ANNUAL REPORT

MINNESOTA DEPARTMENT OF NATURAL RESOURCES

SECONDARY BALL MILL OPTIMIZATION

September 1, 1989

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MINNESOTA DEPARTMENT OF NATURAL RESOURCES

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SECONDARY BALL MILL CIRCUIT OPTIMIZATION

1.0 GENERAL EXECUTIVE SUMMARY

1.1 General Background

Over the years there has been a general effort to reduce the power consumption in the grinding of taconite ores. This effort has resulted in a significant net savings in grinding power through the implementation of such things as finer blasting, tighter crusher settings, primary ball size variations and liner configurations. While there has been significant net power savings, one result has been an increasing load on the secondary grinding circuit.

This project was an attempt to improve the grinding efficiencies of a secondary grinding circuit in two parts. First, through optimization of mill operating parameters such as mill solids and ball size. Secondly, by improving classification efficiencies on the recirculating load.

1.2 Scope of Testwork

Part 1 (Grinding)

On this project the M. A. Hanna Research Center, Control International, Inc. and National Steel Pellet Company worked together in an effort to improve the grinding efficiencies in a secondary ball mill.

A mill audit of the five (5) NSPC secondary mill circuits was performed by Control International, Inc., M. A. Hanna and NSPC personnel in November, 1988. The various mill circuit samples were processed at the NSPC plant lab. A small bulk sample of line #5 cyclone underflow was collected and shipped to the University of Utah Comminution Center.

Data obtained from the mill audit sampling program was used by Control International for mass balance calculations to determine stream flowrates and to evaluate reliability of results for complex flowsheets.

A set of laboratory ball mill grinding experiments at various % solids and ball sizes was performed on the cyclone underflow sample. The batch grinding results were used as input to the computer estimator/simulator "GRINDSIM.S™". This computer model provides the statistically best estimates of grinding parameters for any ore from batch grinding data.

Part 2 (Classification)

Based on the data from the mill audit, batch grinding tests and the computer simulations, pilot plant scale ball mill grinding-classification tests were performed using the predicted optimum grinding parameters of 70-72% mill % solids and a graded ball charge based on a 50% 1.25" - 50% 1.0" topsize new ball addition. NSPC cobber concentrate was used as the new feed to the circuit.

Some thirty-one pilot plant tests were conducted using a conventional hydrocyclone, static and vibrating screens and a modified cyclone equipped with a JD spigot valve.

1.3 Conclusions and Recommendations

The conclusions and recommendations developed from this testwork are listed separately in the EXECUTIVE SUMMARIES of the following two reports on this project:

Grinding Tests and Computer Simulation For
Ball Mill Circuit Optimization at
National Steel Pellet Plant

and

Secondary Ball Mill Circuit Optimization
HRC Pilot Plant Testing

GRINDING TESTS AND COMPUTER SIMULATION FOR BALL MILL CIRCUIT OPTIMIZATION AT NATIONAL STEEL PELLET PLANT

GRINDING TESTS AND COMPUTER SIMULATION FOR BALL MILL CIRCUIT OPTIMIZATION AT NATIONAL STEEL PELLET PLANT

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EXECUTIVE SUMMARY

The objective of this project was to analyze the National Steel Pellet Plant grinding circuit with a view toward achieving optimal mill performance for improving plant production. The analysis was carried out using a combination of experimental data and mathematical models for the grinding process.

From laboratory and plant data it was found that ball size and % solids had a significant affect on mill throughput. Capacity changes were identified as follows:

Simulation Results Different Operating Conditions at a Product Size of 85% -100 Mesh in the Mill Discharge

Top Ball Size (inch)	% Solids	Energy Requirement KWh/t	Mill Capacity T/H	% Increase	Confidence in Predictions
0.75	70	6.78	370	+23.3	85%
1.00	70	6.94	361	+20.3	90%
1.50	70	9.24	271	-9.7	90%
50% 1.00	70	7.27	344	+14.7	90%
50% 1.25					
50% 1.25	70	8.37	300	base case	90%
50% 1.50	*	*	*	*	*
0.75	65	7.23	347	-6.2	90%
0.75	70	6.78	370	0	90%
0.75	75	7.04	356	-3.8	90%

The influence of % solids was determined based on laboratory and plant data. The influence of ball size was evaluated through laboratory testing and computer predictions of plant performance.

From the above table it can be concluded that:

1. Laboratory ball size tests and computer simulations indicate that the mill capacity increases with decreasing top size of balls. An increase of 8% or more can probably be acheived with 1.25 inches and 1.0 inches top size balls the confidence of this prediction is 90%.

2. Computer simulation and plant data indicate that optimum percent solids in the mill should be kept around 70%. The confidence of this prediction is 90%.

3. Automatic control of % solids in each mill is important to achieving maximum capacity.

Based on the findings of this study, the following recommendations have been made:

1. In the first step, change to 50% 1.25 inch and 50% 1.00 inch top size balls. Confirm computer predictions of about 10% increase in capacity.

2. Mill percent solids control should be implemented with a setpoint of 70-72%.

3. Because of the relatively low volume fillings observed in the ball mills No. and No. 5 (30%), we suggest an increase in ball load to increase power draw in the mills.

4. A quantitative study of the optimal rationed ball charge for National Steel Pellet Plant should be carried out in CII's laboratory to determine the maximum benefit achievable from a ball size change.

5. Screen classification test and computer simulation should be explored to determine the potential for additional mill capacity increase.

6. Feed flowrate meter should be installed for each grinding mill.

As a final conclusion the principal investigators feel confident that in the first step by a proper combination of a ball size change and percent solids control that additional capacity in excess of 10% can be made available in the National Steel Pellet Plant.

I. INTRODUCTION

The objective of this project was to analyze the National Steel Pellet Plant regrinding circuit performance with a view toward determining promising alternatives for increasing plant production. This analysis was carried out and capacity increases were predicted in the context of detailed population balance models developed for the National Steel Pellet Plant regrinding circuit.

Recent research has shown that population balance models provide an excellent basis for accurate mill scale-up from batch grinding experiments. The work at Control International, Inc. has proceeded along the following lines:

- A model for the grinding process has been developed. That is, a mathematical description has been written of how the size distribution in the mill changes with time spent in the mill, or, alternatively, with energy input to the mill. The model developed explicitly accounts for the major subprocesses that occur during grinding, namely, breakage kinetics, transport and classification. The breakage description deals with how fast particles of a given size break and what distribution of smaller size fragments are produced. Transport deals with how material moves through the mill. Classification is not part of the actual grinding process, but it is explicitly provided for in the model so that closed- as well as open-circuit grinding can be described.

- A set of laboratory grinding experiments have been designed from which inherent material characteristics important in scale-up can be determined.

- The model has been tested using a wide variety of laboratory pilot-scale and industrial-scale ball mills.

- A procedure for grinding process optimization using the population balance approach has been developed.

II. SCOPE OF WORK

The work described in this report involves six parts:

1. Plant testwork to determine the efficiency of operation of grinding lines and to obtain samples for batch tests for optimization.

2. Mass balance calculations to determine stream flowrates and to evaluate reliability of results for complex flowsheets.

3. Experiments to determine breakage parameters of the iron ore and to investigate the effect of important operating variables such as ball size and percent solids on mill performance.

4. Estimation of breakage kinetic parameters, computer simulation to determine the energy requirements at a desired product size with different ball size distributions and percent solids.

5. Computer simulation of mill capacity predictions for all grinding circuit conditions.

6. Determination of promising alternatives for optimization.

III. POPULATION BALANCE MODELS

The size discretized population balance model for breakage kinetics has been presented by several authors (Reid, 1965; Herbst, et. al., 1971; Austin, 1971-72). In brief, a mass balance for the material in the ith size interval at time t yields the kinetic model:

$$\frac{d(Hm_i(t))}{dt} = -S_i Hm_i(t) + \sum_{j=1}^{i-1} b_{ij} S_j Hm_j(t) \qquad (1)$$

where $m_i(t)$ is the mass fraction in the ith size interval and H is total mass of the material being ground. In Equation 1, S_i, the size-discretized selection function for the ith interval, denotes the fractional rate at which material is broken out of the ith size interval and b_{ij}, the size-discretized breakage function, represents the fraction of the primary breakage product of material in the jth size interval which appears in the ith size interval. Equation 1 is referred to as the size-discretized batch grinding model.

In order to apply the population balance model equations to practical solutions the dependence of the kinetic parameters (S_i, b_{ij}) on mill dimensions and operating conditions must be known. According to findings first presented by Herbst and Fuerstenau (1973), the size-discretized selection functions are to a good approximation proportional to the specific power delivered to the mill (P/H), that is,

$$S_i = S_i^E \, (P/H) \qquad (2)$$

where S_i^E termed the "specific selection function" is essentially independent of mill dimensions. In addition the breakage functions b_{ij} have been found to be to a good approximation invariant with respect to design and operating variables over a wide range of conditions. Incorporating these findings into Equation 1 yields the energy normalized form of the equation:

$$\frac{dm_i(\bar{E})}{d\bar{E}} = -S_i^E \, m_i(E) + \sum_{j=1}^{i-1} b_{ij} \, S_j^E \, m_j(\bar{E}) \qquad (3)$$

where E is the specific energy input to the mill, given by E = P/H. The normalized form of the model can be extended to continuous grinding using residence time distribution (RTD) information (Herbst, et. al., 1971). The mill product size distribution for a continuous mill is given by:

$$\underline{m}_{MP} = \int_0^{\infty} \underline{m}_{batch} (\bar{E})\ \phi\ (\bar{E})\ d\bar{E} \tag{4}$$

where $\underline{m}_{MP}$ is an average of batch responses, $\underline{m}_{batch}$ (E), weighted according to the amount of material that resides for various energy input in the mill. (E) is an energy density function (or "input energy distribution") that is related to the residence time distribution by:

$$\phi\ (\bar{E})\ d\ \bar{E} = \phi\ (t)\ dt \tag{5}$$

ϕ (t), the residence time distribution is an experimentally determinable function. In many instances the residence time distribution in a mill can be represented with a highly flexible mixers-in-series model (Himmelblau and Bischoff, 1968).

$$\phi\ (t) = \frac{N^N (t/\ \Upsilon)^{N-1}}{\Upsilon\ (N)} \exp\ (-\ \frac{Nt}{\Upsilon}) \tag{6}$$

where N is the mixing parameter which gives the equivalent number of mixers-in-series and Υ is the mean residence time for material in the mill.

To simplify the task of estimating a large set of kinetic parameters from experimental data, frequently a log-polynomial of second order is used to represent the size dependence of the specific selection function:

$$S_i^E = S_1^E \exp.\ (\ \varsigma_1 \ln (\sqrt{X_i\quad} X_{i+1} / \sqrt{X_1 X_2})) \\ +\ \varsigma_2 \ln (\sqrt{X_i\quad} X_{i+1} /\ \sqrt{X_1 X_2})^2 \tag{7}$$

while a three parameter functional form is used to represent the cumulative breakage function,

$$B_{ij} = \alpha_1\ (X_i/X_{j+1})^{\alpha 2} + (1-\ \alpha_1)(X_i X_{j+1})^{\alpha 3} \tag{8}$$

This reduces the parameters to be estimated to:

$$S_i^E,\ \varsigma_1,\ \varsigma_2 \text{ and } \alpha_1,\ \alpha_2 \text{ and } \alpha_3 \tag{9}$$

IV. EXPERIMENTS AND RESULTS

Different phases of the test program were carried out at different locations. Each is discussed here in turn.

1. Plant Testing and Sampling

The plant tests were run at National Steel Pellet Plant. The plant tests involved a baseline audit on each of the grinding mills, factorial design tests and RTD (Residence Time Distribution) tests.

Sampling of various mill streams was carried out during the plant testing. The objective of the sampling campaign was to obtain composite samples for a 20-minute period simultaneously from all streams to evaluate mill performance at steady-state conditions. The procedure for operating the plant during the sampling campaign was as follows. First, the feed rate and water rate were set at the desired values. Then, one to two hours were allowed to pass to permit the circuit to achieve steady state. A strip chart of the important operating variables was referred to in order to verify that the operation was steady during sampling.

A summary of operating conditions for each plant test is listed in Tables 1 and 2. The particle size analysis of mill feed and mill discharge, cyclone underflow and cyclone overflow obtained in the plant tests were carried out in the metallurgical laboratory at National Steel Pellet Plant.

The particle size distributions are tabulated in Appendix I. The mass balance calculation based on the plant testing data is provided in Appendix II.

Table 1: Baseline Audit

Mill No.	Mill Power KW	% Solids	% -150 Mesh (cyclone overflow)
1	1905	71.0	94.8
2	1930	70.7	94.2
3	1925	70.1	94.4
4	2910	69.5	94.9
5	2970	70.9	94.9

Table 2: 2^2 Factorial Design Experiments (Mill 5)

Test No.	Feed Rate T/H	Mill Power KW	% Solids	% -150 Mesh (cyclone overflow)
P-1	261	2960	70.9	96.8
P-2	297	2970	70.9	94.9
P-3	337	2960	74.0	93.9
P-4	324	2995	69.4	89.8
P-5	297	2890	71.6	93.8
P-6	292	2880	70.8	94.0

2. Batch Experiments

A detailed description of batch experiments and the associated scale-up procedure has been given in previous publications (Herbst, et. al., 1980, 1985). Briefly, batch grinding experiments were carried out with plant feed samples in a 10 inch diameter by 11.5 inch long stainless steel mill having eight square lifters. The mill was equipped with a Graham variable speed transmission coupled with a BLH torque sensor and a recorder to measure power draft directly from the drive shaft between the transmission and the mill. The top ball size used in the experiments were 1.5, 1.0, and 0.75 inches. In each case, the ball size distribution used approximated that of an "equilibrium charge distribution" often used in laboratory tests for scale-up design. The various ball size distributions used are presented in Table 3.

Table 3: Ball Size Distributions

Ball Diameter (inch)	d_{top}=1.5" weight %	d_{top}=1.0" weight %	d_{top}=0.75" weight %
1.50	78.6		
1.00	14.2	66.5	
0.75	5.7	26.3	78.6
0.50	1.5	7.2	21.4
Total	100.0	100.0	100.0

Details of the batch grinding condition explored in this study are summarized in Table 4.

Table 4: Batch Test Conditions

Test No.	Mass Hold-up (gm)	Water Addition (c.c)	Percent Solids by Weight	Top Ball Size (inch)	Specific Energy Input (KWH/T)	
B-1	4700	2010	70.0	1.5	4.08	5.10
B-2	4700	2010	70.0	1.0	4.16	5.20
B-3	4700	2010	70.0	0.75	4.47	5.59
B-4	4700	2530	65.0	0.75	4.47	5.59
B-5	4700	2010	70.0	0.75	4.47	5.59
B-6	4700	1570	75.0	0.75	5.40	6.76

A step-by-step description of the grinding procedure used for each experiment is given below:

1. The mill was filled with a predetermined weight of ore, balls and water.

2. The mill speed was adjusted with variable speed arrangement provided on the shaft. The mill was allowed to grind for the desired time (or energy input).

