DE91 005524

IN-PLANT TESTING OF MICROBUBBLE COLUMN FLOTATION

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Received by OSTI

DEC 31 1990.

Contract Number

DE-AC22-89PC89909

Contracting Officer's Representative

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United States Department of Energy
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P. O. Box 10940
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ABSTRACT

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A project to evaluate the performance of the Virginia Tech Microbubble Column Flotation (MCF) process in an operating coal preparation plant was continued during this past quarter. The project is concerned with the collection of process operating data using a 30-inch diameter column, and using these data to scale-up to a prototype, full-scale plant column. The work is being carried out at the Marrowbone Preparation Plant owned by the Shell Mining Corporation. Work during the past reporting period primarily concentrated on the completion of a parametric study to evaluate the performance of the 30-inch diameter column (Task 2.3 - Detailed Testing). The preliminary results obtained from the parametric study suggest that higher gas flow rates and frother additions appear to have a beneficial effect on separation efficiency. However, under these conditions, a larger wash water flow rate was necessary to offset the increased flow of feed water to the product stream. The parametric testing results indicated that the height of the stabilized froth zone had only a limited impact on the separation efficiency, except under conditions of high feed rates. A more detailed analysis of the response surface data is currently under way. Work in other areas (Task 2.5 - Control Systems and Task 3.3 - Column Testing) is continuing, but has progressed at a slower pace than originally anticipated.

PROJECT OBJECTIVES

The objectives of this project are: (1) to conduct in-plant test work on microbubble column flotation of coal to determine the effects of key operating and design parameters on process performance, (2) to develop and validate reliable scale-up criteria for microbubble column flotation of coal, (3) to develop an instrumentation and control system for smooth operation of the microbubble column flotation process, (4) to obtain sufficient engineering data and cost information to evaluate the technical and economic feasibility

of installing full-scale microbubble flotation columns, and (5) to obtain sufficient product from the column flotation unit to perform small-scale combustion tests if DOE so desires.

PROJECT TASKS

Task 2.3 - Detailed Testing

During the past quarter, data collection associated with the parametric test program developed in Task 2.1 was completed. The standard operating conditions for the parametric testing of the 30-inch column are listed in Table 1. Six key operating variables were examined in the parametric study and included:

- 1) volumetric feed rate,
- 2) wash water rate,
- 3) aeration rate,
- 4) frother dosage,
- 5) collector dosage, and
- 6) froth height.

The test levels for each variable used in the parametric test program are shown in Table 2. A statistical design of experiments was utilized to determine the impact of these variables on column performance. A Box-and-Behnken experimental design was selected for use in the present work. This type of design is well suited for the study of flotation systems since it:

- 1) provides a measure of the contribution of each parameter to the given response,
- 2) allows the influence of joint interactions between the various test parameters to be estimated, and

Table 1. Standard Conditions Used for Parametric Test Plan

Parameter	Setting
Column Diameter	30 inches
Column Length	26 feet
Wash Water Addition Point	
Upper Ring	3 inches above lip
Lower Ring	16.5 inches below lip
Generator Length	2 feet
Generator Diameter	2 inches
Number of Generators	3
Frother Type	Betz 1012
Collector Type	Fuel Oil
Baffles	None

Table 2. Test Levels Utilized in the Parametric Test Program

Parameter	Low	Normal	High
Feed Rate (gpm)	60	100	140
Wash Water Rate (gpm)	20	25	30
Aeration Rate (scfm)	16	16	22
Frother Dosage (lb/ton)	0.5	1.0	1.5
Collector Dosage (lb/ton)	0.5	1.0	1.5
Froth Height (inch)	20	40	60

- 3) minimizes the number of test runs required to complete the test program.

The specific tests required by the Box-and-Behnken design are summarized in Table 3. The statistical design requires that 54 individual flotation tests be conducted in order to quantify the effects of the 6 specified test parameters. The specific test levels utilized in the design were selected using the exploratory test results, which were obtained in the earlier stages of this project, as a guideline. All tests were conducted in random order to minimize experimental bias.

2.3.a Parametric Test Overview

The results obtained from the parametric test work are summarized in Table 4. In order to obtain a consistent set of experimental data, all test values were analyzed and adjusted using a single-node material balance program. In most cases, only minor adjustments to the experimental data were required in order to obtain a consistent set of experimental results. The fact that major data manipulation was not required suggests that the measured assay values were reliable.

Baseline Tests: As indicated in Tables 3 and 4, six replicate "baseline" tests were performed at various times throughout the test program. These replicate tests were required so that the amount of pure experimental error could be assessed. In the present work, the experimental errors consisted of random errors associated with the testing procedure, data collection and sample analysis. The yield and energy recovery data obtained from these replicate tests are plotted in Figure 1. As shown, the variation within the data set for the first four replicate tests is within the range which can be expected for in-plant studies. These differences can be accounted for by the natural variations in the system (e.g., slight changes in the feed material,

Table 3. Parametric Test Plan Utilized in the In-Plant Optimization Studies

Test No.	Feed Rate	Wash Water Rate	Aeration Rate	Frother Dosage	Collector Dosage	Froth Height
1	1	0	-1	0	0	-1
2	0	-1	0	0	-1	-1
3	0	0	1	1	0	1
4	-1	0	0	-1	1	0
5	1	1	0	-1	0	0
6	0	-1	0	0	1	-1
7	0	0	1	1	0	-1
8	0	0	0	0	0	0
9	-1	1	0	-1	0	0
10	0	0	-1	-1	0	1
11	0	0	-1	-1	0	-1
12	-1	0	1	0	0	1
13	0	1	1	0	1	0
14	-1	-1	0	1	0	0
15	1	-1	0	1	0	0
16	0	-1	-1	0	-1	0
17	1	0	0	1	-1	0
18	-1	0	-1	0	0	1
19	0	0	0	0	0	0
20	0	0	0	0	0	0
21	-1	0	1	0	0	-1
22	0	0	0	0	0	0
23	-1	0	0	1	1	0
24	1	0	1	0	0	-1
25	0	1	0	0	1	-1
26	0	0	0	0	0	0
27	0	-1	1	0	-1	0
28	0	1	-1	0	1	0
29	0	-1	-1	0	1	0
30	0	-1	0	0	0	1
31	1	0	0	-1	1	0
32	0	0	1	-1	0	1

Table 3. (Continued)

Test No.	Feed Rate	Wash Water Rate	Aeration Rate	Frother Dosage	Collector Dosage	Froth Height
33	-1	1	0	1	0	0
34	-1	0	0	1	-1	0
35	0	-1	0	0	-1	1
36	0	0	0	0	0	0
37	0	1	0	0	-1	1
38	1	0	1	0	0	1
39	0	1	1	0	-1	0
40	0	0	1	-1	0	-1
41	0	1	-1	0	-1	0
42	-1	0	0	-1	-1	0
43	0	0	-1	1	0	-1
44	1	1	0	1	0	0
45	1	0	-1	0	0	1
46	0	-1	1	0	1	0
47	-1	0	-1	0	0	-1
48	0	1	0	0	-1	-1
49	1	-1	0	-1	0	0
50	1	0	0	-1	-1	0
51	1	0	0	1	1	0
52	0	0	-1	1	0	1
53	0	1	0	0	1	1
54	-1	-1	0	-1	0	0

Table 4. Test Results Obtained during the Parametric Testing

ID	Feed Ash	Prod Ash	Tail Ash	Feed Sulfur	Product Sulfur	Reject Sulfur
42	61.03	9.46	74.04	0.21	0.50	0.14
33	59.97	13.23	79.92	0.21	0.45	0.11
24	60.41	8.70	72.78	0.21	0.47	0.15
29	61.50	7.85	76.66	0.25	0.50	0.18
4	61.74	6.93	70.28	0.25	0.47	0.21
35	63.29	13.22	78.15	0.25	0.50	0.18
20	62.34	15.97	73.38	0.21	0.49	0.14
49	60.61	8.99	71.79	0.24	0.45	0.20
3	59.37	6.97	67.18	0.26	0.50	0.22
21	58.92	6.89	62.53	0.23	0.42	0.22
17	58.82	8.19	68.15	0.25	0.46	0.21
47	58.87	10.81	83.51	0.25	0.48	0.13
16	57.79	11.12	79.86	0.28	0.50	0.18
5	59.32	13.74	82.55	0.23	0.46	0.12
6	58.46	9.07	75.44	0.26	0.48	0.18
9	59.26	7.60	74.53	0.24	0.46	0.17
28	56.32	8.95	66.78	0.33	0.48	0.29
45	63.65	8.00	72.31	0.20	0.47	0.16
54	65.68	11.45	72.94	0.19	0.46	0.16
51	62.76	10.78	72.60	0.22	0.47	0.17
43	62.04	27.80	77.35	0.22	0.40	0.14
52	64.17	11.02	70.65	0.20	0.42	0.17
31	63.62	17.68	74.80	0.21	0.43	0.16
44	63.24	23.05	76.53	0.21	0.39	0.16
36	62.45	23.08	79.45	0.23	0.41	0.16
50	64.84	8.46	76.30	0.22	0.54	0.16
11	65.33	12.90	79.14	0.23	0.57	0.14
14	64.00	7.84	75.53	0.25	0.60	0.18
13	64.17	7.89	73.81	0.24	0.61	0.18
39	63.25	11.45	71.11	0.24	0.57	0.19
30	69.37	8.98	78.86	0.20	0.60	0.14
22	65.68	11.34	67.16	0.23	0.55	0.22
7	66.98	9.69	87.30	0.21	0.56	0.09
27	65.76	13.29	88.30	0.26	0.65	0.09
37	65.95	9.53	76.65	0.23	0.57	0.16
53	64.46	8.36	80.42	0.24	0.60	0.14
38	63.94	12.68	72.98	0.22	0.57	0.16
48	62.29	9.53	74.48	0.26	0.57	0.19
12	72.63	17.13	85.09	0.18	0.57	0.10
18	72.76	12.66	82.87	0.17	0.60	0.10
10	72.99	10.61	81.82	0.17	0.61	0.10
25	72.82	9.29	79.23	0.17	0.60	0.12
19	73.24	13.43	84.17	0.17	0.60	0.09
8	73.12	11.25	80.55	0.17	0.59	0.12
46	70.99	8.57	75.17	0.18	0.58	0.15
15	60.79	14.56	79.39	0.25	0.52	0.14
41	58.74	15.45	79.80	0.26	0.53	0.13
34	60.47	11.85	79.28	0.25	0.54	0.13
2	59.99	8.28	72.96	0.25	0.54	0.17
26	63.36	7.71	74.88	0.25	0.57	0.18
32	64.20	9.96	80.31	0.23	0.55	0.14
23	63.93	8.75	80.61	0.23	0.54	0.13
40	63.53	9.73	80.46	0.24	0.56	0.14
1	63.71	10.20	81.93	0.24	0.57	0.13