3. Mill contents were emptied and the ground product was wet screened through a 325 mesh screen mounted on a vibrator. The -325 mesh slurry was dewatered and dried.

4. The +325 mesh fraction was dried, then a 400 gm sample was taken and ro-tapped for 20 minutes.

5. The sample was recombined with the original material (not sampled) for the next grind time.

The data obtained in all batch grinding experiments are tabulated in Table III-1,2,3,4,5, and 6 Appendix III.

V. BREAKAGE PARAMETERS ESTIMATION

The batch grinding results were used as input to the estimator/simulator GRINDSIM.S^{TM}. This computer program provides the statistically best estimates of grinding parameters for any ore from batch grinding data. As an example, Figure 1 compares the fitted size distribution from the program GRINDSIM.S^{TM} with those experimentally observed during the batch Test B-2. The plot indicates that the model can be used to accurately describe the grinding of the cobber concentrate.

The breakage function is shown in Figure 2. The specific selection function obtained for various operating conditions will be discussed below:

Effect of Ball Size

Previous research has shown that in a wet grinding system, the particle size distribution of the ground product can be a strong function of the ball size distribution in the mill (Lo and Herbst, 1986). In this study, a similar effect of ball size on the selection function has been found. The specific selection function estimated for 1.5, 1.0 and 0.75 inch top size balls are shown in Figure 3.

Referring to Figure 3, the selection function parameters in the functional form (Equation 7) are tabulated in Table 5.

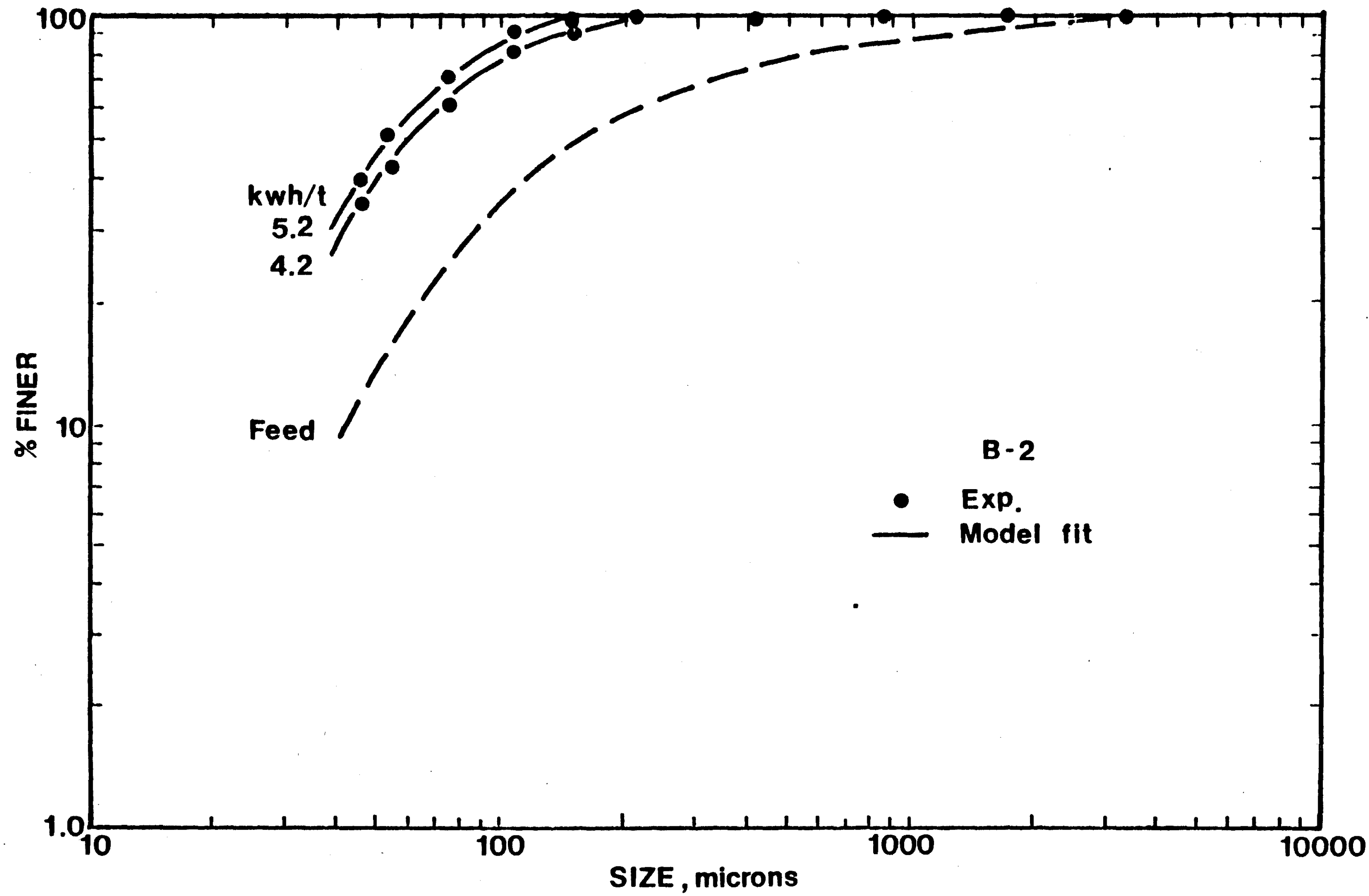

FIGURE 1: Comparison of Experimental Product Size Distribution and Best Fit of Model

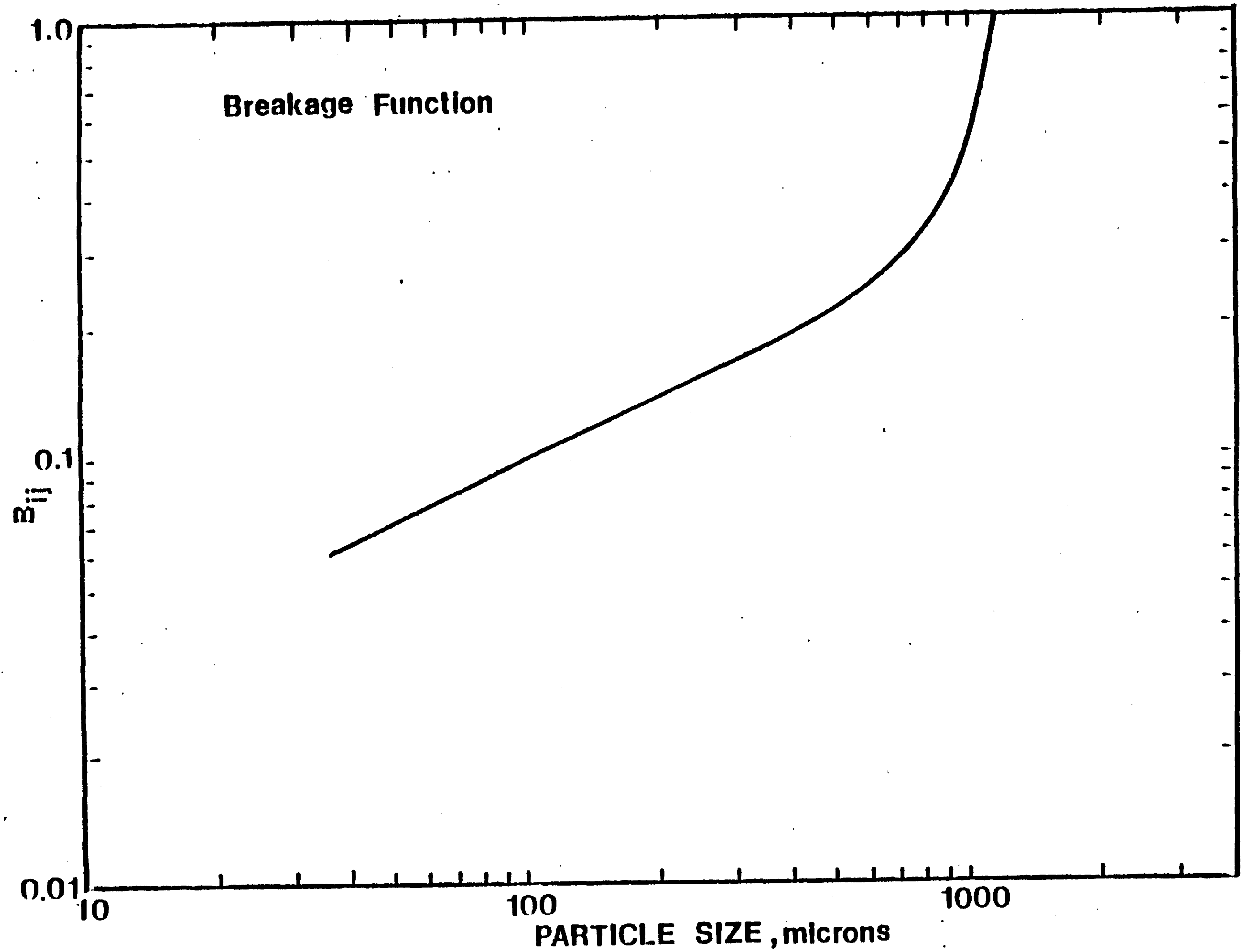

FIGURE 2: Breakage Function for Iron Concentrate

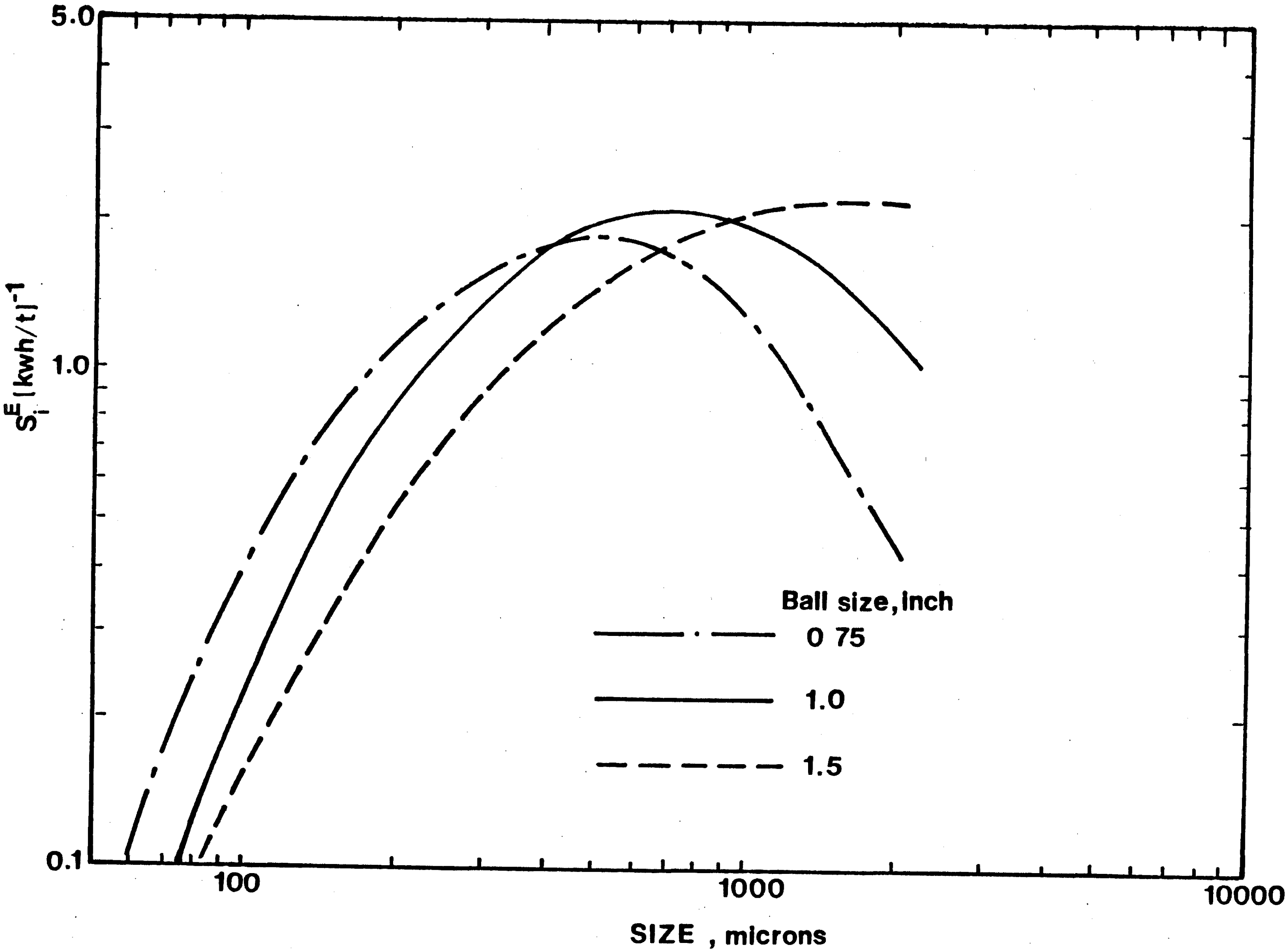

FIGURE 3: Comparison of Specific Selection Functions obtained for Wet Grinding with Different Top Size Balls.

Table 5: Estimates of Specific Selection Function Parameters

Ball Size (inch)	S_i^E	ζ_1	ζ_2
0.75	0.0280	-3.3642	-0.6746
1.00	0.1944	-2.3198	-0.5653
1.50	1.0899	-1.0520	-0.3812

The above values of specific selection function parameters were used for computer simulation to produce a product size of 85% -100 mesh in the mill discharge. As examples, the computer print-out of the simulation are provided in Table V-1, 2, 3, 4, and 5 Appendix V. A comparison of the mill capacity for different ball size distributions at 70% solids in the mill is shown in Table 6 and Figure 4.

Table 6: Simulation Results for Different Ball Size Distributions

Top Ball Size (inch)	Energy Input KWH/T	Feed Rate T/H (dry)	Relative Increase %
0.75	6.78	370	+23.3
1.00	6.94	361	+ 20.3
1.50	9.24	271	-9.7
50% 1.00	7.27	344	+14.7
50% 1.25			
50% 1.25	8.37	300	base case
50% 1.50			

It can be seen from Table 6 that the mill capacity increases with decreasing top size of balls.

Effect of Percent Solids

"Percent solids tests" were performed with the optimum, 0.75 inch ball size chosen from above tests. The specific selection function estimated for 65%, 70% and 75% solids of slurry in the mill are shown in Figure 4. The selection function parameters are tabulated in Table 7.

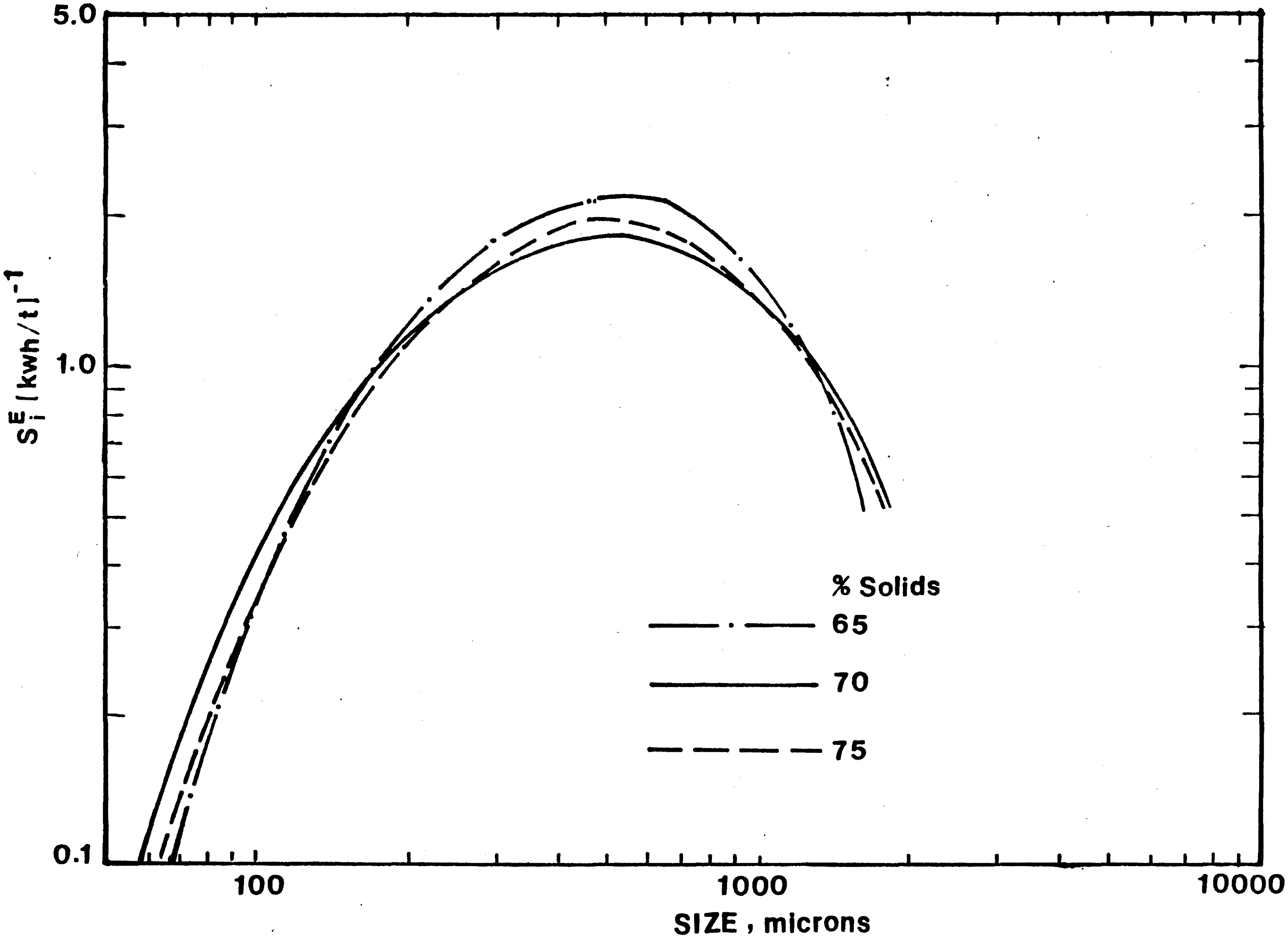

FIGURE 4: Comparison of Specific Selection Functions obtained for Wet Grinding at Different Percent Solids.

Table 7: Estimates of Specific Selection Function Parameters

Percent Solids %	S_i^E	ζ_1	ζ_2
65	0.0181	-3.8718	-0.7823
70	0.0280	-3.3642	-0.6746
75	0.0208	-3.1738	-0.7486

The simulation results for different percent solids are shown in Table 8.

Table 8: Simulation Results for Different Percent Solids

Percent Solids	Energy Input KWH/T	Feed Rate T/H	Relative Increase %
65	7.23	347	-6.2
70	6.78	370	base case
75	7.04	356	-3.8

The simulation results indicate that the percent solids in the mill should be kept around 70%.

VI. RESIDENCE TIME DISTRIBUTION (RTD) TESTS

Residence time distributions were determined using a soldium chloride tracer technique involving the analysis of the supernatent liquid from slurry samples. The assays of Na and Cl were carried out at Hanna Research Center. The residence time data and RTD model fits obtained for Tests P-2 are shown in Figure 5. In the case examined the mixing parameter N=1.7 and the mean residence time τ = 7.5 minutes.

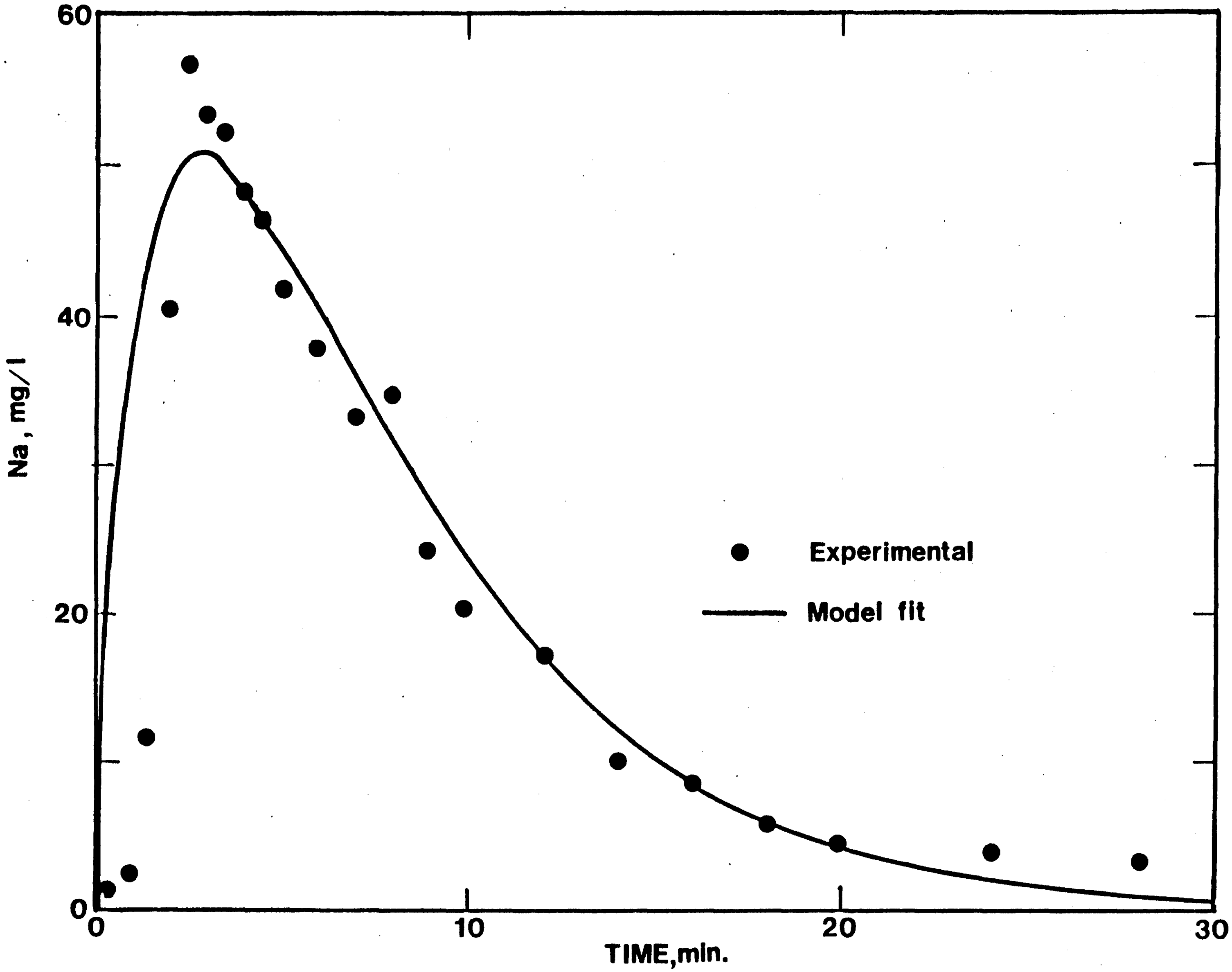

FIGURE 5: Model Fit of the Experimentally Determined Residence Time Distributed for Test P-2.

VII. MILL FILLING DETERMINATIONS

The volumes of mill charge determined are reported in Appendix IV. On average the volume filling of balls was found to be below the filling level which produces maximum power draw (and therefore achieves maximum capacity). In the case of the large mills (No. 4 and 5) the filling was approximately 30% by volume and a substantial increase seemed possible so long as the drive power constraint was not violated.

VIII. MASS BALANCE

The mass balance for the grinding/separation circuit was computed for each line. The computer print-out of the computation is provided in Appendix II. The relative mass flow rates for each stream of ten plant tests are presented in Table 9.

Table 9: Relative Mass Flowrates

Line No.	Cobber Conc.	Cyclone Feed	Cyclone O'Flow	Cyclone U'Flow	Mill Discharge	Finisher Tails	Fine Screen Feed	Fine Screen O'Size	Fine Screen U'Size
1	1.00	3.29	1.01	2.29	2.28	0.14	0.87	0.01	0.86
2	1.00	4.99	2.57	2.42	2.42	0.00	2.57	1.57	1.00
3	1.00	3.13	1.52	1.61	1.61	0.48	1.04	0.52	0.52
4	1.00	4.25	2.49	1.76	1.76	0.01	2.48	1.49	0.99
5-P1	1.00	2.62	1.27	1.35	1.35	0.43	0.84	0.27	0.57
5-P2	1.00	3.24	1.67	1.57	1.57	0.21	1.46	0.67	0.79
5-P3	1.00	2.65	1.21	1.44	1.44	0.26	0.95	0.21	0.74
5-P4	1.00	2.67	1.50	1.17	1.17	0.31	1.19	0.50	0.69
5-P5	1.00	2.72	1.23	1.49	1.49	0.21	1.02	0.24	0.78
5-P6	1.00	3.17	1.64	1.53	1.53	0.21	1.43	0.64	0.79

It can be seen from the Table above that the baseline audit test (line 1,2,3,4, and 5-P2) the values of circulating load to the grinding mill vary in the range of 150-250%, but the recycle rates of fine screen oversize vary significantly from 0 to 150%.

IX. PREDICTION OF PLANT SCALE MILL PERFORMANCE

A test of the utility of the population balance model is to evaluate the predictive capability of the model for scale-up. In this way, it can be determined whether conclusions drawn from small-scale batch tests can be used to predict benefits in a quantitative way for the full-scale plant. In this regard the batch data obtained in the 10 inch mill was used to predict the full-scale mill performance. The RTD information obtained from plant testing was used for predictions. The scale-up predictions given here are based on a narrow specific energy range corresponding to the product fineness expected for the large mill. As an example, Figure 6 shows the predictions and experimental product size distributions for 16.5 x 28 ft. mill (mill No. 4). The product size distribution error (the root mean squared deviation between fitted and experimental values) is 3% with a mill volume scale-up factor of 11400 to 1. These results indicate that accurate extrapolations from laboratory batch data to plant scale performance is possible, using the population balance model and scale-up prediction procedures.

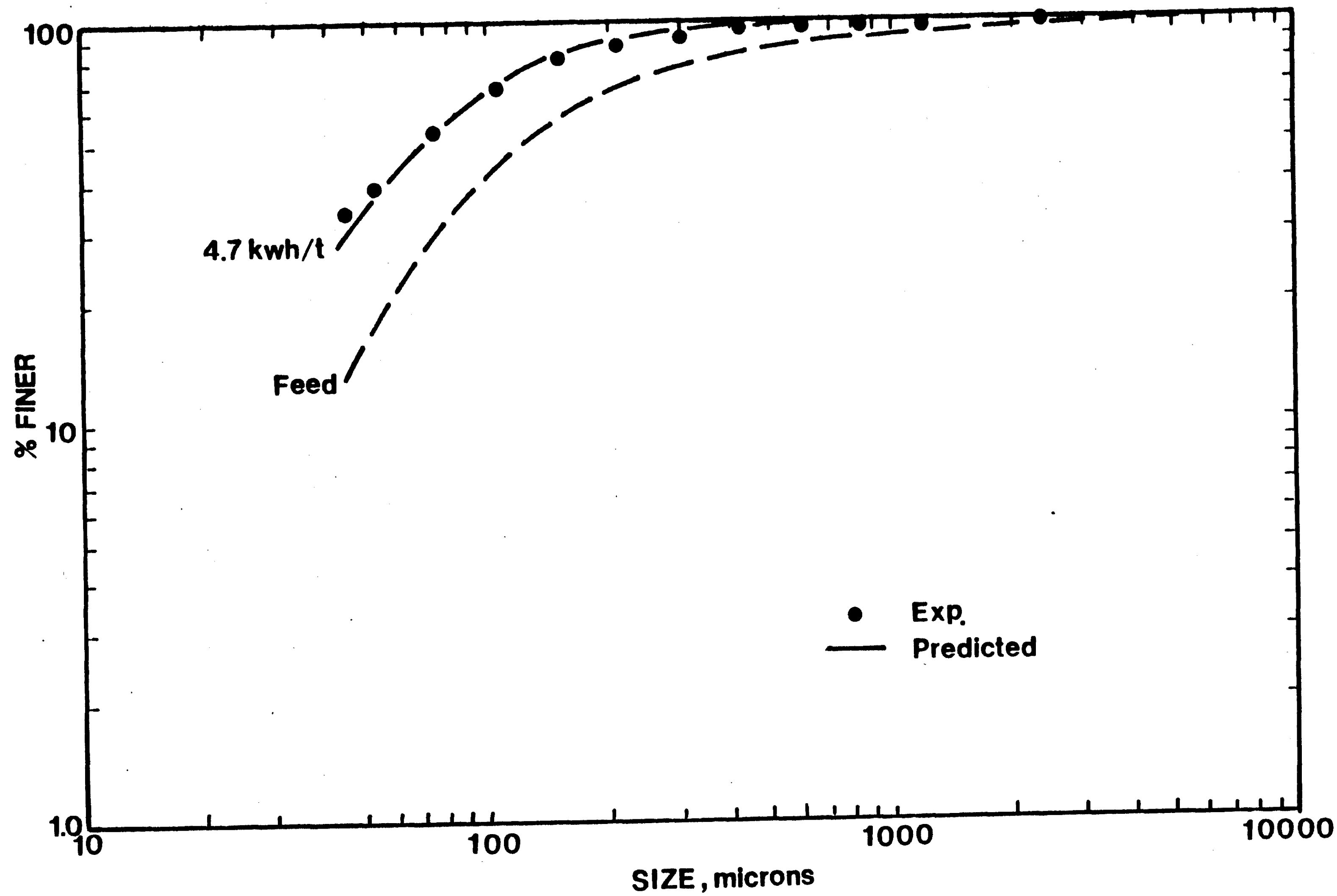

FIGURE 6: Comparison of Experimental Product Size Distribution

X. THE ANALYSIS OF BASELINE AUDIT PLANT TEST

The specific selection functions obtained from plant data for mill number 1,2,3,4, and 5 are shown in Figure 7. As examples, the computer print-out of the simulation are provided in Appendix V. The computer simulations for the performance of each mill are presented in Table 10. It can be seen from the baseline audit that the variation of percent solids is small and the average value of the percent solids in the mill were about 70.5%.