Table 4. (Continued)

ID	Feed Btu	Prod Btu	Tail Btu	Product Yield	Comb Recovery	Ash Recovery
42	4836	13522	2646	20.15	46.80	3.12
33	4959	12953	1546	29.91	64.84	6.60
24	4962	13564	2904	19.30	44.52	2.78
29	4734	13831	2165	22.03	52.73	2.81
4	4708	13994	3262	13.48	32.79	1.51
35	4383	12930	1847	22.89	54.10	4.78
20	4482	12460	2583	19.23	42.91	4.93
49	4918	13668	3023	17.80	41.13	2.64
3	5090	13934	3771	12.97	29.70	1.52
21	5148	14000	4533	6.49	14.71	0.76
17	5177	13777	3592	15.56	34.69	2.17
47	5211	13348	1040	33.89	73.50	6.22
16	5494	13237	1832	32.11	67.61	6.18
5	5011	12813	1035	33.76	71.59	7.82
6	5246	13566	2385	25.58	56.00	3.97
9	5125	13858	2543	22.81	51.75	2.93
28	5724	13528	4001	18.09	37.70	2.87
45	4298	13758	2825	13.47	34.08	1.69
54	3867	13221	2613	11.81	30.46	2.06
51	4381	13350	2683	15.92	38.13	2.73
43	4644	10540	2007	30.90	58.77	13.85
52	4134	13257	3023	10.87	26.99	1.87
31	4253	12234	2311	19.57	44.29	5.44
44	4372	11306	2079	24.85	52.02	9.06
36	4615	11287	1735	30.16	61.78	11.15
50	4179	13660	2251	16.89	43.98	2.20
11	4132	13000	1796	20.85	52.38	4.12
14	4356	13847	2408	17.03	43.61	2.09
13	4300	13750	2681	14.62	37.59	1.80
39	4205	13211	2838	13.17	31.74	2.38
30	3479	13647	1881	13.58	40.36	1.76
22	4046	13238	3795	2.65	6.85	0.46
7	3881	13082	618	26.18	71.61	3.79
27	4216	12935	470	30.05	76.10	6.07
37	3975	13573	2155	15.94	42.36	2.30
53	4418	14191	1638	22.15	57.11	2.87
38	4491	13078	2975	14.99	36.30	2.97
48	4755	13539	2725	18.77	45.03	2.87
12	2832	12238	721	18.33	55.51	4.32
18	2894	13019	1190	4.40	46.17	2.51
10	2799	13372	1304	12.40	41.04	1.80
25	2874	13556	1796	9.17	30.59	1.17
19	2753	12884	901	15.45	49.98	2.83
8	2684	13245	1417	0.72	35.40	1.65
46	3100	13720	2389	6.28	19.78	0.76
15	4870	12741	1701	28.69	62.52	6.87
41	4978	12625	1258	32.73	67.06	8.61
34	4736	13188	1465	27.90	62.21	5.47
2	4747	13527	2544	20.05	45.97	2.77
26	4434	13651	2526	17.15	43.20	2.09
32	4288	13521	1547	22.90	57.59	3.55
23	4334	13418	1589	23.21	58.72	3.18
40	4464	13493	1623	23.94	59.25	3.67
1	4314	13411	1217	25.40	62.85	4.07

Table 4. (Continued)

ID	Btu Rec	Ash Rej	Sul Rej	Comb SE	Total SE
42	56.32	96.88	53.24	43.68	9.56
33	78.14	93.40	36.71	58.24	14.85
24	52.76	97.22	57.64	41.74	10.40
29	64.36	97.19	56.14	49.92	20.50
4	40.07	98.49	72.68	31.28	12.74
35	67.51	95.22	55.52	49.32	23.03
20	53.46	95.07	53.85	37.98	7.30
49	49.47	97.36	68.50	38.49	17.97
3	35.51	98.48	73.64	28.18	9.15
21	17.65	99.24	89.45	13.95	7.09
17	41.41	97.83	70.93	32.52	12.33
47	86.82	93.78	34.38	67.27	21.20
16	77.35	93.82	43.65	61.43	21.00
5	86.31	92.18	34.56	63.77	20.87
6	66.16	96.03	51.52	52.03	17.68
9	61.69	97.07	54.67	48.82	16.36
28	42.74	97.13	71.98	34.83	14.73
45	43.10	98.31	69.23	32.39	12.33
54	40.37	97.94	74.27	28.40	14.64
51	48.51	97.27	64.97	35.40	13.48
43	70.13	86.15	43.97	44.92	14.10
52	34.85	98.13	75.76	25.12	10.61
31	56.30	94.56	61.28	38.85	17.58
44	64.26	90.94	57.26	42.96	21.52
36	73.75	88.85	48.59	50.63	22.34
50	55.22	97.80	60.44	41.78	15.66
11	65.58	95.88	48.18	48.26	13.76
14	54.15	97.91	59.74	41.52	13.88
13	46.76	98.20	64.03	35.80	10.79
39	41.39	97.62	68.74	29.36	10.12
30	53.26	98.24	60.49	38.60	13.75
22	8.68	99.54	93.12	6.39	1.79
7	88.25	96.21	31.64	67.82	19.88
27	92.19	93.93	24.21	70.02	16.40
37	54.43	97.70	58.48	40.05	12.91
53	71.13	97.13	45.41	54.24	16.54
38	43.66	97.03	61.82	33.33	5.48
48	53.44	97.13	59.36	42.16	12.80
12	79.22	95.68	45.37	51.19	24.59
18	64.77	97.49	50.35	43.66	15.12
10	59.22	98.20	51.53	39.24	10.75
25	43.22	98.83	64.12	29.42	7.34
19	72.31	97.17	44.76	47.15	17.07
8	52.90	98.35	63.02	33.75	15.92
46	27.77	99.24	78.10	19.02	5.87
15	75.06	93.13	39.93	55.65	15.00
41	83.00	91.39	33.64	58.46	16.64
34	77.68	94.53	37.49	56.74	15.17
2	57.14	97.23	54.36	43.20	11.51
26	52.80	97.91	59.65	41.11	12.46
32	72.19	96.45	46.93	54.04	19.12
23	71.85	96.82	43.40	55.54	15.26
40	72.34	96.33	44.37	55.58	16.71
1	78.96	95.93	40.41	58.79	19.37

Figure 1. Yield and energy recovery obtained for each of the replicate tests conducted throughout the parametric testing program.

surges in the reagents pumps or feed rate, inaccuracies in reading metering gauges, etc.). However, Figure 1, also indicates that there is a slight difference in the data from replicate tests 5 and 6 as compared to the first four replicate tests. Two possibilities can be given for this inconsistency. First, during "miners vacation", detailed maintenance was performed on the plant. The maintenance included rebuilding and replacing several of the classifying cyclones in the circuit ahead of the test column. Since the feed material to the column comes from the cyclone overflow, the modifications performed may have changed the characteristics of the feed material. Second, the feed to the column for the first four replicate tests came from a single cyclone. This was done to reduce the variations in the feed material. However, this cyclone was removed during the maintenance program. Therefore, the feed to the fifth and sixth replicate tests came from a bank of cyclones.

Even though additional variation was introduced due to the changes made to the plant, the estimated standard deviations were reasonable. The estimated standard deviations for each of the assays determined in the present work are tabulated in Table 5. The relatively low values indicate that the test data acquired from the parametric testing program are reliable and reproducible. It should be noted that the product assays appear to be the most reliable, while the reject assays are the least dependable. This result was not unexpected since the reject stream contains a low concentration of solids and a disproportionate amount of very fine clay particles.

Performance Overview: The effects of the various operating conditions on the recovery and ash rejection relationship are plotted in Figure 2 for each of the tests conducted in the parametric study. For comparison, both the values of energy (i.e., Btu) recovery and combustible recovery have been plotted in the figure. Although there is a considerable degree of scatter among the various test points, most of the points tend to group along a single grade-

Table 5. Estimated Values of Standard Deviation for Various Assays
Used in the Parametric Test Work

Component	Estimated Standard Deviation
Yield (%)	4.32
Product Ash (%)	1.39
Reject Ash (%)	3.82
Feed Ash (%)	1.70
Product Sulfur (%)	0.15
Reject Sulfur (%)	0.12
Feed Sulfur (%)	0.07
Product Btu	365
Reject Btu	513
Feed Btu	362

Figure 2. Btu recovery and combustible recovery as a function of ash rejection for all the test conditions examined in the parametric study.

recovery curve. The separation curve indicates that very high rejections of ash can be obtained with this coal. At the desired market ash content of 10%, a combustible recovery of over 60% and an ash rejection of more than 95% was attainable using the microbubble flotation column. The high ash rejections can be attributed to the high concentration of fine clays in the feed stream which are readily rejected by the microbubble flotation column process. It should also be noted that, as with most coals, the energy recoveries tend to fall slightly above the combustible recoveries for the same level of ash rejection for this coal.

Figure 3 shows the effects of the various operating conditions on recovery and sulfur rejection. In contrast to the ash rejection, an increase in the rejection of sulfur was only possible by sharply decreasing the recovery. This result was expected since the majority of the sulfur in the feed material is associated with the organic fraction of the coal. The slight upward bend in the recovery-sulfur rejection curve does, however, indicate that flotation produced a significant improvement in coal quality.

The effects of the operating parameters on separation efficiency are demonstrated in Figures 4 and 5. Two different separation efficiencies have been calculated, one based on the separation of combustibles from ash and the other based on the overall separation of energy and sulfur. Combustible efficiency ($SE_{\text{combustible}}$) has been calculated using the expression:

$$SE_{\text{combustible}} = 100 Y \frac{100-A_p}{100-A_f} - \frac{A_r}{A_f} \quad [1]$$

in which Y is the product yield and, A_p , A_r and A_f are the ash content of the product, reject and feed streams, respectively. The energy-sulfur separation efficiency (SE_{overall}) was calculated from:

Figure 3. Btu recovery and combustible recovery as a function of total sulfur rejection for all the test conditions examined in the parametric study.

Figure 4. Combustible separation efficiency and overall separation efficiency as a function of ash rejection for all of the test conditions examined in the parametric study.