Table 10: Simulation Results for Five Mills at 95% -150 Mesh Product Size

Mill No.	% Solids	Energy Requirements (KWH/T)*
1	71.0	9.5
2	70.9	9.4
3	70.1	9.5
4	69.5	9.8
5	70.9	10.1

It indicates that all of the five mills were operated in the range of optimum solids. The performance of each mill was quite similar. The 16.5 x 28 ft larger mills (No. 4 and 5) appear to have somewhat lower grinding efficiency, possibly due to the reduced ball charge (about 30%).

* KWh/t Cobber Concentrate

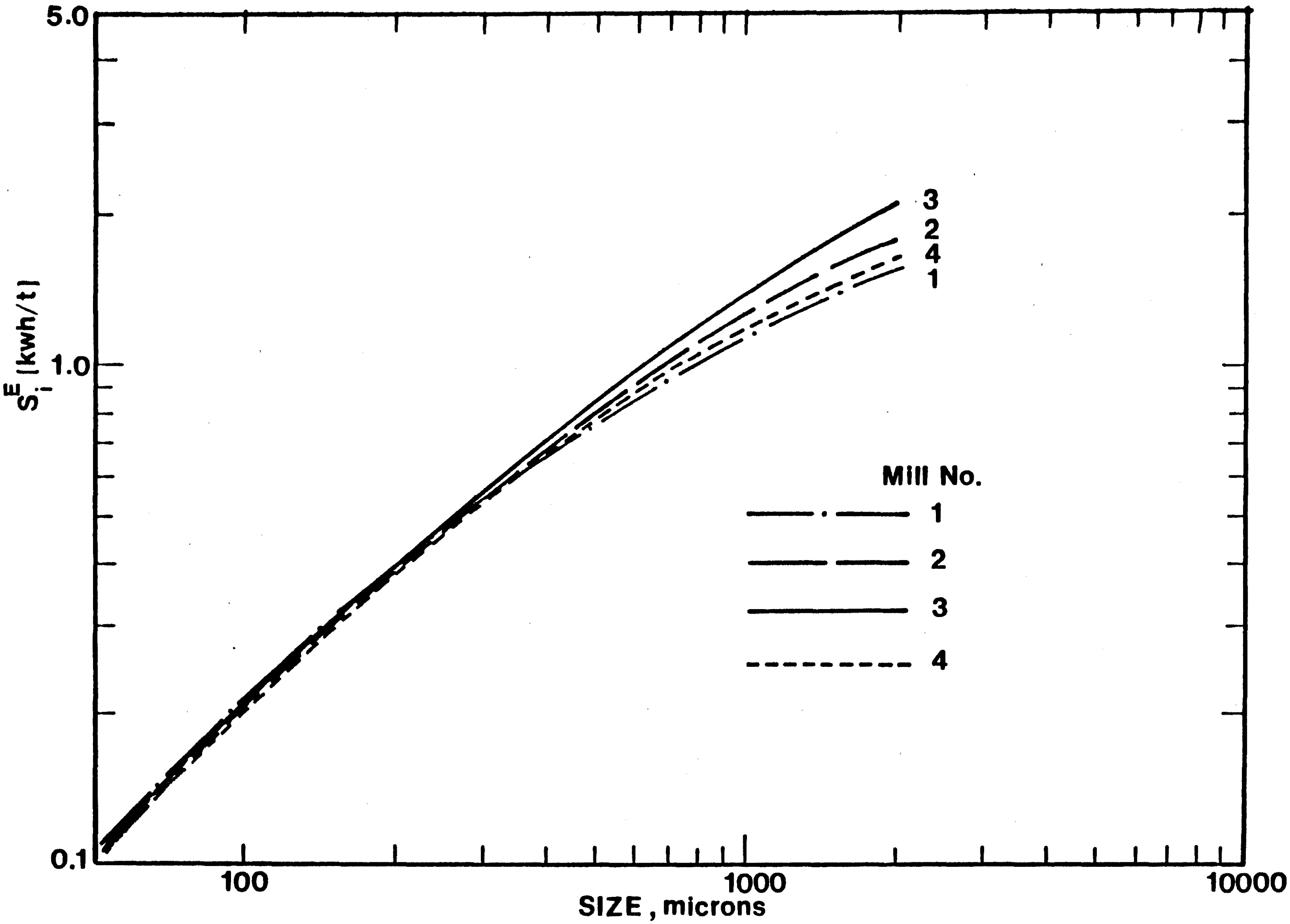

FIGURE 7: Specific Selection Functions for
Mill 1,2,3 and 4.

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XI. FACTORIAL DESIGN TESTS

The data obtained from 2^2 factorial design tests are listed in Table 2 and Appendix I. The manipulated variables are feed tonnage and percent solids. The measured variables are mill power partical size distributions.

The specific selection functions obtained from test P-1, P-2, P-4, P-5 and P-6 are shown in Figure 8.

Computer simulations of mill performance with different operating conditions producing the same product size are shown in Table 11. Comparison of these results show that the mills operating at about 70% solids gave higher grinding efficiency. This trend with mill % solids is also observed in the batch grinding tests mentioned above.

Table 11: Simulation Results for Closed Circuit Grinding with Different Operating Conditions at 95% -150 Mesh Product Size

Test No.	Designed Test Conditions: Feed Rate T/H	% Solids	Simulated Energy Requirement KWH/T
Mill 5			
P-2	297	70	10.1
P-5	297	70	10.5
P-1	261	67	12.4
P-6	292	73	12.6
P-4	324	73	14.1

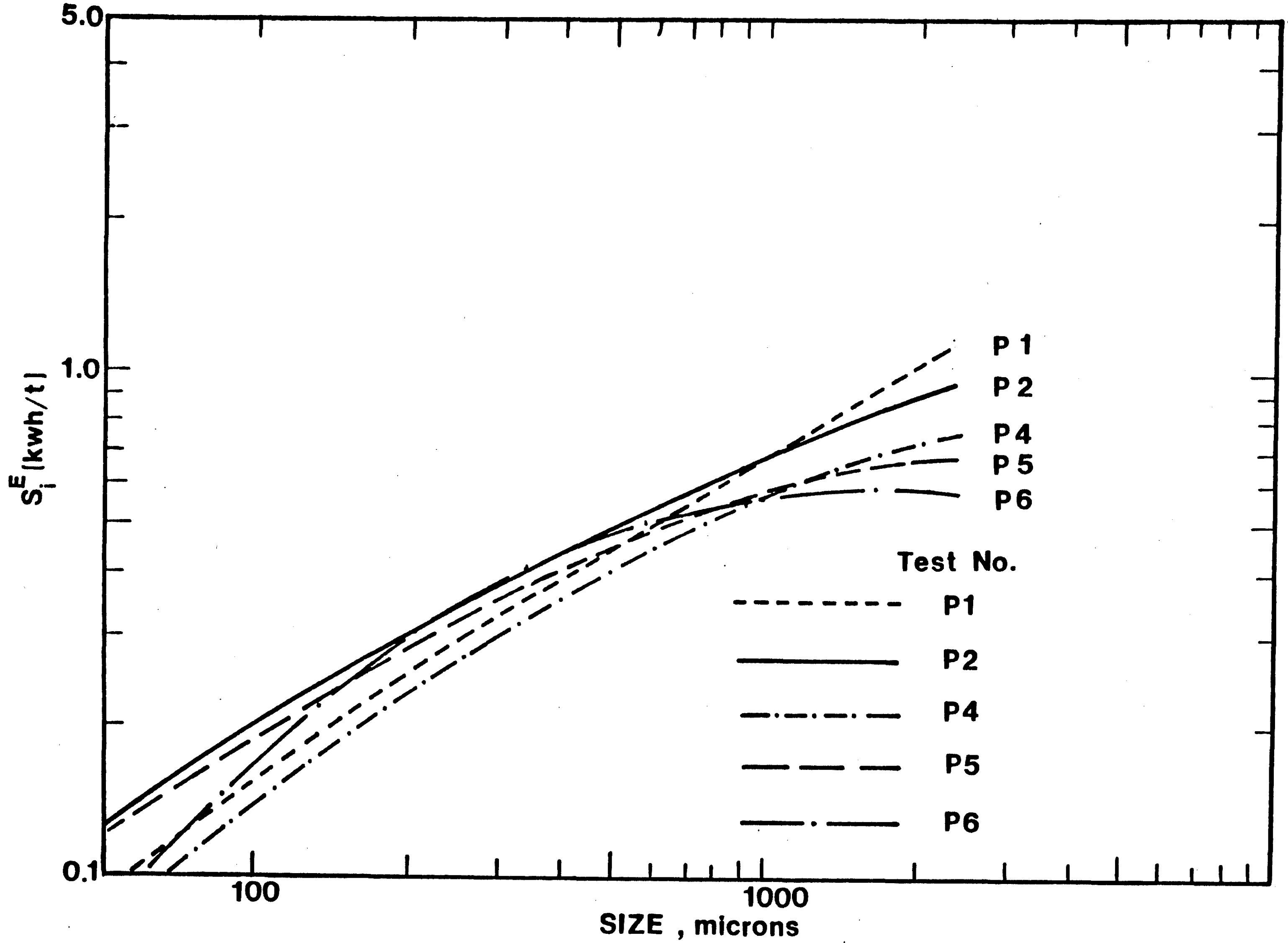

FIGURE 8: Specific Selection Functions for Tests P-1, P-2, P-4, P-5 and P-6.

XII. CONCLUSIONS AND RECOMMENDATIONS

In this investigation a series of batch and plant tests have been carried out to determine promising alternatives for improving steady state grinding circuit performance. The experimental data obtained from batch and plant tests were evaluated using our estimator and simulator computer programs, GRINDSIM.S^{TM}. The major findings of this study are:

1. Laboratory ball size tests and computer simulations indicate that the mill capacity increases with decreasing top size of balls. An increase of 8% or more can probably be achieved with 1.25 inches and 1.0 inches top size balls. The confidence of this prediction is 90%.

2. Computer simulation and plant data indicate that optimum percent solids should be kept around 70%. The confidence of this prediction is also 90%.

Based on the above findings the following recommendations are made:

1. Mill percent solids control should be implemented with a setpoint of 70 - 72%.

2. Because of low volume fillings observed in the ball mills No. 4 and No. 5 (about 30%), we suggest an increase in ball load to increase power draw in the mills.

3. The potential improvement associated with a rationed ball charge (two or three size charging) should be evaluated through additional laboratory testing and computer simulation.

4. The grinding circuit operating with a screen classification system seems to have the potential for mill capacity increase. Screen classification test and computer simulation should be explored.

5. Feed flowrate meter should be installed for each grinding mill.

As a final conclusion the principal investigatiors feel confident that in the first step by a proper combination of a ball size change and percent solids control that additional capacity in excess of 10% can be made available in the National Steel Pellet Plant.

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APPENDIX I

Experimental Product Size Distributions Obtained in Plant Tests

National Steel Pellet Plant
LINE 1

Individual Weight %

Top Size Mesh	Cobber Conc	Cyclone Feed	Cyclone O'Flow	Cyclone U'Flow	Mill Discharge	Finisher Tails	Fine Screen Feed	Fine Screen O'Size	Fine Screen U'Size
4	1.9	0.5	0.0	1.0	0.4	0.0	0.0	0.0	0.0
6	3.7	1.1	0.0	1.4	0.3	0.0	0.0	0.1	0.0
8	4.3	1.1	0.0	1.5	0.3	0.0	0.0	0.1	0.0
10	4.8	1.4	0.0	2.3	0.6	0.0	0.0	0.4	0.0
14	4.8	1.6	0.0	2.8	0.5	0.0	0.0	0.2	0.0
20	5.2	1.9	0.0	3.3	0.7	0.0	0.0	0.3	0.0
28	5.3	2.5	0.0	4.3	1.0	0.0	0.0	0.3	0.0
35	5.8	4.4	0.0	7.1	2.7	0.1	0.0	0.2	0.0
48	6.9	5.8	0.2	9.4	5.7	0.1	0.1	0.6	0.2
65	6.2	6.9	1.1	9.7	6.6	3.1	0.5	2.0	0.4
100	7.1	9.7	3.9	14.0	11.4	13.8	2.4	7.0	1.6
150	6.9	13.0	6.6	17.4	16.8	18.2	5.4	12.6	4.7
200	6.9	13.1	14.8	12.5	15.7	16.6	16.6	24.6	15.0
270	2.7	4.0	6.7	2.3	4.4	4.8	8.0	9.2	8.0
325	27.5	34.0	66.7	11.0	32.9	43.3	67.0	42.4	70.1

National Steel Pellet Plant
LINE 2

Individual Weight %

Top Size Mesh	Cobber Conc	Cyclone Feed	Cyclone O'Flow	Cyclone U'Flow	Mill Discharge	Finisher Tails	Fine Screen Feed	Fine Screen O'Size	Fine Screen U'Size
4	4.6	0.6	0.0	2.3	0.4	0.0	0.0	0.0	0.0
6	6.0	1.4	0.0	2.8	0.6	0.0	0.0	0.0	0.0
8	6.1	0.7	0.0	2.7	0.5	0.0	0.0	0.0	0.0
10	7.2	1.3	0.0	3.1	0.6	0.0	0.0	0.0	0.0
14	6.9	1.5	0.0	3.3	0.5	0.0	0.0	0.0	0.0
20	5.3	1.9	0.0	3.5	0.8	0.0	0.0	0.1	0.0
28	4.7	2.3	0.0	4.3	1.5	0.0	0.0	0.1	0.0
35	4.9	3.8	0.0	6.3	3.7	0.1	0.1	0.2	0.0
48	5.7	5.4	0.4	8.5	5.3	0.5	0.4	1.1	0.3
65	5.0	5.8	1.5	9.0	6.1	6.9	1.2	1.9	0.5
100	5.9	9.2	3.9	13.3	11.1	10.9	2.8	5.7	1.8
150	5.8	12.8	7.3	16.1	15.8	17.0	7.1	11.3	5.1
200	6.0	13.0	15.4	10.8	14.4	14.6	16.7	21.1	14.8
270	2.8	5.0	7.6	2.5	4.9	5.1	8.8	9.7	8.6
325	23.1	35.3	63.9	11.5	33.8	44.2	62.9	48.8	68.9