Figure 5. Combustible separation efficiency and overall separation efficiency as a function of total sulfur rejection for all of the test conditions examined in the parametric study.

$$SE_{overall} = Y \frac{BTU_p}{BTU_f} + (100-Y) \frac{S_r}{S_f} - 100 \quad [2]$$

in which BTU_p and BTU_f are the respective calorific (BTU) values for the product and reject streams and S_r and S_f are the respective sulfur contents of the reject and feed streams. A more appropriate form of this equation would utilize pyritic sulfur in place of total sulfur, but these assays were not determined for this study.

The results shown in Figure 4 show that most of the separation efficiency values fall along two distinct curves. In both cases, however, a maximum separation efficiency could be obtained at a ash rejection of approximately 95%. This value appears to be independent of whether the separation efficiency was calculated on a combustible basis or overall basis. This level of ash rejection corresponds to the linear portion (above 95% ash rejection) in the grade-recovery curve shown in Figure 2. Therefore, it can be concluded that the maximum separation efficiency occurs at the point just before the large deterioration in yield. In the present work, the maximum separation efficiency-ash rejection relationship appears to be a function of the coal characteristics. As a result, various combinations of operating conditions can be utilized to obtain the same maximum separation efficiency.

Figure 5 shows the separation efficiency values calculated for the various tests as a function of sulfur rejection. As before, most of the points fall along two distinct curves. However, Figure 5 shows that as sulfur rejection increases, both $SE_{combustible}$ and $SE_{overall}$ decreases. This finding indicates that the sulfur is intimately associated with the coal and the only way to reject more sulfur is to simultaneously recover less coal. This phenomenon is demonstrated more clearly in Figure 6 in which sulfur rejection has been plotted as a function of ash rejection. As shown, there is a distinct relationship between ash rejection and sulfur rejection. If both

Figure 6. Relationship between ash rejection and total sulfur rejection for test results obtained during the parametric study.

sulfur and ash were rejected equally, the points should fall along the dashed line shown in the figure. Since this is clearly not the case, this plot once again demonstrates that the ash-bearing components in this coal are more readily rejected than the sulfur-bearing components (i.e., the sulfur is more closely associated with the organic fractions in the coal). The data plotted in Figure 6 suggest that the best separation point for this particular coal would be at an ash rejection of 92% and a sulfur rejection of 30%.

Although the experimental test program was carried out over a wide range of operating conditions, the performance curves shown in Figures 2-5 indicate that most of data points roughly fall along single grade-recovery curves. In fact, a close inspection of the test data indicates that a great deal of the experimental scatter can be attributed to the tests in which the bias flow rate (i.e. flow rate of wash water downward through the stabilized froth phase) was affected by the test variables. It is now believed that when a flotation separation is made over a range of operating conditions, only those parameters that can alter entrainment (i.e., the hydraulic carry-over of feed water into the product launder) are capable of substantially impacting the grade-recovery curve for a given sample. Therefore, the grade-recovery relationship obtained from a properly operated flotation column should be primarily determined by the characteristic nature of the coal sample, i.e., the degree of liberation and hydrophobicity of the various components in the feed stream. It must be stressed, however, that this general conclusion holds true only if the wash water that is added to the column is effective in preventing entrainment. Changes in any of the operational parameters that would produce a change in the bias flow rate could produce a sharp change in the performance of the column.

2.3.b Statistical Data Analysis and Response Surface Development

After all of the flotation data were collected and mass balanced, the

assay values were analyzed using a statistical data analysis program (DESIGN-EXPERT) developed by Stat-Ease of Minneapolis, Minnesota. DESIGN-EXPERT was used to set up the experimental design and to perform all required statistical computations and regression analyses. The overall objective of this effort was to develop an empirical relationship between the various operating parameters (i.e. feed rate, wash water, etc.) and a variety of response variables (i.e. recovery, product ash, separation efficiency, etc.). This goal was accomplished via the following steps:

- 1) Data Collection - The first stage of the experimental design required the set up and collection of the experimental data. The test matrix utilized in the present work is provided in Table 3. The tests were performed in random order and the results were mass-balanced to obtain a consistent set of results prior to proceeding to the next step.
- 2) Data Analysis - After collecting the specified experimental data, the response data were entered into the DESIGN-EXPERT software package. The data analysis was an iterative process since, in most cases, several analyses were required in order to obtain a suitable response surface. When deemed necessary, data transformations were conducted in order to obtain the best possible response surface that described the experimental data. In the present work, either no transformation or log transformations were found to provide the best fits for the experimental data. After selecting an appropriate transformation and response surface, the initial model fitting was performed by the DESIGN-EXPERT software. The available models included standard linear, quadratic and cubic models. After selecting an appropriate model, a variety of statistical routines were executed to identity the goodness-of-fit. For all 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.

- 3) Response Surface Plotting - After a reasonable mathematical model of the desired response was analyzed in light of the various operational parameters, the resultant response surface was plotted using a surface contour program. When combined with the modeling expressions, these plots provide the final product from the parametric test work. The influence of key operating parameters and the joint interaction of various parameters on the process performance can be visualized from the response surface plots.

To date, the following performance indicators have been analyzed using the aforementioned procedures:

- 1) energy recovery,
- 2) product ash,
- 3) total sulfur rejection, and
- 4) combustible separation efficiency.

A summary of the statistical data analysis computations is provided in Appendix 1 for each of the performance indicators. Comparisons between the results predicted by the modeling exercise and results obtained from the experimental measurements are shown in Figures 7-10. In general, very good correlations were obtained between the predictions obtained from the empirical model and the experimental test results.

The response surface plots for each of the four performance indicators are provided in Appendix 2. Because of the relatively large amount of response data contained in Appendices 1 and 2, it is not practical within the context of this report to discuss the wealth of information which can be

Figure 7. Comparison of experimental results with predictions made by the empirical model developed to describe energy recovery as a function of the various operating parameters.

Figure 8. Comparison of experimental results with predictions made by the empirical model developed to describe product ash content as a function of the various operating parameters.

Figure 9. Comparison of experimental results with predictions made by the empirical model developed to describe product sulfur rejection as a function of the various operating parameters.

Figure 10. Comparison of experimental results with predictions made by the empirical model developed to describe separation efficiency as a function of the various operating parameters.

obtained from the parametric test program. However, due to the importance of separation efficiency in establishing the trade-off between grade and recovery, a detailed examination of these response surfaces should provide information as to the appropriate level for each of operating parameters (i.e., gas rate, frother dosage, collector dosage, etc.).

A number of significant trends can be observed from an analysis of the separation efficiency response curves. These include:

- 1) The height of the stabilized froth zone appears to have only a limited impact on the separation efficiency, except under conditions of high feed rates. Under this condition, the separation efficiency drops rapidly due to a sharp decrease in overall recovery.
- 2) Higher gas flow rates appear to have a beneficial effect on separation efficiency for all cases. However, the response surface plots appear to suggest that higher frother dosages may be required, when using the high gas rates, in order to obtain the highest possible separation efficiencies. This result can probably be attributed to the fact that a large amount of bubble surface area is present at the higher gas rates. Higher frother dosages could then be required to maintain a small bubble size.
- 3) Higher gas rates generally dictate the use of larger wash water flow rates. At the higher gas rates, more water is carried into the froth launder by the increased flow of air bubbles. In order to maintain the desired bias flow rate for removing entrained particles, additional wash water must be added to compensate for water lost at higher gas rates.
- 4) Separation efficiency was found to increase at the higher frother

dosages. In general, too low a frother dosage resulted in the production of large bubbles and a loss of recovery (which reduced the separation efficiency). Low frother dosages also contributed to a decrease in froth stability which also adversely affected the flotation recovery. On the other hand, the increased production of small bubbles at higher frother dosages enhanced the stability of the froth. It should be noted, however, that if the frother dosage exceeds a critical amount, too stable a froth can be produced. As indicated previously, this condition results in an excessive flow of water into the product stream and, in many cases, a decrease in the separation efficiency.

A more detailed analysis of the response surface data is currently under way. The results of these analyses will be reported in forthcoming technical progress reports as they become available.

Task 2.4 Design Evaluation/Modification

As indicated in previous technical progress reports, no major design flaws have been identified with either the prototype or full-scale test columns. Most of the minor problems associated with the operation or design of the columns have now been corrected or are in the process of being corrected.

One of the primary concerns related to the design of the column is the wear of the in-line microbubble generators. Since slurry, containing abrasive particles, must pass through the generators at a relatively high superficial velocity, the possibility exists that this will be an area of high wear. However, tests conducted to date in both the 30-inch and 8-foot diameter columns qualitatively indicates that the wear of the generators is not a major concern. Preliminary estimates now suggest that the hardened-steel generators

will have a life of approximately 6-12 months. However, a detailed assessment of the wear problem can not be made available until the project is completed and the generators and associated distribution manifolds can be disassembled and inspected. It is encouraging to note, however, that a firm has now been identified which can cast the microbubble generators from wear-resistant urethane. The tests carried out in a separate project have demonstrated that these new wear-resistant generators last at least 4 times longer than the original hardened-steel mixers. In addition, the urethane mixers are nearly 1/3-1/2 the cost of their hardened-steel counterparts.

Task 2.5 Control Systems

As indicated in the last technical progress report, the design and installation of the column control system has taken considerably more time than originally planned. Two reasons can be given for the delay. First, obtaining much of the instrumentation that was to be purchased for monitoring the performance of the 30-inch diameter unit has been slow due to problems associated with the specification of equipment sizes and the bidding and purchasing process at the university. In addition, much of the effort associated with the design of the control has been focused on the development of a "turn-key" system that is compatible with existing plant hardware and requires no direct operator attention. At the same time, the system must provide basic stabilizing control and serve as a central host for data acquisition and performance monitoring. Development of a complete system which can meet all these objects and operate effectively in a plant environment has been challenging. Plant personnel have been tremendously helpful in providing assistance in meeting these objectives, but the task has still fallen considerably behind schedule. Due to these delays, it is likely that a no cost time extension will be required in order to complete the original objectives of this task.

Task 3.3 Column Testing

Testing of the full-scale column has been temporarily delayed pending the installation of a new air compressor by plant personnel to replace the portable air compressor that was used in the first stages of the test program. The installation is expected to be completed shortly, at which time the testing will be continued. A parametric test plan for optimizing the performance of the 8-foot diameter column is currently under development and will be submitted to DOE in the near future for review.

SUMMARY, STATUS AND PLANNED WORK

The overall project is on schedule although a few areas of concern have now arisen. Data collected from the 30-inch and 8-foot diameter columns continue to be encouraging. Scale-up and operational guidelines are still being formulated for both test units. During the next quarter, considerable effort will be directed toward the continued development of schemes for monitoring and controlling the in-plant test units. In addition, a large data base should be developed for the full-scale test column during the next period of performance.