National Steel Pellet Plant
LINE 3

Individual Weight %

Top Size Mesh	Cobber Conc	Cyclone Feed	Cyclone O'Flow	Cyclone U'Flow	Mill Discharge	Finisher Tails	Fine Screen Feed	Fine Screen O'Size	Fine Screen U'Size
4	2.1	0.8	0.0	1.5	0.2	0.0	0.0	0.0	0.0
6	3.1	1.3	0.0	2.1	0.3	0.0	0.0	0.0	0.0
8	3.0	1.3	0.0	2.4	0.4	0.0	0.0	0.0	0.0
10	4.6	1.8	0.0	3.1	0.3	0.0	0.0	0.0	0.0
14	4.6	2.1	0.0	3.5	0.5	0.0	0.0	0.1	0.0
20	5.1	2.3	0.0	4.1	0.7	0.0	0.0	0.1	0.0
28	5.2	2.7	0.0	5.1	1.5	0.0	0.0	0.0	0.0
35	5.9	4.4	0.1	7.0	3.6	0.0	0.0	0.3	0.1
48	7.0	5.8	0.4	9.0	5.3	0.3	0.1	1.3	0.4
65	6.3	6.1	1.3	9.2	6.2	2.9	0.8	2.0	0.7
100	7.1	9.1	3.8	12.6	10.4	9.8	2.3	5.5	1.8
150	7.1	11.8	6.9	15.1	14.7	14.2	5.3	11.2	3.7
200	7.2	12.5	14.5	11.2	15.0	15.7	15.4	24.8	12.9
270	3.2	4.4	6.6	2.3	4.6	5.3	7.8	8.0	7.6
325	28.5	33.6	66.4	11.8	36.3	51.8	68.3	46.7	72.8

National Steel Pellet Plant
LINE 4

Individual Weight %

Top Size Mesh	Cobber Conc	Cyclone Feed	Cyclone O'Flow	Cyclone U'Flow	Mill Discharge	Finisher Tails	Fine Screen Feed	Fine Screen O'Size	Fine Screen U'Size
4	0.8	0.2	0.0	1.1	0.2	0.0	0.0	0.0	0.0
6	1.7	0.2	0.0	1.5	0.2	0.0	0.0	0.0	0.0
8	2.0	0.2	0.0	2.0	0.4	0.0	0.0	0.0	0.0
10	4.7	0.6	0.0	2.5	0.6	0.0	0.0	0.0	0.0
14	4.6	0.9	0.0	3.1	0.9	0.0	0.0	0.0	0.0
20	4.5	1.4	0.0	3.2	1.1	0.0	0.0	0.0	0.0
28	5.0	2.3	0.0	4.4	2.0	0.0	0.0	0.0	0.0
35	5.9	4.1	0.0	6.6	4.2	0.0	0.1	0.2	0.1
48	7.2	6.0	0.3	8.4	5.6	0.4	0.3	1.1	0.1
65	6.7	6.2	1.1	8.5	6.0	2.7	0.9	1.7	0.4
100	7.7	9.9	3.7	12.3	9.9	11.0	3.0	5.4	1.1
150	7.7	13.6	7.3	15.6	14.5	17.3	7.4	12.1	3.4
200	7.8	15.0	14.7	14.5	15.6	17.4	16.1	21.9	11.1
270	3.7	5.2	8.2	3.6	5.0	5.7	9.3	9.7	8.2
325	30.0	34.2	64.7	12.7	33.8	45.5	62.9	47.9	75.6

National Steel Pellet Plant
LINE 5-P1

Individual Weight %

p Size Mesh	Cobber Conc	Cyclone Feed	Cyclone O'Flow	Cyclone U'Flow	Mill Discharge	Finisher Tails	Fine Screen Feed	Fine Screen O'Size	Fine Screen U'Size
4	0.5	0.9	0.0	2.4	0.1	0.0	0.0	0.0	0.0
6	0.8	0.9	0.0	2.4	0.4	0.0	0.0	0.0	0.0
8	1.7	1.2	0.0	2.8	0.5	0.0	0.0	0.0	0.0
10	2.5	1.4	0.0	3.2	0.6	0.0	0.0	0.0	0.0
14	3.5	1.6	0.0	3.4	0.5	0.0	0.0	0.1	0.0
20	4.3	2.0	0.0	4.2	1.6	0.0	0.0	0.1	0.0
28	5.0	3.0	0.0	5.2	2.1	0.0	0.0	0.1	0.0
35	5.8	4.9	0.1	7.0	4.4	0.1	0.1	0.2	0.0
48	7.4	6.2	0.2	8.7	5.9	0.1	0.0	0.4	0.0
65	7.0	6.1	0.6	8.7	6.0	1.0	0.4	0.9	0.2
100	8.3	8.9	2.3	11.4	9.4	7.3	1.6	2.9	0.8
150	8.4	11.9	5.0	13.3	12.7	13.4	3.9	6.4	2.6
200	8.3	14.1	11.2	12.7	14.8	17.0	11.6	17.4	9.5
270	3.7	4.7	7.4	3.0	4.8	6.0	8.3	11.2	7.4
-325	32.6	32.2	73.2	11.6	36.2	55.1	74.1	60.3	79.5

National Steel Pellet Plant
LINE 5-P2

Individual Weight %

Top Size Mesh	Cobber Conc	Cyclone Feed	Cyclone O'Flow	Cyclone U'Flow	Mill Discharge	Finisher Tails	Fine Screen Feed	Fine Screen O'Size	Fine Screen U'Size
4	0.9	0.6	0.0	1.8	0.1	0.0	0.0	0.0	0.0
6	1.7	0.9	0.0	2.0	0.4	0.0	0.0	0.0	0.0
8	2.5	1.1	0.0	1.7	0.4	0.0	0.0	0.0	0.0
10	3.3	1.4	0.0	2.6	0.7	0.0	0.0	0.0	0.0
14	3.9	1.4	0.0	3.0	0.8	0.0	0.0	0.1	0.0
20	4.4	1.9	0.0	3.9	1.1	0.0	0.0	0.1	0.0
28	4.8	1.9	0.1	4.8	2.6	0.0	0.0	0.0	0.0
35	5.6	2.8	0.1	7.1	4.8	0.0	0.1	0.2	0.0
48	7.2	5.1	0.4	9.4	5.9	0.3	0.4	0.7	0.2
65	6.7	6.1	1.2	8.8	5.7	2.8	0.9	1.5	0.4
100	8.0	9.4	3.3	11.9	9.1	10.8	2.5	4.1	1.1
150	8.1	13.1	6.6	15.0	13.2	14.9	5.7	8.5	3.1
200	8.0	15.2	14.4	12.9	14.8	16.4	15.3	22.2	10.8
270	3.3	5.3	7.9	3.1	4.9	4.6	8.7	8.3	7.1
325	31.6	34.2	66.0	12.4	35.5	50.2	66.4	54.3	77.3

National Steel Pellet Plant
LINE 5-P3

Individual Weight %

Top Size Mesh	Cobber Conc	Cyclone Feed	Cyclone O'Flow	Cyclone U'Flow	Mill Discharge	Finisher Tails	Fine Screen Feed	Fine Screen O'Size	Fine Screen U'Size
4	0.4	1.8	0.0	2.9	0.3	0.0	0.0	0.0	0.0
6	1.3	2.1	0.0	3.3	0.7	0.0	0.0	0.1	0.0
8	1.6	2.1	0.0	2.5	0.7	0.0	0.0	0.1	0.0
10	2.5	1.9	0.0	3.1	1.0	0.0	0.0	0.2	0.0
14	3.6	1.9	0.0	3.6	1.1	0.0	0.0	0.2	0.0
20	4.4	2.2	0.0	4.2	1.4	0.0	0.0	0.1	0.0
28	5.1	3.2	0.0	5.2	2.2	0.0	0.0	0.2	0.0
35	5.8	4.9	0.0	6.9	4.2	0.0	0.1	0.5	0.0
48	7.5	5.9	0.7	9.0	6.0	0.6	0.5	1.5	0.2
65	6.8	6.2	1.6	8.9	6.5	3.8	1.1	2.3	0.7
100	8.2	9.7	3.8	12.1	10.4	11.3	3.1	4.8	1.6
150	8.0	12.9	7.4	13.5	14.1	15.1	7.0	10.4	4.2
200	8.0	12.7	16.0	10.1	13.4	16.6	17.0	22.1	13.0
270	3.6	4.2	7.3	2.6	4.6	4.8	8.2	8.2	7.5
325	33.2	28.3	63.2	12.1	33.4	47.8	63.0	49.3	72.8

National Steel Pellet Plant
LINE 5-P4

Individual Weight %

Top Size Mesh	Cobber Conc	Cyclone Feed	Cyclone O'Flow	Cyclone U'Flow	Mill Discharge	Finisher Tails	Fine Screen Feed	Fine Screen O'Size	Fine Screen U'Size
4	0.3	0.2	0.0	1.4	0.3	0.0	0.0	0.0	0.0
6	0.7	0.5	0.0	1.5	0.2	0.0	0.0	0.0	0.0
8	1.4	0.9	0.0	2.4	0.6	0.0	0.0	0.0	0.0
10	2.2	1.1	0.0	3.2	0.7	0.0	0.0	0.0	0.0
14	3.2	1.6	0.0	4.4	1.2	0.0	0.0	0.1	0.0
20	4.3	2.1	0.0	5.7	1.7	0.0	0.0	0.1	0.0
28	5.3	3.3	0.0	7.1	3.3	0.0	0.0	0.1	0.0
35	6.4	5.5	0.2	9.1	5.6	0.1	0.1	0.3	0.0
48	8.2	7.1	1.3	10.9	7.1	2.2	1.2	2.1	0.2
65	7.7	7.7	3.0	9.8	7.5	6.5	2.7	4.5	0.9
100	9.0	11.4	5.7	11.9	11.5	12.9	5.6	8.1	3.2
150	8.4	13.0	9.8	11.0	13.4	15.3	11.0	14.8	7.7
200	8.9	12.0	16.5	7.6	11.7	16.4	18.3	21.3	15.2
270	3.5	4.2	6.8	2.1	4.2	5.8	7.1	7.4	7.3
325	30.5	29.4	56.7	11.9	31.0	40.8	54.0	41.2	65.5

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National Steel Pellet Plant
LINE 5-P5

Individual Weight %

Top Size Mesh	Cobber Conc	Cyclone Feed	Cyclone O'Flow	Cyclone U'Flow	Mill Discharge	Finisher Tails	Fine Screen Feed	Fine Screen O'Size	Fine Screen U'Size
4	0.4	1.0	0.0	1.1	0.3	0.0	0.0	0.0	0.0
6	0.9	1.0	0.0	1.8	0.7	0.0	0.0	0.0	0.0
8	1.6	1.1	0.0	1.9	0.7	0.0	0.0	0.1	0.0
10	2.3	1.3	0.0	2.6	0.8	0.0	0.0	0.1	0.0
14	3.3	1.3	0.0	3.1	0.9	0.0	0.0	0.1	0.0
20	4.2	1.6	0.0	3.9	1.3	0.0	0.0	0.1	0.0
28	4.8	2.2	0.0	5.7	2.0	0.0	0.0	0.1	0.0
35	5.9	4.3	0.1	8.0	4.6	0.1	0.1	0.3	0.1
48	7.8	6.3	0.5	9.7	6.0	0.5	0.4	1.4	0.1
65	7.3	6.7	1.6	9.5	6.9	3.8	1.4	2.4	0.6
100	8.9	10.2	4.0	13.0	10.5	11.3	3.3	5.6	1.8
150	8.7	13.4	7.6	14.8	14.1	15.0	6.8	12.3	4.4
200	8.4	13.7	16.0	11.2	13.7	17.1	16.6	22.9	13.2
270	3.5	4.9	7.7	2.6	4.4	5.6	8.3	8.3	8.2
325	32.0	31.0	62.5	11.1	33.1	46.6	63.1	46.4	71.6

National Steel Pellet Plant
LINE 5-P6

Individual Weight %

Top Size Mesh	Cobber Conc	Cyclone Feed	Cyclone O'Flow	Cyclone U'Flow	Mill Discharge	Finisher Tails	Fine Screen Feed	Fine Screen O'Size	Fine Screen U'Size
4	0.1	0.5	0.0	1.7	0.8	0.0	0.0	0.0	0.0
6	0.7	0.7	0.0	1.9	0.7	0.0	0.0	0.0	0.0
8	1.2	1.0	0.0	1.8	0.6	0.0	0.0	0.0	0.0
10	2.1	1.1	0.0	2.7	0.7	0.0	0.0	0.0	0.0
14	3.2	1.3	0.0	3.4	0.9	0.0	0.0	0.1	0.0
20	4.2	1.6	0.0	4.5	1.4	0.0	0.0	0.1	0.0
28	5.0	2.3	0.0	5.9	2.8	0.0	0.0	0.0	0.0
35	6.2	4.5	0.1	7.8	4.9	0.0	0.1	0.2	0.0
48	8.0	5.8	0.5	9.8	5.9	0.3	0.4	1.1	0.1
65	7.6	6.4	1.5	9.5	6.2	3.3	1.2	1.8	0.6
100	9.0	10.0	3.9	12.3	10.3	12.5	3.2	4.7	1.6
150	8.9	13.8	7.3	13.4	14.0	15.3	7.3	9.2	4.3
200	8.8	14.2	15.6	10.3	14.3	17.8	17.2	23.0	14.0
270	3.5	4.8	7.6	2.7	4.5	5.3	8.4	8.2	7.4
325	31.5	32.0	63.5	12.3	32.0	45.5	62.2	51.8	72.0

APPENDIX II

Computer Print-Out for Mass Balance

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NSL1.DAT
National Steel Secondary Mill Testing LINE 1


    POWELL ALGORITHM

  N =  3    MAXIT =   10    ESCALE =   .10

 STARTING VALUES (X)      REQUIRED ACCURACIES (E)
   0.32000000E+01            0.63999999E-01
   0.17000000E+01            0.33999999E-01
   0.20000000E+00            0.39999999E-02
A RELATIVE ORE FLOW RATE IS FOUND NEGATIVE
RUN CONTINUES
A RELATIVE ORE FLOW RATE IS FOUND NEGATIVE
RUN CONTINUES


    POWELL ALGORITHM


ITERATION  1      168  FUNCTION EVALUATIONS,  F = 0.12502839E+04

ESTIMATES :   4.04265  1.00300   .13320
A RELATIVE ORE FLOW RATE IS FOUND NEGATIVE
RUN CONTINUES


    POWELL ALGORITHM


ITERATION  2      182  FUNCTION EVALUATIONS,  F = 0.11613435E+04

ESTIMATES :   3.28108  1.00300   .13512
A RELATIVE ORE FLOW RATE IS FOUND NEGATIVE
RUN CONTINUES


    POWELL ALGORITHM


ITERATION  3      193  FUNCTION EVALUATIONS,  F = 0.11613315E+04

ESTIMATES :   3.29211  1.00300   .13502
A RELATIVE ORE FLOW RATE IS FOUND NEGATIVE
RUN CONTINUES


    POWELL ALGORITHM
```

ITERATION 4 205 FUNCTION EVALUATIONS, F = 0.11613294E+04

ESTIMATES : 3.28906 1.00300 .13506

END OF CRITERION MINIMIZATION
CRITERION VALUE FOR NETWORK 3 DATA : 1161.3294

1161.3294

RELATIVE ORE FLOW RATES VALUES :

STREAMS	RELATIVE FLOW RATES
CONC	1.0000
CYCFEED	3.2891
CYCOFLW	1.0030
CYCUFLW	2.2861
MILDISC	2.2861
FINTAIL	.1351
SCRFEED	.8679
SCROSIZ	.0030
SCRUSIZ	.8649

MASS BALANCE RESULTS

ESTIMATES OF NETWORK 3 MASS FRACTIONS

STREAMS	CONC				CYCFEED			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	1.90	1.36	28.61	5.00	.50	.65	30.32	5.00
+8	3.70	3.04	17.92	5.00	1.10	1.12	2.25	5.00
+10	4.30	3.25	24.38	5.00	1.10	1.19	8.07	5.00
+14	4.80	4.05	15.63	5.00	1.40	1.63	16.34	5.00
+20	4.80	4.74	1.31	5.00	1.60	1.79	11.62	5.00
+28	5.20	5.27	1.29	5.00	1.90	2.09	9.92	5.00
+35	5.30	5.90	11.36	5.00	2.50	2.52	.82	5.00
+48	5.80	6.53	12.67	5.00	4.40	4.09	7.00	5.00
+65	6.90	7.12	3.19	5.00	5.80	6.26	7.86	5.00
+100	6.20	6.47	4.42	5.00	6.90	6.90	.05	5.00
+150	7.10	7.32	3.04	5.00	9.70	10.60	9.25	5.00
+200	6.90	7.06	2.34	5.00	13.00	14.40	10.79	5.00
+270	6.90	7.08	2.60	5.00	13.10	13.73	4.80	5.00
+325	2.70	2.71	.46	5.00	4.00	3.88	3.04	5.00
-325	27.50	28.10	2.18	5.00	34.00	30.15	11.32	5.00

STREAMS	CYCOFLW				CYCUFLW			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00	1.00	.94	6.25	5.00
+8	.00	0.00	100.00	0.00	1.40	1.62	15.58	5.00
+10	.00	0.00	100.00	0.00	1.50	1.71	14.02	5.00
+14	.00	0.00	100.00	0.00	2.30	2.34	1.88	5.00
+20	.00	0.00	100.00	0.00	2.80	2.57	8.23	5.00
+28	.00	0.00	100.00	0.00	3.30	3.00	8.95	5.00
+35	.00	0.00	100.00	0.00	4.30	3.63	15.67	5.00
+48	.00	0.00	100.00	0.00	7.10	5.89	17.08	5.00
+65	.20	.13	35.70	5.00	9.40	8.94	4.85	5.00
+100	1.10	.85	22.77	5.00	9.70	9.56	1.45	5.00
+150	3.90	3.54	9.13	5.00	14.00	13.69	2.20	5.00
+200	6.60	6.68	1.16	5.00	17.40	17.79	2.26	5.00
+270	14.80	15.22	2.86	5.00	12.50	13.07	4.59	5.00
+325	6.70	7.28	8.67	5.00	2.30	2.39	3.73	5.00
-325	66.70	66.30	.60	5.00	11.00	12.86	16.87	5.00

STREAMS	MILDISC				FINTAIL			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.40	.34	13.96	5.00	.00	0.00	100.00	0.00
+8	.30	.29	3.47	5.00	.00	0.00	100.00	0.00
+10	.30	.29	4.04	5.00	.00	0.00	100.00	0.00
+14	.60	.57	4.76	5.00	.00	0.00	100.00	0.00
+20	.50	.50	.56	5.00	.00	0.00	100.00	0.00
+28	.70	.70	.06	5.00	.00	0.00	100.00	0.00
+35	1.00	1.04	4.41	5.00	.00	0.00	100.00	0.00
+48	2.70	3.03	12.17	5.00	.10	0.00	99.06	5.00
+65	5.70	5.89	3.25	5.00	.10	.10	2.39	5.00
+100	6.60	7.10	7.53	5.00	3.10	3.36	8.34	5.00
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

+200	16.80	17.62	4.86	5.00	18.20	17.85	1.90	5.00
+270	15.70	16.62	5.88	5.00	16.60	16.34	1.54	5.00
+325	4.40	4.38	.42	5.00	4.80	4.76	.80	5.00
-325	32.90	29.59	10.05	5.00	43.30	43.36	.15	5.00

STREAMS	SCRFEED				SCROSIZ			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+8	.00	0.00	100.00	0.00	.10	.10	1.87	5.00
+10	.00	0.00	100.00	0.00	.10	.10	1.87	5.00
+14	.00	0.00	100.00	0.00	.40	.31	23.34	5.00
+20	.00	0.00	100.00	0.00	.20	.19	7.07	5.00
+28	.00	0.00	100.00	0.00	.30	.26	14.62	5.00
+35	.00	0.00	100.00	0.00	.30	.26	14.62	5.00
+48	.00	0.00	100.00	0.00	.20	.18	7.74	5.00
+65	.10	.13	32.67	5.00	.60	.60	.35	5.00
+100	.50	.46	8.18	5.00	2.00	2.01	.25	5.00
+150	2.40	1.88	21.53	5.00	7.00	7.02	.31	5.00
+200	5.40	4.94	8.57	5.00	12.60	12.62	.14	5.00
+270	16.60	15.05	9.35	5.00	24.60	24.65	.19	5.00
+325	8.00	7.67	4.09	5.00	9.20	9.20	.05	5.00
-325	67.00	69.87	4.28	5.00	42.40	42.52	.29	5.00

STREAMS	SCRUSIZ			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00
+8	.00	0.00	100.00	0.00
+10	.00	0.00	100.00	0.00
+14	.00	0.00	100.00	0.00
+20	.00	0.00	100.00	0.00
+28	.00	0.00	100.00	0.00
+35	.00	0.00	100.00	0.00
+48	.00	0.00	100.00	0.00
+65	.20	.13	34.47	5.00
+100	.40	.45	13.43	5.00
+150	1.60	1.87	16.60	5.00
+200	4.70	4.91	4.48	5.00
+270	15.00	15.01	.10	5.00
+325	8.00	7.67	4.16	5.00
-325	70.10	69.96	.20	5.00

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NSL2.DAT
National Steel Secondary Mill Testing LINE 2


     POWELL ALGORITHM

   N =  3    MAXIT =   10    ESCALE =   .10

 STARTING VALUES (X)      REQUIRED ACCURACIES (E)
   0.32000000E+01            0.63999999E-01
   0.17000000E+01            0.33999999E-01
   0.20000000E+00            0.39999999E-02
A RELATIVE ORE FLOW RATE IS FOUND NEGATIVE
RUN CONTINUES
A RELATIVE ORE FLOW RATE IS FOUND NEGATIVE
RUN CONTINUES


     POWELL ALGORITHM


ITERATION  1      408  FUNCTION EVALUATIONS,  F = 0.23205550E+04

ESTIMATES :   3.92884  2.00874  0.00000
A RELATIVE ORE FLOW RATE IS FOUND NEGATIVE
RUN CONTINUES


     POWELL ALGORITHM


ITERATION  2      425  FUNCTION EVALUATIONS,  F = 0.22500891E+04

ESTIMATES :   4.76575  2.30933  0.00000
A RELATIVE ORE FLOW RATE IS FOUND NEGATIVE
RUN CONTINUES


     POWELL ALGORITHM


ITERATION  3      439  FUNCTION EVALUATIONS,  F = 0.22421643E+04

ESTIMATES :   4.98212  2.57095  0.00000
A RELATIVE ORE FLOW RATE IS FOUND NEGATIVE
RUN CONTINUES


     POWELL ALGORITHM
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ITERATION  4       450  FUNCTION EVALUATIONS,  F = 0.22421573E+04

ESTIMATES :   4.99218  2.57492  0.00000
A RELATIVE ORE FLOW RATE IS FOUND NEGATIVE
RUN CONTINUES


    POWELL ALGORITHM


ITERATION  5       461  FUNCTION EVALUATIONS,  F = 0.22421573E+04

ESTIMATES :   4.99186  2.57463  0.00000

END OF CRITERION MINIMIZATION
       CRITERION VALUE FOR NETWORK 3 DATA :  2242.1573
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                                             2242.1573

RELATIVE ORE FLOW RATES VALUES :

STREAMS          RELATIVE FLOW RATES
 CONC                   1.0000
 CYCFEED                4.9919
 CYCOFLW                2.5746
 CYCUFLW                2.4172
 MILDISC                2.4172
 FINTAIL                0.0000
 SCRFEED                2.5746
 SCROSIZ                1.5746
 SCRUSIZ                1.0000
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MASS BALANCE RESULTS

ESTIMATES OF NETWORK 3 MASS FRACTIONS

STREAMS	CONC MEAS. VALUES	CONC ESTIM. VALUES	CONC RESID. VALUES	CONC RELAT. ST.DEV.	CYCFEED MEAS. VALUES	CYCFEED ESTIM. VALUES	CYCFEED RESID. VALUES	CYCFEED RELAT. ST.DEV.
+6	4.60	3.18	30.84	5.00	.60	.82	36.26	5.00
+8	6.00	5.76	4.08	5.00	1.40	1.44	2.76	5.00
+10	6.10	3.73	38.93	5.00	.70	.97	38.34	5.00
+14	7.20	6.16	14.51	5.00	1.30	1.51	16.40	5.00
+20	6.90	6.78	1.76	5.00	1.50	1.60	6.53	5.00
+28	5.30	6.06	14.37	5.00	1.90	1.62	14.81	5.00
+35	4.70	5.40	14.84	5.00	2.30	1.88	18.33	5.00
+48	4.90	5.30	8.19	5.00	3.80	3.05	19.82	5.00
+65	5.70	6.17	8.17	5.00	5.40	4.30	20.35	5.00
+100	5.00	5.31	6.19	5.00	5.80	4.95	14.74	5.00
+150	5.90	6.15	4.22	5.00	9.20	8.43	8.42	5.00
+200	5.80	5.99	3.28	5.00	12.80	12.22	4.49	5.00
+270	6.00	6.15	2.50	5.00	13.00	14.12	8.60	5.00
+325	2.80	2.81	.40	5.00	5.00	5.58	11.52	5.00
-325	23.10	25.07	8.52	5.00	35.30	37.53	6.32	5.00

STREAMS	CYCOFLW MEAS. VALUES	CYCOFLW ESTIM. VALUES	CYCOFLW RESID. VALUES	CYCOFLW RELAT. ST.DEV.	CYCUFLW MEAS. VALUES	CYCUFLW ESTIM. VALUES	CYCUFLW RESID. VALUES	CYCUFLW RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00	2.30	1.69	26.59	5.00
+8	.00	0.00	100.00	0.00	2.80	2.97	6.11	5.00
+10	.00	0.00	100.00	0.00	2.70	2.00	25.93	5.00
+14	.00	0.00	100.00	0.00	3.10	3.12	.80	5.00
+20	.00	0.00	100.00	0.00	3.30	3.30	0.00	5.00
+28	.00	0.00	100.00	0.00	3.50	3.34	4.50	5.00
+35	.00	0.00	100.00	0.00	4.30	3.88	9.79	5.00
+48	.00	0.00	100.00	0.00	6.30	6.29	.13	5.00
+65	.40	.46	14.65	5.00	8.50	8.39	1.25	5.00
+100	1.50	1.34	10.58	5.00	9.00	8.78	2.40	5.00
+150	3.90	3.50	10.27	5.00	13.30	13.67	2.79	5.00
+200	7.30	7.86	7.65	5.00	16.10	16.87	4.81	5.00
+270	15.40	17.05	10.72	5.00	10.80	10.99	1.79	5.00
+325	7.60	8.46	11.34	5.00	2.50	2.50	.09	5.00
-325	63.90	61.33	4.02	5.00	11.50	12.18	5.94	5.00

STREAMS	MILDISC MEAS. VALUES	MILDISC ESTIM. VALUES	MILDISC RESID. VALUES	MILDISC RELAT. ST.DEV.	FINTAIL MEAS. VALUES	FINTAIL ESTIM. VALUES	FINTAIL RESID. VALUES	FINTAIL RELAT. ST.DEV.
+6	.40	.37	6.93	5.00	.00	0.00	100.00	0.00
+8	.60	.59	1.66	5.00	.00	0.00	100.00	0.00
+10	.50	.46	8.28	5.00	.00	0.00	100.00	0.00
+14	.60	.58	3.60	5.00	.00	0.00	100.00	0.00
+20	.50	.50	.87	5.00	.00	0.00	100.00	0.00
+28	.80	.83	4.34	5.00	.00	0.00	100.00	0.00
+35	1.50	1.65	9.75	5.00	.00	0.00	100.00	0.00
+48	3.70	4.10	10.77	5.00	.10	.10	0.00	5.00
+65	5.30	5.96	12.39	5.00	.50	.50	0.00	5.00
+100	6.10	6.79	11.36	5.00	6.90	6.90	0.00	5.00
+150	11.10	11.84	6.65	5.00	10.90	10.90	0.00	5.00

+200	15.80	16.39	3.74	5.00	17.00	17.00	0.00	5.00
+270	14.40	14.15	1.73	5.00	14.60	14.60	0.00	5.00
+325	4.90	4.71	3.86	5.00	5.10	5.10	0.00	5.00
-325	33.80	31.09	8.03	5.00	44.20	44.20	0.00	5.00

STREAMS	SCRFEED				SCROSIZ			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+8	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+10	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+14	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+20	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+28	.00	0.00	100.00	0.00	.10	0.00	99.93	5.00
+35	.00	0.00	100.00	0.00	.10	0.00	99.93	5.00
+48	.10	0.00	99.93	5.00	.20	0.00	99.94	5.00
+65	.40	.46	14.65	5.00	1.10	.58	47.66	5.00
+100	1.20	1.34	11.77	5.00	1.90	1.88	1.17	5.00
+150	2.80	3.50	24.98	5.00	5.70	4.63	18.74	5.00
+200	7.10	7.86	10.69	5.00	11.30	9.79	13.37	5.00
+270	16.70	17.05	2.10	5.00	21.10	19.13	9.35	5.00
+325	8.80	8.46	3.84	5.00	9.70	8.66	10.72	5.00
-325	62.90	61.33	2.50	5.00	48.80	55.34	13.40	5.00

STREAMS	SCRUSIZ			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00
+8	.00	0.00	100.00	0.00
+10	.00	0.00	100.00	0.00
+14	.00	0.00	100.00	0.00
+20	.00	0.00	100.00	0.00
+28	.00	0.00	100.00	0.00
+35	.00	0.00	100.00	0.00
+48	.00	0.00	100.00	0.00
+65	.30	.27	8.62	5.00
+100	.50	.50	.70	5.00
+150	1.80	1.72	4.63	5.00
+200	5.10	4.82	5.52	5.00
+270	14.80	13.78	6.88	5.00
+325	8.60	8.15	5.24	5.00
-325	68.90	70.76	2.70	5.00

NSL3.DAT
National Steel Secondary Mill Testing LINE 3

POWELL ALGORITHM

N = 3 MAXIT = 10 ESCALE = .10

STARTING VALUES (X)	REQUIRED ACCURACIES (E)
0.32000000E+01	0.63999999E-01
0.17000000E+01	0.33999999E-01
0.20000000E+00	0.39999999E-02

POWELL ALGORITHM

ITERATION 1 537 FUNCTION EVALUATIONS, F = 0.27624929E+04

ESTIMATES : 3.38605 1.61486 .45760

POWELL ALGORITHM

ITERATION 2 550 FUNCTION EVALUATIONS, F = 0.27453693E+04

ESTIMATES : 3.16755 1.55564 .49744

POWELL ALGORITHM

ITERATION 3 561 FUNCTION EVALUATIONS, F = 0.27444493E+04

ESTIMATES : 3.13445 1.51547 .47817

POWELL ALGORITHM

ITERATION 4 569 FUNCTION EVALUATIONS, F = 0.27444488E+04

ESTIMATES : 3.13436 1.51537 .47661

POWELL ALGORITHM

ITERATION 5 576 FUNCTION EVALUATIONS, F = 0.27444488E+04

ESTIMATES : 3.13453 1.51544 .47661

END OF CRITERION MINIMIZATION

CRITERION VALUE FOR NETWORK 3 DATA : 2744.4488

2744.4488

RELATIVE ORE FLOW RATES VALUES :

STREAMS	RELATIVE FLOW RATES
CONC	1.0000
CYCFEED	3.1345
CYCOFLW	1.5154
CYCUFLW	1.6191
MILDISC	1.6191
FINTAIL	.4766
SCRFEED	1.0388
SCROSIZ	.5154
SCRUSIZ	.5234

MASS BALANCE RESULTS

ESTIMATES OF NETWORK 3 MASS FRACTIONS

STREAMS	CONC MEAS. VALUES	CONC ESTIM. VALUES	CONC RESID. VALUES	CONC RELAT. ST.DEV.	CYCFEED MEAS. VALUES	CYCFEED ESTIM. VALUES	CYCFEED RESID. VALUES	CYCFEED RELAT. ST.DEV.
+6	2.10	2.12	1.05	5.00	.80	.78	2.44	5.00
+8	3.10	3.15	1.48	5.00	1.30	1.16	10.84	5.00
+10	3.00	3.16	5.44	5.00	1.30	1.22	6.28	5.00
+14	4.60	4.71	2.39	5.00	1.80	1.66	7.88	5.00
+20	4.60	4.92	7.03	5.00	2.10	1.83	12.74	5.00
+28	5.10	5.42	6.23	5.00	2.30	2.10	8.89	5.00
+35	5.20	5.46	5.07	5.00	2.70	2.54	5.97	5.00
+48	5.90	6.01	1.84	5.00	4.40	3.81	13.32	5.00
+65	7.00	7.05	.77	5.00	5.80	5.04	13.10	5.00
+100	6.30	6.37	1.15	5.00	6.10	5.55	8.94	5.00
+150	7.10	7.17	1.05	5.00	9.10	8.55	6.04	5.00
+200	7.10	7.10	.01	5.00	11.80	11.54	2.20	5.00
+270	7.20	7.09	1.52	5.00	12.50	13.55	8.37	5.00
+325	3.20	3.12	2.37	5.00	4.40	4.58	4.01	5.00
-325	28.50	27.13	4.81	5.00	33.60	36.10	7.43	5.00

STREAMS	CYCOFLW MEAS. VALUES	CYCOFLW ESTIM. VALUES	CYCOFLW RESID. VALUES	CYCOFLW RELAT. ST.DEV.	CYCUFLW MEAS. VALUES	CYCUFLW ESTIM. VALUES	CYCUFLW RESID. VALUES	CYCUFLW RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00	1.50	1.51	.74	5.00
+8	.00	0.00	100.00	0.00	2.10	2.24	6.85	5.00
+10	.00	0.00	100.00	0.00	2.40	2.36	1.72	5.00
+14	.00	0.00	100.00	0.00	3.10	3.21	3.55	5.00
+20	.00	0.00	100.00	0.00	3.50	3.55	1.35	5.00
+28	.00	0.00	100.00	0.00	4.10	4.06	1.05	5.00
+35	.00	0.00	100.00	0.00	5.10	4.91	3.63	5.00
+48	.10	0.00	99.96	5.00	7.00	7.38	5.49	5.00
+65	.40	.19	52.09	5.00	9.00	9.58	6.42	5.00
+100	1.30	1.49	14.64	5.00	9.20	9.36	1.73	5.00
+150	3.80	4.52	18.86	5.00	12.60	12.33	2.17	5.00
+200	6.90	8.17	18.34	5.00	15.10	14.70	2.66	5.00
+270	14.50	16.43	13.30	5.00	11.20	10.85	3.13	5.00
+325	6.60	6.98	5.81	5.00	2.30	2.32	1.04	5.00
-325	66.40	62.22	6.29	5.00	11.80	11.64	1.37	5.00

STREAMS	MILDISC MEAS. VALUES	MILDISC ESTIM. VALUES	MILDISC RESID. VALUES	MILDISC RELAT. ST.DEV.	FINTAIL MEAS. VALUES	FINTAIL ESTIM. VALUES	FINTAIL RESID. VALUES	FINTAIL RELAT. ST.DEV.
+6	.20	.20	.20	5.00	.00	0.00	100.00	0.00
+8	.30	.30	.29	5.00	.00	0.00	100.00	0.00
+10	.40	.41	1.26	5.00	.00	0.00	100.00	0.00
+14	.30	.30	.31	5.00	.00	0.00	100.00	0.00
+20	.50	.51	1.34	5.00	.00	0.00	100.00	0.00
+28	.70	.71	1.53	5.00	.00	0.00	100.00	0.00
+35	1.50	1.54	2.68	5.00	.00	0.00	100.00	0.00
+48	3.60	3.69	2.56	5.00	.00	0.00	100.00	0.00
+65	5.30	5.41	2.04	5.00	.30	.34	12.39	5.00
+100	6.20	6.39	3.11	5.00	2.90	2.62	9.70	5.00
+150	10.40	10.88	4.65	5.00	9.80	8.39	14.39	5.00

+200	14.70	15.14	3.01	5.00	14.20	12.70	10.58	5.00
+270	15.00	14.70	2.01	5.00	15.70	15.14	3.58	5.00
+325	4.60	4.39	4.55	5.00	5.30	5.30	.01	5.00
-325	36.30	35.43	2.40	5.00	51.80	55.52	7.18	5.00

STREAMS	SCRFEED				SCROSIZ			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+8	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+10	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+14	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+20	.00	0.00	100.00	0.00	.10	0.00	99.84	5.00
+28	.00	0.00	100.00	0.00	.10	0.00	99.85	5.00
+35	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+48	.00	0.00	100.00	0.00	.30	-.06	120.03	5.00
+65	.10	.12	24.87	5.00	1.30	-.02	101.87	5.00
+100	.80	.97	21.58	5.00	2.00	1.34	33.19	5.00
+150	2.30	2.74	19.12	5.00	5.50	3.89	29.28	5.00
+200	5.30	6.09	14.83	5.00	11.20	8.84	21.08	5.00
+270	15.40	17.02	10.52	5.00	24.80	22.45	9.46	5.00
+325	7.80	7.76	.57	5.00	8.00	7.98	.27	5.00
-325	68.30	65.30	4.39	5.00	46.70	55.59	19.03	5.00

STREAMS	SCRUSIZ			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00
+8	.00	0.00	100.00	0.00
+10	.00	0.00	100.00	0.00
+14	.00	0.00	100.00	0.00
+20	.00	0.00	100.00	0.00
+28	.00	0.00	100.00	0.00
+35	.00	0.00	100.00	0.00
+48	.10	.06	40.69	5.00
+65	.40	.27	32.04	5.00
+100	.70	.61	12.19	5.00
+150	1.80	1.61	10.70	5.00
+200	3.70	3.38	8.78	5.00
+270	12.90	11.67	9.55	5.00
+325	7.60	7.54	.84	5.00
-325	72.80	74.87	2.84	5.00