Appendix 1

DESIGN-EXPERT Data Analysis Sheets for:

Energy (Btu) Recovery
Product Ash Content
Sulfur Rejection
Separation Efficiency

Response: Energy Rec.; File = INPLT

Run on 11/01/90 at 13:24:01

NO	VARIABLE	UNITS	-1 LEVEL	+1 LEVEL
1	Feed Rate	(ton/hr)	-1.000	1.000
2	Wash Water	(ton/hr)	-1.000	1.000
3	Air Rate	(cc/min)	-1.000	1.000
4	Spreader	(lb/ton)	-1.000	1.000
5	Diesel	(lb/ton)	-1.000	1.000
6	Proth Hite	(inches)	-1.000	1.000

Results of Linear Response Surface Model Fitting

ANOVA for Selected Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	6858.05	4	1143.0091	5.333	0.0000
ERROR	10072.63	47	214.3112		
COR TOTAL	16930.68	51			
ROOT MSE	14.6374		R-SQUARED	0.4051	
DEP MEAN	58.8439		ADJ R-SQUARED	0.3291	
C.V.	24.88%				

Predicted Residual Sum of Squares (PRESS) = 13316.38

Results of Quadratic Response Surface Model Fitting

ANOVA for Selected Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	11573.92	27	428.6638	2.081	0.0328
ERROR	5356.76	26	206.0293		
COR TOTAL	16930.68	53			
ROOT MSE	14.3537		R-SQUARED	0.6836	
DEP MEAN	58.8439		ADJ R-SQUARED	0.3550	
C.V.	24.39%				

Predicted Residual Sum of Squares (PRESS) = 24964.61

Results of Cubic Response Surface Model Fitting

ANOVA for Selected Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	15260.05	45	339.1122	1.624	0.2401
ERROR	1670.63	8	208.8293		
COR TOTAL	16930.68	53			
ROOT MSE	14.4509		R-SQUARED	0.9013	

COR TOTAL 52.2409 ADJ R-SQUARED 0.3463
 C.V. 24.56%

Predicted Residual Sum of Squares (PRESS) = 224429.49

ANOVA Summary of models fit

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
LINEAR	3858.05	4	964.51	5.333	0.0003
QUADRATIC	4715.87	21	224.57	1.090	0.4127
CUBIC	3684.17	13	283.39	0.9806	0.5437
ERROR	1670.63	8	208.83		
COR TOTAL	16930.68	53			

Lack of Fit tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
LINEAR	9274.18	42	220.81	1.383	0.3902
QUADRATIC	4858.31	21	231.35	1.389	0.3950
CUBIC	372.18	3	124.06	1.821	0.2603
PURE ERR	795.45	5	159.09		

Response: Energy Rec.: File = INPLT

Run on 11/01/90 at 13:26:24

VARIABLE	UNITS	-1 LEVEL	+1 LEVEL
X1 Feed Rate	(gpm)	-1.000	1.000
X2 Wash Water	(gpm)	-1.000	1.000
X3 Air Rate	(scfm)	-1.000	1.000
X4 Frother	(lb/ton)	-1.000	1.000
X5 Diesel	(lb/ton)	-1.000	1.000
X6 Froth Hile	(inches)	-1.000	1.000

Results of Cubic Response Surface Model Fitting

ANOVA for Selected Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	15260.05	45	339.1122	1.624	0.2401
ERROR	1670.63	8	208.8293		
COR TOTAL	16930.68	53			

ROOT MSE 14.4509 R-SQUARED 0.9013
 DEP MEAN 58.8439 ADJ R-SQUARED 0.3463
 C.V. 24.56%

Predicted Residual Sum of Squares (PRESS) = 224429.49

VARIABLE	PARAMETER ESTIMATE	DF	STANDARD ERROR	t FOR H0 PARAMETER=0	PROB > t
Intercept	49.9250	1	5.2896	8.462	

X1	-4.3856	1	5.1092	-0.3583	0.4157
X2	3.2450	1	5.1092	0.6331	0.5431
X3	-2.9437	1	5.1092	-0.5762	0.5803
X4	14.7338	1	5.1092	2.884	0.0204
X5	0.1350	1	5.1092	2.64E-02	0.9796
X6	-10.1262	1	5.1092	-1.982	0.0828
X1X1	8.7671	1	4.5059	1.746	0.0876
X2X2	-2.4472	1	4.5059	1.875	0.0977
X3X3	1.5896	1	4.5059	0.3528	0.7334
X4X4	-3.5767	1	4.5059	-0.2823	0.4032
X5X5	4.8171	1	4.5059	1.091	0.3069
X6X6	0.3233	1	4.5059	7.18E-02	0.9446
X1X2	1.3975	1	5.1092	0.2735	0.7914
X1X3	0.3450	1	5.1092	6.75E-02	0.9478
X1X4	-4.3925	1	3.6127	-1.216	0.2587
X1X5	5.5825	1	5.1092	1.093	0.3064
X1X6	-2.0200	1	5.1092	-0.3954	0.7011
X2X3	1.3762	1	5.1092	0.2694	0.7945
X2X4	6.1500	1	5.1092	1.204	0.2631
X2X5	2.9331	1	3.6127	0.8119	0.4403
X2X6	1.8000	1	5.1092	0.3523	0.7337
X3X4	-6.5413	1	5.1092	-1.280	0.2363
X3X5	3.4512	1	5.1092	0.6755	0.5184
X3X6	2.6094	1	3.6127	0.7223	0.4907
X4X5	-3.5050	1	5.1092	-0.6860	0.5121
X4X6	9.8362	1	5.1092	1.925	0.0904
X5X6	3.7750	1	5.1092	0.7389	0.4811
X1X1X1	ALIASED	0			
X1X1X2	ALIASED	0			
X2X1X3	ALIASED	0			
X3X4X4	ALIASED	0			
X5X5X5	ALIASED	0			
X6X6X6	ALIASED	0			
X1X1X2	-12.2250	1	7.2255	-1.692	0.1291
X1X1X3	11.0012	1	7.2255	1.523	0.1664
X1X1X4	-8.5113	1	7.2255	-1.178	0.2727
X1X1X5	1.7600	1	7.2255	0.2436	0.8137
X1X1X6	2.3037	1	7.2255	0.3188	0.7580
X2X2X3	12.3675	1	7.2255	1.712	0.1253
X2X2X4	4.0200	1	7.2255	0.5564	0.5932
X2X2X5	ALIASED	0			
X2X2X6	-0.5312	1	7.2255	-7.35E-02	0.9432
X3X3X4	ALIASED	0			
X3X3X5	-1.6837	1	7.2255	-0.2330	0.8216
X3X3X6	ALIASED	0			
X4X4X5	ALIASED	0			
X4X4X6	ALIASED	0			
X5X5X6	ALIASED	0			
X1X2X2	-4.7100	1	7.2255	-0.6519	0.5328
X1X2X3	-5.7725	1	7.2255	-0.7989	0.4474
X1X4X4	ALIASED	0			
X1X5X5	ALIASED	0			
X1X6X6	ALIASED	0			
X2X3X3	-0.6388	1	7.2255	-8.84E-02	0.9317
X2X4X4	ALIASED	0			
X2X5X5	ALIASED	0			
X2X6X6	ALIASED	0			
X3X4X4	ALIASED	0			
X3X5X5	ALIASED	0			
X3X6X6	ALIASED	0			

11417785	ALIASED	0			
11417786	ALIASED	0			
11417786	ALIASED	0			
11417783	ALIASED	0			
11417784	-5.1975	1	5.1092	-1.017	0.3386
11417785	ALIASED	0			
11417786	ALIASED	0			
11417784	ALIASED	0			
11417785	ALIASED	0			
11417786	-4.9575	1	5.1092	-0.9507	0.3696
11417785	10.7525	1	5.1092	2.108	0.0685
11417786	ALIASED	0			
11417786	ALIASED	0			
12417784	ALIASED	0			
12417785	-2.6513	1	5.1092	-0.5189	0.6179
12417786	ALIASED	0			
12417785	ALIASED	0			
12417786	ALIASED	0			
12417786	4.3775	1	5.1092	0.8568	0.4165
13417785	ALIASED	0			
13417786	4.0112	1	5.1092	0.7851	0.4550
13417786	ALIASED	0			
14417786	ALIASED	0			

SUM ERROR 1.9665

Obs	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	t VALUE	Run Ord
1	79.9600	79.3475	-0.3875	0.938	-0.107	0.004	-0.303	54
2	57.1400	56.7525	0.3875	0.938	0.107	0.004	0.303	49
3	35.5100	35.8975	-0.3875	0.938	-0.107	0.004	-0.303	9
4	40.0700	39.6825	0.3875	0.938	0.107	0.004	0.303	5
5	86.3100	85.9225	0.3875	0.938	0.107	0.004	0.303	14
6	66.1600	66.5475	-0.3875	0.938	-0.107	0.004	-0.303	15
7	88.2500	87.8625	0.3875	0.938	0.107	0.004	0.303	33
8	52.9000	53.2875	-0.3875	0.938	-0.107	0.004	-0.303	44
9	61.6900	64.8094	-3.1194	0.938	-0.863	0.243	-2.326	16
10	59.2200	56.1006	3.1194	0.938	0.863	0.243	2.326	41
11	65.5800	68.6994	-3.1194	0.938	-0.863	0.243	-2.326	27
12	79.2200	76.1006	3.1194	0.937	0.863	0.243	2.326	39
13	46.7600	43.6406	3.1194	0.937	0.863	0.243	2.326	29
14	54.1500	57.2694	-3.1194	0.938	-0.863	0.243	-2.326	28
15	75.0600	71.9406	3.1194	0.937	0.863	0.243	2.326	46
16	77.3500	80.4694	-3.1194	0.937	-0.863	0.243	-2.326	13
17	41.4100	48.0906	-6.6806	0.937	-1.849	1.115	-3.958	11
18	64.7700	58.0894	6.6806	0.937	1.849	1.115	3.958	40
19	72.3100	78.9906	-6.6806	0.937	-1.849	1.115	-3.958	43
20	53.4600	46.7794	6.6806	0.937	1.849	1.115	3.958	7
21	17.6500	10.9694	6.6806	0.937	1.849	1.115	3.958	10
22	8.6800	15.3606	-6.6806	0.937	-1.849	1.115	-3.958	32
23	71.8500	65.1694	6.6806	0.937	1.849	1.115	3.958	52
24	52.7600	59.4406	-6.6806	0.937	-1.849	1.115	-3.958	3
25	43.2200	42.8325	0.3875	0.937	0.107	0.004	0.303	42
26	52.8000	53.1875	-0.3875	0.937	-0.107	0.004	-0.303	50
27	92.1900	92.5775	-0.3875	0.937	-0.107	0.004	-0.303	34
28	42.7400	42.3525	0.3875	0.937	0.107	0.004	0.303	17
29	64.3600	63.9725	0.3875	0.937	0.107	0.004	0.303	4
30	53.2600	53.6475	-0.3875	0.937	-0.107	0.004	-0.303	31
31	56.3000	56.6875	-0.3875	0.937	-0.107	0.004	-0.303	23