```
NSL4.DAT
National Steel Secondary Mill Testing LINE 4


    POWELL ALGORITHM

  N =  3    MAXIT =   10    ESCALE =   .10

 STARTING VALUES (X)      REQUIRED ACCURACIES (E)
   0.20000000E+01            0.39999999E-01
   0.15000000E+01            0.29999999E-01
   0.50000000E+00            0.99999998E-02
A RELATIVE ORE FLOW RATE IS FOUND NEGATIVE
RUN CONTINUES


    POWELL ALGORITHM


ITERATION  1      190  FUNCTION EVALUATIONS,   F = 0.18240837E+04

ESTIMATES :   2.98174  1.83451   .22000
A RELATIVE ORE FLOW RATE IS FOUND NEGATIVE
RUN CONTINUES


    POWELL ALGORITHM


ITERATION  2      206  FUNCTION EVALUATIONS,   F = 0.15924297E+04

ESTIMATES :   3.86174  2.21624   .06238
A RELATIVE ORE FLOW RATE IS FOUND NEGATIVE
RUN CONTINUES


    POWELL ALGORITHM


ITERATION  3      247  FUNCTION EVALUATIONS,   F = 0.15540903E+04

ESTIMATES :   4.20233  2.67158   .01327
A RELATIVE ORE FLOW RATE IS FOUND NEGATIVE
RUN CONTINUES


    POWELL ALGORITHM


ITERATION  4      263  FUNCTION EVALUATIONS,   F = 0.15273959E+04

ESTIMATES :   4.22912  2.47784   .01145
A RELATIVE ORE FLOW RATE IS FOUND NEGATIVE
RUN CONTINUES
A RELATIVE ORE FLOW RATE IS FOUND NEGATIVE
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```
RUN CONTINUES


    POWELL ALGORITHM


ITERATION  5      274  FUNCTION EVALUATIONS,  F = 0.15235428E+04

ESTIMATES :   4.25347  2.49403   .00236
A RELATIVE ORE FLOW RATE IS FOUND NEGATIVE
RUN CONTINUES


    POWELL ALGORITHM


ITERATION  6      288  FUNCTION EVALUATIONS,  F = 0.15235427E+04

ESTIMATES :   4.25347  2.49403   .00279


END OF CRITERION MINIMIZATION
       CRITERION VALUE FOR NETWORK 3 DATA :  1523.5427
                                            ----------
                                             1523.5427


RELATIVE ORE FLOW RATES VALUES :