71	71.1800	71.8325	0.3575	0.937	0.167	0.004	0.303	51
72	75.1400	75.0206	3.1194	0.937	-0.863	0.243	2.326	2
73	77.6800	80.7794	-3.1194	0.937	-0.863	0.243	-2.326	48
74	57.5100	70.6294	-3.1194	0.937	-0.863	0.243	-2.326	6
75	53.7500	70.6306	3.1194	0.937	0.863	0.243	2.326	25
76	54.4300	51.3106	3.1194	0.937	0.863	0.243	2.326	35
78	43.6600	46.7794	-3.1194	0.937	-0.863	0.243	-2.326	37
79	41.3900	44.5094	-3.1194	0.937	-0.863	0.243	-2.326	30
80	32.3400	59.2206	3.1194	0.937	0.863	0.243	2.326	57
41	83.0000	76.3194	6.6806	0.938	1.849	1.115	3.958	47
42	56.3200	49.6394	6.6806	0.938	1.849	1.115	3.958	1
43	70.1300	76.6106	-6.6806	0.938	-1.849	1.115	-3.958	21
44	64.2600	70.9406	-6.6806	0.938	-1.849	1.115	-3.958	24
45	43.1000	49.7806	-6.6806	0.938	-1.849	1.115	-3.958	18
46	27.7700	34.4306	-6.6806	0.938	-1.849	1.115	-3.958	45
47	36.8200	80.1394	6.6806	0.938	1.849	1.115	3.958	12
48	53.4400	46.7594	6.6806	0.938	1.849	1.115	3.958	33
49	45.4700	49.9250	-0.4550	0.167	-0.034	0.000	-0.098	8
50	55.2200	49.9250	5.2950	0.167	0.401	0.001	1.124	26
51	42.5100	49.9250	-1.4150	0.167	-0.107	0.000	-0.303	20
52	34.8500	49.9250	-15.0750	0.167	-1.143	0.006	-2.957	22
53	71.1300	49.9250	21.2050	0.167	1.607	0.011	3.741	36
54	40.3700	49.9250	-9.5550	0.167	-0.724	0.002	-1.980	19

Response: ProdAsh: File = INFLT

Run on 11/01/99 at 14:06:45

NO	VARIABLE	UNITS	-1 LEVEL	+1 LEVEL
01	Feed Rate	(gpm)	-1.000	1.000
02	Wash Water	(gpm)	-1.000	1.000
03	Air Rate	(scfm)	-1.000	1.000
04	Frillage	(lb/ton)	-1.000	1.000
05	Diesel	(lb/ton)	-1.000	1.000
06	Frill Rate	(inches)	-1.000	1.000

Results of Linear Response Surface Model Fitting

ANOVA for Selected Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	469.0286	6	78.17143	7.935	0.0001
ERROR	463.0291	47	9.85381		
COR TOTAL	932.4526	53			
ROOT MSE	3.13941		R-SQUARED	0.5032	
DEP MEAN	11.33185		ADJ R-SQUARED	0.4398	
C.V.	27.70%				

Predicted Residual Sum of Squares (PRESS) = 624.0079

Results of Quadratic Response Surface Model Fitting

ANOVA for Selected Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	720.8070	27	26.69656	3.280	0.0017
ERROR	211.6456	26	8.14022		
COR TOTAL	932.4526	53			
ROOT MSE	2.95311		R-SQUARED	0.7730	
DEP MEAN	11.33185		ADJ R-SQUARED	0.5373	
C.V.	25.18%				

Predicted Residual Sum of Squares (PRESS) = 1069.0864

Results of Cubic Response Surface Model Fitting

ANOVA for Selected Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	873.7413	45	19.41647	2.646	0.0732
ERROR	58.7113	8	7.33891		
COR TOTAL	932.4526	53			
ROOT MSE	2.70904		R-SQUARED	0.9370	

COEFF. METHOD: 11/01/90 ADJ. R-SQUARED = 0.5829
 11/01/90 11:41:17

Predicted Residual Sum of Squares (PRESS) = 12564.5901

ANOVA Summary of Model Fit

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
LINEAR	749.2146	4	72.2041	7.538	0.0001<
QUADRATIC	281.5907	21	11.9801	1.472	0.1737
CUBIC	153.9347	12	9.4964	1.152	0.4370
ERROR	58.7113	8	7.3389		
TOTAL	973.4526	53			

Level of Fit Tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
LINEAR	483.5427	42	10.7984	5.575	0.0711
QUADRATIC	201.9402	21	9.6172	4.965	0.0417
CUBIC	89.0260	3	16.3420	8.438	0.0211
MODEL SSE	21.252	5	1.9371		

Response: ProdAsh: Filt = INFLT

Run on 11/01/90 at 14:08:07

VAR	VARIABLE	UNITS	-1 LEVEL	+1 LEVEL
X1	Feed Rate	(gpm)	-1.000	1.000
X2	Wash Water	(gpm)	-1.000	1.000
X3	Air Rate	(scfm)	-1.000	1.000
X4	Frother	(lb/ton)	-1.000	1.000
X5	Pulpal	(lb/ton)	-1.000	1.000
X6	Froth Hite	(inches)	-1.000	1.000

Results of Cubic Response Surface Model Fitting

ANOVA for Selected Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	873.7413	45	19.41647	2.646	0.0732
ERROR	58.7113	8	7.33891		
TOTAL	932.4526	53			

ROOT MSE 2.70904 R-SQUARED 0.9370
 DEP MEAN 11.33185 ADJ R-SQUARED 0.5829
 C.V. 23.917

Predicted Residual Sum of Squares (PRESS) = 12564.5901

VARIABLE	PARAMETER ESTIMATE	DF	STANDARD ERROR	t FOR H0: PARAMETER=0	PROB > t
Intercept	9.41771	1	1.11594	8.438	0.0001

1	1.58373	1	0.95779	-1.523	0.1913
2	1.23275	1	0.95779	1.293	0.2320
3	1.42833	1	0.95779	1.489	0.1748
4	0.97115	1	0.95779	1.014	0.3402
5	1.23375	1	0.95779	1.330	0.0202
6	-1.20125	1	0.95779	-1.902	0.0937
7	1.50907	1	0.94469	1.786	0.1118
8	-0.00260	1	0.94469	-3.12E-03	0.9976
9	0.42067	1	0.94469	0.4980	0.6317
10	-1.87347	1	0.94469	-2.171	0.0619
11	0.94469	1	0.94469	1.119	0.2956
12	2.31069	1	0.94469	2.734	0.0256
13	1.01375	1	0.95779	1.058	0.3108
14	-0.07625	1	0.95779	-7.96E-02	0.9385
15	-0.79750	1	0.67726	-1.178	0.0722
16	-0.05779	1	0.95779	-9.74E-02	0.5325
17	1.05375	1	0.95779	1.309	0.2269
18	-0.27125	1	0.95779	-0.2632	0.7842
19	0.32875	1	0.95779	0.3537	0.7327
20	-0.07250	1	0.67726	-0.4024	0.4990
21	-0.98125	1	0.95779	-0.9201	0.3544
22	-0.80375	1	0.95779	-0.8392	0.4257
23	-0.03375	1	0.95779	-0.2441	0.8133
24	-1.94875	1	0.67726	-2.287	0.0515
25	0.39625	1	0.95779	0.7269	0.4680
26	-1.15225	1	0.95779	-1.218	0.2521
27	-1.07125	1	0.95779	-1.599	0.1485
28	612347	0			
29	ALIASED	0			
30	ALIASED	0			
31	ALIASED	0			
32	ALIASED	0			
33	ALIASED	0			
34	ALIASED	0			
35	-2.04500	1	1.35452	-1.510	0.1695
36	2.28750	1	1.35452	1.699	0.1297
37	1.03500	1	1.35452	0.7641	0.4667
38	-0.62000	1	1.35452	-0.4577	0.6593
39	-3.03500	1	1.35452	-2.241	0.0554
40	1.29500	1	1.35452	0.9561	0.3670
41	-0.58500	1	1.35452	-0.4319	0.6772
42	ALIASED	0			
43	-0.42750	1	1.35452	-0.3156	0.7604
44	ALIASED	0			
45	-2.12750	1	1.35452	-1.571	0.1549
46	ALIASED	0			
47	ALIASED	0			
48	ALIASED	0			
49	ALIASED	0			
50	0.93000	1	1.35452	0.6866	0.5117
51	0.13250	1	1.35452	9.78E-02	0.9245
52	ALIASED	0			
53	ALIASED	0			
54	ALIASED	0			
55	-0.77000	1	1.35452	-0.5685	0.5853
56	ALIASED	0			
57	ALIASED	0			
58	ALIASED	0			
59	ALIASED	0			
60	ALIASED	0			

00000000	ALIASED	0			
00000000	ALIASED	0			
00000000	ALIASED	0			
00000000	ALIASED	0			
00000000	0.54375	1	0.95779	0.3677	0.5858
00000000	ALIASED	0			
00000000	ALIASED	0			
00000000	ALIASED	0			
00000000	ALIASED	0			
00000000	-0.29625	1	0.95779	-0.4033	0.4973
00000000	-0.76125	1	0.95779	-0.7848	0.4497
00000000	ALIASED	0			
00000000	ALIASED	0			
00000000	ALIASED	0			
00000000	ALIASED	0			
00000000	-0.57625	1	0.95779	-0.6016	0.5641
00000000	ALIASED	0			
00000000	ALIASED	0			
00000000	ALIASED	0			
00000000	-1.01375	1	0.95779	-2.102	0.8687
00000000	ALIASED	0			
00000000	-0.32125	1	0.95779	-0.3354	0.7459
00000000	ALIASED	0			
00000000	ALIASED	0			

SIG ERROR 0.36265

Obs	ACTUAL	PREDICTED	RESIDUAL	LEVER	STUDENT	COOK'S	t	Run
Ord	VALUE	VALUE			RESID	DIST	VALUE	Ord
1	10.20000	9.54625	0.65375	0.938	0.965	0.304	2.566	54
2	8.29000	8.93375	-0.65375	0.938	-0.965	0.304	-2.566	49
3	6.97000	6.31625	0.65375	0.938	0.965	0.304	2.566	9
4	6.93000	7.58375	-0.65375	0.938	-0.965	0.304	-2.566	5
5	13.74000	14.39375	-0.65375	0.938	-0.965	0.304	-2.566	14
6	9.07000	8.41625	0.65375	0.938	0.965	0.304	2.566	15
7	9.69000	10.34375	-0.65375	0.938	-0.965	0.304	-2.566	33
8	11.25000	10.59625	0.65375	0.938	0.965	0.304	2.566	44
9	7.60000	8.66875	-1.06875	0.938	-1.578	0.812	-3.704	16
10	10.61000	9.54125	1.06875	0.938	1.578	0.812	3.704	41
11	12.90000	13.96875	-1.06875	0.938	-1.578	0.812	-3.704	27
12	17.13000	16.06125	1.06875	0.937	1.578	0.812	3.704	39
13	7.39000	6.82125	1.06875	0.937	1.578	0.812	3.704	29
14	7.84000	8.90875	-1.06875	0.938	-1.578	0.812	-3.704	28
15	14.56000	13.49125	1.06875	0.937	1.578	0.812	3.704	46
16	11.12000	12.18875	-1.06875	0.937	-1.578	0.812	-3.704	13
17	8.19000	6.96750	1.22250	0.937	1.805	1.062	3.931	11
18	12.66000	13.88250	-1.22250	0.937	-1.805	1.062	-3.931	40
19	13.43000	12.20750	1.22250	0.937	1.805	1.062	3.931	43
20	15.97000	17.19250	-1.22250	0.937	-1.805	1.062	-3.931	7
21	6.89000	8.11250	-1.22250	0.937	-1.805	1.062	-3.931	10
22	11.34000	10.11750	1.22250	0.937	1.805	1.062	3.931	32
23	9.75000	9.97250	-1.22250	0.937	-1.805	1.062	-3.931	52
24	8.70000	7.47750	1.22250	0.937	1.805	1.062	3.931	3
25	9.29000	9.94375	-0.65375	0.937	-0.965	0.304	-2.566	42
26	7.71000	7.05625	0.65375	0.937	0.965	0.304	2.566	50
27	13.29000	12.63625	0.65375	0.937	0.965	0.304	2.566	34
28	8.95000	9.60375	-0.65375	0.937	-0.965	0.304	-2.566	17
29	7.95000	8.50375	-0.55375	0.937	-0.965	0.304	-2.566	4
30	8.98000	8.32625	0.65375	0.937	0.965	0.304	2.566	31
31	17.59000	17.02625	0.56375	0.937	0.965	0.304	2.566	23

32	8.93000	10.81375	-0.85375	0.937	-0.965	0.304	-2.565	51
33	13.23000	12.13115	1.06875	0.937	1.578	0.812	3.704	2
34	11.65000	12.91375	-1.06875	0.937	-1.578	0.812	-3.704	48
35	13.22000	14.26575	-1.06875	0.937	-1.578	0.812	-3.704	6
36	23.08000	22.01115	1.06875	0.937	1.578	0.812	3.704	25
37	9.53000	8.44125	1.06875	0.937	1.578	0.812	3.704	35
38	12.58000	13.74975	-1.06875	0.937	-1.578	0.812	-3.704	37
39	11.45000	12.51675	-1.06875	0.937	-1.578	0.812	-3.704	30
40	9.73000	9.54175	1.06875	0.937	1.578	0.812	3.704	53
41	15.45000	16.67250	-1.22250	0.938	-1.805	1.062	-3.931	47
42	9.46000	10.68250	-1.22250	0.938	-1.805	1.062	-3.931	1
43	27.60000	26.57750	1.22250	0.938	1.805	1.062	3.931	21
44	23.05000	21.82750	1.22250	0.938	1.805	1.062	3.931	24
45	8.00000	6.77750	1.22250	0.938	1.805	1.062	3.931	18
46	5.57000	7.34750	1.22250	0.938	1.805	1.062	3.931	45
47	10.81000	12.03250	-1.22250	0.938	-1.805	1.062	-3.931	12
48	9.53000	10.75250	-1.22250	0.938	-1.805	1.062	-3.931	38
49	8.99000	9.84333	-0.85333	0.167	-0.345	0.001	-0.969	8
50	8.46000	9.84333	-1.38333	0.167	-0.559	0.001	-1.551	26
51	10.78000	9.84333	0.93667	0.167	0.379	0.001	1.062	20
52	11.02000	9.84333	1.17667	0.167	0.476	0.001	1.327	22
53	8.36000	9.84333	-1.48333	0.167	-0.600	0.002	-1.658	34
54	11.45000	9.84333	1.60667	0.167	0.650	0.002	1.789	19

2. Selected: Sol. Ret. File = HPLT

Run on 11/21/90 at 13:27:23

NO	VARIABLE	UNITS	-1 LEVEL	+1 LEVEL
01	Feed Rate	(gpm)	-1.000	1.000
02	Wash Water	(gpm)	-1.000	1.000
03	Air Rate	(scfm)	-1.000	1.000
04	Frother	(lb/ton)	-1.000	1.000
05	Diesel	(lb/ton)	-1.000	1.000
06	Froth Ht	(inches)	-1.000	1.000

Results of Linear Response Surface Model Fitting

ANOVA for Selected Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	4375.89	6	729.4734	5.059	0.0004
ERROR	8776.71	47	144.1953		
COR TOTAL	11153.55	53			
ROOT MSE	12.0077		R-SQUARED	0.3924	
DEP MEAN	55.6941		ADJ R-SQUARED	0.3149	
C.V.	21.56%				

Predicted Residual Sum of Squares (PRESS) = 8872.01

Results of Quadratic Response Surface Model Fitting

ANOVA for Selected Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	7764.48	27	287.5734	2.206	0.0236
ERROR	3389.07	26	130.3488		
COR TOTAL	11153.55	53			
ROOT MSE	11.4170		R-SQUARED	0.6961	
DEP MEAN	55.6941		ADJ R-SQUARED	0.3806	
C.V.	20.50%				

Predicted Residual Sum of Squares (PRESS) = 15365.63

Results of Cubic Response Surface Model Fitting

ANOVA for Selected Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	9835.64	45	218.6359	1.330	0.3540
ERROR	1317.89	8	164.3812		
COR TOTAL	11153.55	53			
ROOT MSE	12.6307		R-SQUARED	0.5621	

LEF REGR 57.4741 ADJ R-SQUARED 0.0190
 D.V. 173.009

Predicted Residual Sum of Squares (PRESS) = 179179.44

ANOVA Summary of model: fit

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
LINEAR	4376.84	1	720.47	5.059	0.0004
QUADRATIC	3387.64	21	161.32	1.238	0.3090
CUBIC	2074.16	18	115.23	0.7011	0.7482
ERROR	1314.99	8	164.37		
COR TOTAL	11150.55	53			

Leak of Fit tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
LINEAR	6158.26	42	146.63	1.185	0.4734
QUADRATIC	2770.82	21	131.93	1.067	0.5229
CUBIC	696.44	3	232.15	1.877	0.2512
PURE ERR	612.45	5	123.69		

Response: Pul. Sel.: File = INFLI

Run on 11/01/90 at 13:39:52

NO	VARIABLE	UNITS	-1 LEVEL	+1 LEVEL
1	Feed Rate	(gpm)	-1.000	1.000
2	Wash Water	(gpm)	-1.000	1.000
3	Air Rate	(scfm)	-1.000	1.000
4	Fertilizer	(lb/ton)	-1.000	1.000
5	Diesel	(lb/ton)	-1.000	1.000
6	Froth Hits	(inches)	-1.000	1.000

Results of Cubic Response Surface Model Fitting

ANOVA for Selected Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	9838.64	45	218.6369	1.330	0.3540
ERROR	1314.39	8	164.3612		
COR TOTAL	11153.55	53			
SUM OF S	12.5203		R-SQUARED	0.8821	
DEP MEAN	85.4941		ADJ R-SQUARED	0.2190	
C.V.	23.02%				

Predicted Residual Sum of Squares (PRESS) = 179178.44

VARIABLE	PARAMETER ESTIMATE	DF	STANDARD ERROR	t FOR H0 PARAMETER=0	PROB > t
Intercept	64.8917	1	5.2339	12.40	
X1	4.1625	1	4.5327	0.9183	0.3853
X2	-3.3975	1	4.5327	-0.7496	0.4750
X3	0.5025	1	4.5327	0.1770	0.8639
X4	-13.0250	1	4.5327	-2.874	0.0207
X5	2.3400	1	4.5327	0.6266	0.5484
X6	7.5650	1	4.5327	1.757	0.1169
X1*X1	-7.0981	1	3.9974	-1.776	0.1137
X2*X2	-7.2568	1	3.9974	-1.815	0.1070
X3*X3	-2.3618	1	3.9974	-0.5908	0.5709
X4*X4	2.1919	1	3.9974	0.5483	0.5984
X5*X5	-4.3856	1	3.9974	-1.097	0.3045
X6*X6	-1.7643	1	3.9974	-0.4464	0.6672
X1*X2	-0.0612	1	4.5327	-1.35E-02	0.9895
X1*X3	1.2250	1	4.5327	0.2703	0.7938
X1*X4	4.3056	1	3.2051	1.343	0.2160
X1*X5	-6.6625	1	4.5327	-1.470	0.1798
X1*X6	0.1200	1	4.5327	2.65E-02	0.9795
X2*X3	1.0425	1	4.5327	0.2300	0.8239
X2*X4	-5.3712	1	4.5327	-1.185	0.2700
X2*X5	-1.8775	1	3.2051	-0.5858	0.5742
X2*X6	-1.9600	1	4.5327	-0.4104	0.6923
X3*X4	5.0300	1	4.5327	1.110	0.2994
X3*X5	-3.4425	1	4.5327	-0.7595	0.4693
X3*X6	-2.4085	1	3.2051	-0.7515	0.4739
X4*X5	2.3750	1	4.5327	0.5284	0.6115
X4*X6	-7.0000	1	4.5327	-1.623	0.1432

01X11X1	-1.3375	1	4.5327	-1.121	0.7346
01X11X2	ALIASED	0			
01X22X2	ALIASED	0			
01X33X3	ALIASED	0			
01X44X4	ALIASED	0			
01X55X5	ALIASED	0			
01X66X6	ALIASED	0			
01X11X2	10.8137	1	5.4102	1.703	0.1271
01X11X2	-5.7075	1	5.4102	-0.2960	0.3992
01X11X4	8.5250	1	5.4102	1.330	0.2202
01X11X5	-1.2301	1	5.4102	-0.3479	0.7349
01X11X6	-1.3450	1	5.4102	-0.2099	0.8391
02X33X2	-7.4075	1	5.4102	-1.156	0.2812
02X33X3	-0.0430	1	5.4102	-0.4748	0.5476
02X33X4	ALIASED	0			
02X33X5	-1.0775	1	5.4102	-0.1681	0.8707
02X33X6	ALIASED	0			
03X33X5	-1.3900	1	5.4102	-0.2948	0.7750
03X33X6	ALIASED	0			
04X33X5	ALIASED	0			
04X33X6	ALIASED	0			
01X01X2	3.5038	1	5.4102	0.5466	0.5996
01X01X3	4.1800	1	5.4102	0.6521	0.5326
01X44X4	ALIASED	0			
01X55X5	ALIASED	0			
01X66X6	ALIASED	0			
02X33X3	2.5825	1	5.4102	0.4029	0.3976
02X44X4	ALIASED	0			
02X55X5	ALIASED	0			
02X66X6	ALIASED	0			
03X44X4	ALIASED	0			
03X55X5	ALIASED	0			
03X66X6	ALIASED	0			
04X55X5	ALIASED	0			
04X66X6	ALIASED	0			
05X66X6	ALIASED	0			
01X22X3	ALIASED	0			
01X22X4	3.6662	1	4.5327	0.8088	0.4420
01X22X5	ALIASED	0			
01X22X6	ALIASED	0			
01X33X4	ALIASED	0			
01X33X5	ALIASED	0			
01X33X6	2.8025	1	4.5327	0.6183	0.5536
01X44X5	-8.8675	1	4.5327	-1.956	0.0861
01X44X6	ALIASED	0			
01X55X6	ALIASED	0			
02X33X4	ALIASED	0			
02X33X5	0.9600	1	4.5327	0.2118	0.8376
02X33X6	ALIASED	0			
02X44X5	ALIASED	0			
02X44X6	ALIASED	0			
02X55X6	-2.5000	1	4.5327	-0.5516	0.5963
03X44X5	ALIASED	0			
03X44X6	-2.3875	1	4.5327	-0.5267	0.6127
03X55X6	ALIASED	0			
04X55X6	ALIASED	0			

916 EPRDF 1.7446

Obs Ord	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	t VALUE	Run Ord
1	40.4100	40.3969	0.1131	0.938	0.035	0.000	0.100	54
2	54.3600	54.4731	-0.1131	0.938	-0.035	0.000	-0.100	49
3	73.6400	73.5069	0.1131	0.938	0.035	0.000	0.100	9
4	72.6800	72.7931	-0.1131	0.938	-0.035	0.000	-0.100	5
5	34.5600	34.6731	-0.1131	0.938	-0.035	0.000	-0.100	14
6	51.5200	51.4069	0.1131	0.938	0.035	0.000	0.100	15
7	31.6400	31.7531	-0.1131	0.938	-0.035	0.000	-0.100	33
8	63.0200	62.9069	0.1131	0.938	0.035	0.000	0.100	44
9	54.6700	52.1200	2.5500	0.938	0.796	0.206	2.159	16
10	51.5300	54.0800	-2.5500	0.938	-0.796	0.206	-2.159	41
11	48.1900	45.6300	2.5500	0.938	0.796	0.206	2.159	27
12	45.3700	47.9200	-2.5500	0.937	-0.796	0.206	-2.159	39
13	64.0300	66.5800	-2.5500	0.937	-0.796	0.206	-2.159	29
14	59.7400	57.1900	2.5500	0.936	0.796	0.206	2.159	28
15	39.9300	42.4800	-2.5500	0.937	-0.796	0.206	-2.159	46
16	43.6500	41.1000	2.5500	0.937	0.796	0.206	2.159	13
17	70.9300	68.3463	2.5837	0.937	1.898	1.175	3.980	11
18	50.3500	56.4337	-6.0838	0.937	-1.898	1.175	-3.980	40
19	44.7600	38.6762	6.0838	0.937	1.898	1.175	3.980	43
20	53.8500	59.9338	-6.0838	0.937	-1.898	1.175	-3.980	7
21	59.4500	65.5378	-6.0838	0.937	-1.898	1.175	-3.980	19
22	93.1200	87.0362	6.0838	0.937	1.898	1.175	3.980	32
23	40.4000	49.4838	-6.0838	0.937	-1.898	1.175	-3.980	52
24	57.6400	51.5562	6.0838	0.937	1.898	1.175	3.980	3
25	64.1200	64.2331	-0.1131	0.937	-0.035	0.000	-0.100	42
26	59.6500	59.5369	0.1131	0.937	0.035	0.000	0.100	50
27	24.2100	24.0969	0.1131	0.937	0.035	0.000	0.100	34
28	71.9800	72.0931	-0.1131	0.937	-0.035	0.000	-0.100	17
29	56.1400	56.2531	-0.1131	0.937	-0.035	0.000	-0.100	4
30	60.4900	60.3769	0.1131	0.937	0.035	0.000	0.100	31
31	61.2800	61.1669	0.1131	0.937	0.035	0.000	0.100	23
32	46.9300	47.0431	-0.1131	0.937	-0.035	0.000	-0.100	51
33	36.7100	39.2600	-2.5500	0.937	-0.796	0.206	-2.159	2
34	37.4900	34.9400	2.5500	0.937	0.796	0.206	2.159	48
35	55.5200	52.9700	2.5500	0.937	0.796	0.206	2.159	6
36	48.5900	51.1400	-2.5500	0.937	-0.796	0.206	-2.159	25
37	56.4800	61.0300	-2.5500	0.937	-0.796	0.206	-2.159	35
38	61.8200	59.2700	2.5500	0.937	0.796	0.206	2.159	37
39	68.7400	66.1900	2.5500	0.937	0.796	0.206	2.159	30
40	44.3700	46.9200	-2.5500	0.937	-0.796	0.206	-2.159	53
41	33.6400	39.7238	-6.0838	0.938	-1.898	1.175	-3.980	47
42	53.2400	59.3238	-6.0838	0.938	-1.898	1.175	-3.980	1
43	43.9700	37.8862	6.0838	0.938	1.898	1.175	3.980	21
44	57.2600	51.1762	6.0838	0.938	1.898	1.175	3.980	24
45	69.2300	63.1462	6.0838	0.938	1.898	1.175	3.980	18
46	78.1000	72.0162	6.0838	0.938	1.898	1.175	3.980	45
47	34.3800	40.4638	-6.0838	0.938	-1.898	1.175	-3.980	12
48	59.3600	65.4438	-6.0838	0.938	-1.898	1.175	-3.980	38
49	63.5000	64.8917	-1.3917	0.167	-0.308	0.000	-0.867	8
50	60.4400	64.8917	-4.4517	0.167	-0.380	0.001	-1.066	26
51	64.9700	64.8917	0.0783	0.167	0.007	0.000	0.019	20
52	75.7600	64.8917	10.8683	0.167	0.929	0.004	2.481	22
53	45.4100	64.8917	-19.4817	0.167	-1.665	0.012	-3.807	36
54	74.2700	64.8917	9.3783	0.167	0.801	0.003	2.174	19

Response: SeComb; File = UNPL1

Run on 11/01/90 at 13:51:14

NO	VARIABLE	UNIT	-1 LEVEL	+1 LEVEL
01	Feed Rate	(rpm)	-1.000	1.000
02	Main Motor	(rpm)	-1.000	1.000
03	Air Flow	(scfm)	-1.000	1.000
04	Friction	(lb/ton)	-1.000	1.000
05	Diesel	(lb/ton)	-1.000	1.000
06	Fract Rate	(inches)	-1.000	1.000

Results of Linear Response Surface Model Fitting

ANOVA for Selected Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	3080.399	5	616.0798	3.806	0.0035
ERROR	6339.909	47	134.89185		
COR TOTAL	9420.307	52			
SOUT MSE	11.61429		R-SQUARED	0.3270	
DEP MEAN	43.0022		ADJ R-SQUARED	0.2411	
C.V.	26.76%				

Predicted Residual Sum of Squares (PRESS) = 9392.980

Results of Quadratic Response Surface Model Fitting

ANOVA for Selected Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	6065.757	27	224.65767	1.741	0.0807
ERROR	3354.550	26	129.02113		
COR TOTAL	9420.307	53			
SOUT MSE	11.35875		R-SQUARED	0.6439	
DEP MEAN	43.40722		ADJ R-SQUARED	0.2741	
C.V.	26.17%				

Predicted Residual Sum of Squares (PRESS) = 15483.700

Results of Cubic Response Surface Model Fitting

ANOVA for Selected Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	8279.536	45	183.98969	1.290	0.0728
ERROR	1140.771	8	142.59632		
COR TOTAL	9420.307	52			
SOUT MSE	11.39137		R-SQUARED	0.8749	

200.444 17.511 400 R-SQUARED 0.1977
 100. 17.511

Restricted Residual Sum of Squares (PRESS) = 154678.777

ANAL. Summary of models fit

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
LINEAR	2090.335	6	513.400	3.806	0.0038
QUADRATIC	2091.352	21	142.160	1.102	0.4027
CUBIC	2092.779	13	162.998	0.9625	0.5260
PURE ERR	1110.771	9	123.596		
COR TOTAL	9420.307	55			

Test of Fit tests

MODEL	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
LINEAR	500.338	42	132.103	1.220	0.4312
QUADRATIC	2217.250	21	134.045	1.242	0.4412
CUBIC	2091.171	1	200.390	1.857	0.2544
PURE ERR	512.600	9	107.920		

Response: SeComb: File = INFLT

Run on 11/01/90 at 13:52:28

VAR	VARIABLE	UNITS	-1 LEVEL	+1 LEVEL
X1	Feed Rate	(gpm)	-1.000	1.000
X2	Wash Water	(gpm)	-1.000	1.000
X3	Air Rate	(scfm)	-1.000	1.000
X4	Frother	(lb/ton)	-1.000	1.000
X5	Diesel	(lb/ton)	-1.000	1.000
X6	Froth Hile	(inches)	-1.000	1.000

Results of Cubic Response Surface Model Fitting

ANOVA for Selected Model

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F VALUE	PROB > F
MODEL	3279.536	45	183.99969	1.290	0.3735
ERROR	1140.771	8	142.59632		
TOTAL	9420.307	53			
ROOT MSE	11.94137		R-SQUARED	0.8789	
DEV MEAN	43.40722		ADJ R-SQUARED	0.1977	
C.V.	27.51%				

Predicted Residual Sum of Squares (PRESS) = 154676.777

VARIABLE	PARAMETER ESTIMATE	DF	STANDARD ERROR	t FOR H0 PARAMETER=0	PROB > t
Intercept	37.23833	1	4.87504	7.639	
X1	-2.45375	1	4.22191	-0.5812	0.5771
X2	2.41375	1	4.22191	0.5717	0.5832
X3	-2.42375	1	4.22191	-0.5741	0.5817
X4	10.73625	1	4.22191	2.543	0.0345
X5	-0.43375	1	4.22191	-0.1027	0.9207
X6	-5.46125	1	4.22191	-1.294	0.2319
X1*X1	6.40167	1	3.72338	1.719	0.1239
X2*X2	6.30208	1	3.72338	1.693	0.1290
X3*X3	0.65000	1	3.72338	0.1746	0.8658
X4*X4	-2.58958	1	3.72338	-0.6955	0.5064
X5*X5	3.54833	1	3.72338	0.9530	0.3685
X6*X6	-0.43250	1	3.72338	-0.1162	0.9104
X1*X2	-0.45500	1	4.22191	-0.1078	0.9168
X1*X3	0.13500	1	4.22191	3.20E-02	0.9753
X1*X4	-3.35562	1	2.98534	-1.124	0.2936
X1*X5	3.42125	1	4.22191	0.8104	0.4412
X1*X6	-2.71750	1	4.22191	-0.6437	0.5378
X2*X3	1.57125	1	4.22191	0.3722	0.7194
X2*X4	3.53750	1	4.22191	0.8379	0.4264
X2*X5	3.36675	1	2.98534	1.128	0.2918
X2*X6	2.46125	1	4.22191	0.5830	0.5760
X3*X4	-2.71875	1	4.22191	-0.7861	0.4545
X3*X5	3.54625	1	4.22191	0.8400	0.4253
X3*X6	2.35938	1	2.98534	1.025	0.3354
X4*X5	-2.74375	1	4.22191	-0.6867	0.4011
X4*X6	5.05875	1	4.22191	1.013	0.0789

04*01	0.12375	1	4.22191	0.7575	0.4575
X1X01X01	ALIASED	0			
X0X02X02	ALIASED	0			
X0X03X03	ALIASED	0			
X0X04X04	ALIASED	0			
X0X05X05	ALIASED	0			
X0X06X06	ALIASED	0			
X0X07X07	-9.50875	1	5.97069	-1.593	0.1499
X0X08X08	7.89075	1	5.97069	1.322	0.2227
X0X09X09	-5.90000	1	5.97069	-0.9982	0.3520
X1X11X05	1.16751	1	5.97069	0.1989	0.8473
X1X12X05	1.51375	1	5.97069	0.3038	0.7690
X2X12X03	5.81751	1	5.97069	1.477	0.1780
X2X12X04	2.15375	1	5.97069	0.3607	0.7275
X2X12X05	ALIASED	0			
X2X12X06	-1.61500	1	5.97069	-0.2705	0.7936
X3X11X09	ALIASED	0			
X1X13X05	1.29500	1	5.97069	0.2169	0.8337
X0X07X06	ALIASED	0			
X0X14X05	ALIASED	0			
X0X04X02	ALIASED	0			
X0X05X06	ALIASED	0			
X0X07X02	-4.33375	1	5.97069	-0.8096	0.4416
X1X13X03	-6.44875	1	5.97069	-0.7451	0.4775
X1X09X04	ALIASED	0			
X1X05X05	ALIASED	0			
X1X06X06	ALIASED	0			
X2X03X03	-1.30750	1	5.97069	-0.3027	0.7698
X2X04X04	ALIASED	0			
X2X05X05	ALIASED	0			
X2X06X06	ALIASED	0			
X3X04X04	ALIASED	0			
X3X05X05	ALIASED	0			
X3X06X06	ALIASED	0			
X4X05X05	ALIASED	0			
X4X06X06	ALIASED	0			
X5X06X06	ALIASED	0			
X1X02X03	ALIASED	0			
X1X02X04	-5.12750	1	4.22191	-1.214	0.2592
X1X02X05	ALIASED	0			
X1X02X06	ALIASED	0			
X1X03X04	ALIASED	0			
X1X03X05	ALIASED	0			
X1X03X06	-3.07000	1	4.22191	-0.7272	0.4879
X1X04X05	9.17375	1	4.22191	2.173	0.0615
X1X04X06	ALIASED	0			
X1X05X06	ALIASED	0			
X2X03X04	ALIASED	0			
X2X03X05	-1.55625	1	4.22191	-0.3686	0.7220
X2X03X06	ALIASED	0			
X2X04X05	ALIASED	0			
X2X04X06	ALIASED	0			
X2X05X06	3.75625	1	4.22191	0.8921	0.3984
X3X04X05	ALIASED	0			
X3X04X06	1.75875	1	4.22191	0.4166	0.6879
X3X05X06	ALIASED	0			
X3X05X06	ALIASED	0			
510 ERROR	0.12501				

Obs	ACTUAL VALUE	PREDICTED VALUE	RESIDUAL	LEVER	STUDENT RESID	COOK'S DIST	t VALUE	Fun Ord
1	58.79000	59.59937	-0.80937	0.938	-0.271	0.024	-0.763	54
2	43.20000	42.35062	0.80938	0.938	0.271	0.024	0.763	37
3	29.18000	29.93937	-0.80937	0.938	-0.271	0.024	-0.763	9
4	31.29000	30.47062	0.80938	0.938	0.271	0.024	0.763	5
5	63.77000	62.96062	0.80938	0.938	0.271	0.024	0.763	10
6	52.03000	52.83937	-0.80937	0.938	-0.271	0.024	-0.763	15
7	67.82000	67.01062	0.80938	0.938	0.271	0.024	0.763	37
8	33.75000	34.55937	-0.80937	0.938	-0.271	0.024	-0.763	44
9	48.82000	49.92000	-1.10000	0.938	-0.368	0.044	-1.033	16
10	39.24000	38.14000	1.10000	0.938	0.368	0.044	1.033	41
11	48.25000	49.35000	-1.10000	0.938	-0.368	0.044	-1.033	37
12	51.19000	50.99000	1.10000	0.937	0.368	0.044	1.033	39
13	35.88000	34.78000	1.10000	0.937	0.368	0.044	1.033	27
14	41.52000	42.62000	-1.10000	0.938	-0.368	0.044	-1.033	28
15	55.65000	54.55000	1.10000	0.937	0.368	0.044	1.033	43
16	51.47000	52.57000	-1.10000	0.937	-0.368	0.044	-1.033	17
17	32.52000	38.9563	-5.97563	0.937	-2.002	1.307	-4.000	11
18	43.66000	37.68437	5.97563	0.937	2.002	1.307	4.000	40
19	47.18000	53.12563	-5.97563	0.937	-2.002	1.307	-4.000	43
20	31.98000	32.00437	5.97563	0.937	2.002	1.307	4.000	7
21	13.95000	7.97437	5.97563	0.937	2.002	1.307	4.000	10
22	6.39000	12.34563	-5.97563	0.937	-2.002	1.307	-4.000	32
23	55.54000	49.56437	5.97563	0.937	2.002	1.307	4.000	52
24	41.74000	47.71563	-5.97563	0.937	-2.002	1.307	-4.000	3
25	29.42000	28.61062	0.80938	0.937	0.271	0.024	0.763	42
26	41.11000	41.91937	-0.80937	0.937	-0.271	0.024	-0.763	56
27	70.02000	70.82938	-0.80937	0.937	-0.271	0.024	-0.763	34
28	34.83000	34.02063	0.80938	0.937	0.271	0.024	0.763	17
29	49.92000	49.11062	0.80938	0.937	0.271	0.024	0.763	4
30	38.60000	39.40937	-0.80937	0.937	-0.271	0.024	-0.763	31
31	38.85000	39.65937	-0.80937	0.937	-0.271	0.024	-0.763	23
32	54.94000	53.23062	0.80938	0.937	0.271	0.024	0.763	51
33	58.24000	57.14000	1.10000	0.937	0.368	0.044	1.033	2
34	56.74000	57.84000	-1.10000	0.937	-0.368	0.044	-1.033	48
35	49.32000	50.42000	-1.10000	0.937	-0.368	0.044	-1.033	6
36	50.63000	49.53000	1.10000	0.937	0.368	0.044	1.033	25
37	40.05000	38.95000	1.10000	0.937	0.368	0.044	1.033	35
38	33.33000	34.43000	-1.10000	0.937	-0.368	0.044	-1.033	37
39	29.36000	30.46000	-1.10000	0.937	-0.368	0.044	-1.033	30
40	55.58000	54.48000	1.10000	0.937	0.368	0.044	1.033	53
41	58.46000	52.48437	5.97563	0.938	2.002	1.307	4.000	47
42	43.68000	37.70437	5.97563	0.938	2.002	1.307	4.000	1
43	44.92000	50.89562	-5.97563	0.938	-2.002	1.307	-4.000	21
44	42.96000	48.93563	-5.97563	0.938	-2.002	1.307	-4.000	24
45	32.39000	38.36563	-5.97563	0.938	-2.002	1.307	-4.000	18
46	19.02000	24.99563	-5.97563	0.938	-2.002	1.307	-4.000	45
47	67.27000	61.29437	5.97563	0.938	2.002	1.307	4.000	12
48	42.16000	36.18437	5.97563	0.938	2.002	1.307	4.000	38
49	38.49000	37.23933	1.25167	0.167	0.115	0.000	0.324	8
50	41.78000	37.23833	4.54167	0.167	0.417	0.001	1.166	26
51	35.40000	37.23833	-1.83833	0.167	-0.169	0.000	-0.476	20
52	25.12000	37.23833	-12.11833	0.167	-1.112	0.005	-2.891	22
53	54.24000	37.23833	17.00167	0.167	1.560	0.011	3.580	36
54	29.40000	37.23833	-8.33833	0.167	-0.811	0.003	-2.197	19

Appendix 2

Response Surface Plots for:

**Energy (Btu) Recovery
Product Ash Content
Sulfur Rejection
Separation Efficiency**

END

DATE FILMED

02 / 19 / 91