STREAMS          RELATIVE FLOW RATES
 CONC                   1.0000
 CYCFEED                4.2535
 CYCOFLW                2.4940
 CYCUFLW                1.7594
 MILDISC                1.7594
 FINTAIL                 .0028
 SCRFEED                2.4912
 SCROSIZ                1.4940
 SCRUSIZ                 .9972
```

MASS BALANCE RESULTS

ESTIMATES OF NETWORK 3 MASS FRACTIONS

STREAMS	CONC				CYCFEED			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.80	.74	7.23	5.00	.20	.25	27.23	5.00
+8	1.70	.89	47.77	5.00	.20	.28	41.59	5.00
+10	2.00	.69	65.74	5.00	.20	.29	43.89	5.00
+14	4.70	2.56	45.61	5.00	.60	.82	37.11	5.00
+20	4.60	3.47	24.58	5.00	.90	1.15	28.21	5.00
+28	4.50	4.20	6.67	5.00	1.40	1.43	1.82	5.00
+35	5.00	5.10	1.94	5.00	2.30	1.99	13.58	5.00
+48	5.90	6.00	1.69	5.00	4.10	3.18	22.45	5.00
+65	7.20	7.37	2.40	5.00	6.00	4.20	29.97	5.00
+100	6.70	6.84	2.14	5.00	6.20	4.58	26.05	5.00
+150	7.70	7.87	2.23	5.00	9.90	7.62	22.99	5.00
+200	7.70	7.86	2.07	5.00	13.60	11.48	15.57	5.00
+270	7.80	8.02	2.88	5.00	15.00	15.37	2.45	5.00
+325	3.70	3.84	3.81	5.00	5.20	6.27	20.57	5.00
-325	30.00	34.55	15.16	5.00	34.20	41.08	20.10	5.00

STREAMS	CYCOFLW				CYCUFLW			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00	1.10	.62	44.08	5.00
+8	.00	0.00	100.00	0.00	1.50	.68	54.36	5.00
+10	.00	0.00	100.00	0.00	2.00	.70	65.21	5.00
+14	.00	0.00	100.00	0.00	2.50	1.99	20.45	5.00
+20	.00	0.00	100.00	0.00	3.10	2.79	10.02	5.00
+28	.00	0.00	100.00	0.00	3.20	3.45	7.69	5.00
+35	.00	0.00	100.00	0.00	4.40	4.81	9.21	5.00
+48	.00	.12	100.00	5.00	6.60	7.51	13.82	5.00
+65	.30	.34	12.94	5.00	8.40	9.68	15.22	5.00
+100	1.10	1.05	4.17	5.00	8.50	9.59	12.82	5.00
+150	3.70	3.49	5.70	5.00	12.30	13.48	9.63	5.00
+200	7.30	8.00	9.66	5.00	15.60	16.41	5.21	5.00
+270	14.70	16.55	12.58	5.00	14.50	13.69	5.58	5.00
+325	8.20	8.44	2.90	5.00	3.60	3.20	11.21	5.00
-325	64.70	62.00	4.17	5.00	12.70	11.41	10.16	5.00

STREAMS	MILDISC				FINTAIL			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.20	.19	3.33	5.00	.00	0.00	100.00	0.00
+8	.20	.18	10.04	5.00	.00	0.00	100.00	0.00
+10	.40	.31	23.44	5.00	.00	0.00	100.00	0.00
+14	.60	.54	10.70	5.00	.00	0.00	100.00	0.00
+20	.90	.82	9.15	5.00	.00	0.00	100.00	0.00
+28	1.10	1.06	3.71	5.00	.00	0.00	100.00	0.00
+35	2.00	2.00	.17	5.00	.00	0.00	100.00	0.00
+48	4.20	4.15	1.11	5.00	.00	.10	100.00	5.00
+65	5.60	5.54	1.01	5.00	.40	.40	.02	5.00
+100	6.00	5.93	1.23	5.00	2.70	2.70	.01	5.00
+150	9.90	9.65	2.55	5.00	11.00	11.00	.01	5.00
+200	14.50	13.88	4.29	5.00	17.30	17.29	.06	5.00
+270	15.60	15.31	1.84	5.00	17.40	17.39	.07	5.00
+325	5.00	5.26	5.21	5.00	5.70	5.70	.04	5.00
-325	33.80	35.19	4.11	5.00	45.50	45.43	.16	5.00

STREAMS	SCRFEED				SCROSIZ			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+8	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+10	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+14	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+20	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+28	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+35	.00	0.00	100.00	5.00	.00	-.10	100.00	5.00
+48	.10	.12	23.31	5.00	.20	.14	27.51	5.00
+65	.30	.34	12.92	5.00	1.10	.50	54.52	5.00
+100	.90	1.05	16.92	5.00	1.70	1.49	12.20	5.00
+150	3.00	3.48	16.02	5.00	5.40	5.07	6.02	5.00
+200	7.40	7.99	8.03	5.00	12.10	11.09	8.37	5.00
+270	16.10	16.55	2.78	5.00	21.90	20.35	7.10	5.00
+325	9.30	8.44	9.24	5.00	9.70	9.08	6.36	5.00
-325	62.90	62.02	1.40	5.00	47.90	52.38	9.34	5.00

STREAMS	SCRUSIZ			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00
+8	.00	0.00	100.00	0.00
+10	.00	0.00	100.00	0.00
+14	.00	0.00	100.00	0.00
+20	.00	0.00	100.00	0.00
+28	.00	0.00	100.00	0.00
+35	.00	.16	100.00	5.00
+48	.10	.09	9.17	5.00
+65	.10	.10	3.30	5.00
+100	.40	.39	1.89	5.00
+150	1.10	1.09	.71	5.00
+200	3.40	3.36	1.16	5.00
+270	11.10	10.86	2.17	5.00
+325	8.20	7.48	8.81	5.00
-325	75.60	76.47	1.16	5.00

NSL5P1.DAT
National Steel Secondary Mill Testing LINE 5-P1

POWELL ALGORITHM

N = 3   MAXIT = 10   ESCALE = .10

STARTING VALUES (X)	REQUIRED ACCURACIES (E)
0.32000000E+01	0.63999999E-01
0.17000000E+01	0.33999999E-01
0.20000000E+00	0.39999999E-02

POWELL ALGORITHM

ITERATION 1   135 FUNCTION EVALUATIONS, F = 0.29489003E+04

ESTIMATES : 3.22563 1.46932 .29680

POWELL ALGORITHM

ITERATION 2   166 FUNCTION EVALUATIONS, F = 0.28374195E+04

ESTIMATES : 2.64558 1.28480 .39282

POWELL ALGORITHM

ITERATION 3   178 FUNCTION EVALUATIONS, F = 0.28363482E+04

ESTIMATES : 2.62157 1.27947 .42492

POWELL ALGORITHM

ITERATION 4   186 FUNCTION EVALUATIONS, F = 0.28361710E+04

ESTIMATES : 2.62157 1.27232 .43228

POWELL ALGORITHM

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ITERATION  5      193  FUNCTION EVALUATIONS,  F = 0.28361704E+04

ESTIMATES :   2.62215  1.27251   .43262

END OF CRITERION MINIMIZATION
      CRITERION VALUE FOR NETWORK 3 DATA :  2836.1704
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                                            2836.1704
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RELATIVE ORE FLOW RATES VALUES :

STREAMS	RELATIVE FLOW RATES
CONC	1.0000
CYCFEED	2.6221
CYCOFLW	1.2725
CYCUFLW	1.3496
MILDISC	1.3496
FINTAIL	.4326
SCRFEED	.8399
SCROSIZ	.2725
SCRUSIZ	.5674

MASS BALANCE RESULTS

ESTIMATES OF NETWORK 3 MASS FRACTIONS

STREAMS	CONC				CYCFEED			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.50	.63	25.84	5.00	.90	.30	67.22	5.00
+8	.80	.98	23.00	5.00	.90	.61	31.88	5.00
+10	1.70	2.02	18.74	5.00	1.20	1.05	12.81	5.00
+14	2.50	2.76	10.34	5.00	1.40	1.37	2.06	5.00
+20	3.50	3.59	2.68	5.00	1.60	1.63	1.83	5.00
+28	4.30	3.78	12.04	5.00	2.00	2.22	10.79	5.00
+35	5.00	4.78	4.31	5.00	3.00	2.88	4.06	5.00
+48	5.80	5.47	5.74	5.00	4.90	4.24	13.53	5.00
+65	7.40	6.80	8.13	5.00	6.20	5.36	13.62	5.00
+100	7.00	6.56	6.33	5.00	6.10	5.44	10.74	5.00
+150	8.30	7.98	3.90	5.00	8.90	7.87	11.58	5.00
+200	8.40	8.33	.86	5.00	11.90	10.21	14.23	5.00
+270	8.30	8.40	1.21	5.00	14.10	12.75	9.60	5.00
+325	3.70	3.76	1.50	5.00	4.70	5.11	8.63	5.00
-325	32.60	33.97	4.20	5.00	32.20	38.99	21.07	5.00

STREAMS	CYCOFLW				CYCUFLW			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00	2.40	.57	76.12	5.00
+8	.00	0.00	100.00	0.00	2.40	1.19	50.37	5.00
+10	.00	0.00	100.00	0.00	2.80	2.03	27.40	5.00
+14	.00	0.00	100.00	0.00	3.20	2.66	16.75	5.00
+20	.00	0.00	100.00	0.00	3.40	3.17	6.90	5.00
+28	.00	0.00	100.00	0.00	4.20	4.30	2.49	5.00
+35	.00	0.00	100.00	0.00	5.20	5.59	7.54	5.00
+48	.10	.09	13.05	5.00	7.00	8.15	16.43	5.00
+65	.20	.04	80.64	5.00	8.70	10.37	19.19	5.00
+100	.60	.61	2.21	5.00	8.70	10.00	14.95	5.00
+150	2.30	2.89	25.66	5.00	11.40	12.56	10.21	5.00
+200	5.00	6.28	25.53	5.00	13.30	13.91	4.60	5.00
+270	11.20	13.23	18.13	5.00	12.70	12.29	3.23	5.00
+325	7.40	7.52	1.63	5.00	3.00	2.83	5.71	5.00
-325	73.20	69.34	5.27	5.00	11.60	10.36	10.66	5.00

STREAMS	MILDISC				FINTAIL			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.10	.11	6.97	5.00	.00	0.00	100.00	0.00
+8	.40	.46	15.51	5.00	.00	0.00	100.00	0.00
+10	.50	.54	7.42	5.00	.00	0.00	100.00	0.00
+14	.60	.62	3.32	5.00	.00	0.00	100.00	0.00
+20	.50	.50	.50	5.00	.00	0.00	100.00	0.00
+28	1.60	1.50	6.11	5.00	.00	0.00	100.00	0.00
+35	2.10	2.05	2.53	5.00	.00	0.00	100.00	0.00
+48	4.40	4.13	6.07	5.00	.10	.10	4.55	5.00
+65	5.90	5.37	9.01	5.00	.10	.11	13.82	5.00
+100	6.00	5.55	7.58	5.00	1.00	1.00	.29	5.00
+150	9.40	8.80	6.37	5.00	7.30	5.66	22.53	5.00

+200	12.70	12.41	2.30	5.00	13.40	11.23	16.17	5.00
+270	14.80	15.14	2.27	5.00	17.00	16.38	3.63	5.00
+325	4.50	4.42	2.43	5.00	6.00	5.70	1.59	5.00
-325	38.20	37.91	4.74	5.00	55.10	59.61	5.18	5.00

STREAMS	SCRFEED				SCROSIZ			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+8	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+10	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+14	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+20	.00	0.00	100.00	0.00	.10	0.00	99.56	5.00
+28	.00	0.00	100.00	0.00	.10	0.00	99.56	5.00
+35	.00	0.00	100.00	0.00	.10	0.00	99.56	5.00
+48	.10	.08	22.11	5.00	.20	.24	20.02	5.00
+65	.00	0.00	100.00	0.00	.40	0.00	99.96	5.00
+100	.40	.42	3.89	5.00	.90	.87	3.30	5.00
+150	1.60	1.47	8.38	5.00	2.90	2.86	1.32	5.00
+200	3.90	3.72	4.54	5.00	6.40	6.20	3.15	5.00
+270	11.60	11.61	.06	5.00	17.40	16.86	3.09	5.00
+325	8.30	8.35	.63	5.00	11.20	11.00	1.82	5.00
-325	74.10	74.36	.35	5.00	60.30	61.97	2.77	5.00

STREAMS	SCRUSIZ			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00
+8	.00	0.00	100.00	0.00
+10	.00	0.00	100.00	0.00
+14	.00	0.00	100.00	0.00
+20	.00	0.00	100.00	0.00
+28	.00	0.00	100.00	0.00
+35	.00	0.00	100.00	0.00
+48	.00	0.00	100.00	0.00
+65	.00	0.00	100.00	0.00
+100	.20	.20	1.43	5.00
+150	.80	.80	.55	5.00
+200	2.60	2.53	2.54	5.00
+270	9.50	9.08	4.39	5.00
+325	7.40	7.08	4.28	5.00
-325	79.50	80.31	1.02	5.00

NSL5P2.DAT
National Steel Secondary Mill Testing LINE 5 - P2

POWELL ALGORITHM

N = 3   MAXIT = 10   ESCALE = .10

STARTING VALUES (X)	REQUIRED ACCURACIES (E)
0.20000000E+01	0.39999999E-01
0.15000000E+01	0.29999999E-01
0.50000000E+00	0.99999998E-02

POWELL ALGORITHM

ITERATION 1   161 FUNCTION EVALUATIONS, F = 0.16040113E+04

ESTIMATES : 3.08556 1.54893 .21456

POWELL ALGORITHM

ITERATION 2   171 FUNCTION EVALUATIONS, F = 0.15908473E+04

ESTIMATES : 3.22671 1.67212 .20250

POWELL ALGORITHM

ITERATION 3   178 FUNCTION EVALUATIONS, F = 0.15906401E+04

ESTIMATES : 3.23890 1.67267 .20710

POWELL ALGORITHM

ITERATION 4   186 FUNCTION EVALUATIONS, F = 0.15906305E+04

ESTIMATES : 3.23985 1.67291 .20914

POWELL ALGORITHM

ITERATION 5   194 FUNCTION EVALUATIONS, F = 0.15906304E+04

ESTIMATES : 3.23951 1.67287 .20922

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END OF CRITERION MINIMIZATION
      CRITERION VALUE FOR NETWORK 3 DATA :  1590.6304
                                            ----------
                                            1590.6304
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RELATIVE ORE FLOW RATES VALUES :

STREAMS	RELATIVE FLOW RATES
CONC	1.0000
CYCFEED	3.2395
CYCOFLW	1.6729
CYCUFLW	1.5666
MILDISC	1.5666
FINTAIL	.2092
SCRFEED	1.4636
SCROSIZ	.6729
SCRUSIZ	.7908

MASS BALANCE RESULTS

ESTIMATES OF NETWORK 3 MASS FRACTIONS

STREAMS	CONC				CYCFEED			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.90	1.18	30.94	5.00	.60	.41	30.88	5.00
+8	1.70	1.95	14.89	5.00	.90	.81	10.35	5.00
+10	2.50	2.42	3.22	5.00	1.10	.94	14.66	5.00
+14	3.30	3.24	1.91	5.00	1.40	1.34	4.62	5.00
+20	3.90	3.60	7.76	5.00	1.40	1.49	6.24	5.00
+28	4.40	4.40	.03	5.00	1.90	1.89	.58	5.00
+35	4.80	4.00	16.74	5.00	1.90	2.31	21.46	5.00
+48	5.60	4.84	13.48	5.00	2.80	3.43	22.38	5.00
+65	7.20	7.00	2.84	5.00	5.10	5.03	1.47	5.00
+100	6.70	6.76	.96	5.00	6.10	5.17	15.18	5.00
+150	8.00	8.13	1.68	5.00	9.40	7.84	16.62	5.00
+200	8.10	8.25	1.88	5.00	13.10	10.92	16.66	5.00
+270	8.00	8.09	1.18	5.00	15.20	14.23	6.41	5.00
+325	3.30	3.37	2.23	5.00	5.30	5.34	.83	5.00
-325	31.60	32.76	3.67	5.00	34.20	39.27	14.82	5.00

STREAMS	CYCOFLW				CYCUFLW			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00	1.80	.86	52.36	5.00
+8	.00	0.00	100.00	0.00	2.00	1.67	16.58	5.00
+10	.00	0.00	100.00	0.00	1.70	1.94	14.18	5.00
+14	.00	0.00	100.00	0.00	2.60	2.76	6.19	5.00
+20	.00	0.00	100.00	0.00	3.00	3.08	2.52	5.00
+28	.00	0.00	100.00	0.00	3.90	3.91	.15	5.00
+35	.10	0.00	99.99	5.00	4.80	4.77	.58	5.00
+48	.10	.09	12.19	5.00	7.10	6.99	1.53	5.00
+65	.40	.40	.55	5.00	9.40	9.96	5.97	5.00
+100	1.20	1.16	3.58	5.00	8.80	9.46	7.54	5.00
+150	3.30	3.50	6.02	5.00	11.90	12.47	4.80	5.00
+200	6.60	6.82	3.35	5.00	15.00	15.29	1.94	5.00
+270	14.40	15.70	9.04	5.00	12.90	12.65	1.93	5.00
+325	7.90	7.56	4.32	5.00	3.10	2.98	3.90	5.00
-325	66.00	64.77	1.86	5.00	12.40	11.61	6.37	5.00

STREAMS	MILDISC				FINTAIL			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.10	.11	5.37	5.00	.00	0.00	100.00	0.00
+8	.40	.42	5.43	5.00	.00	0.00	100.00	0.00
+10	.40	.40	.86	5.00	.00	0.00	100.00	0.00
+14	.70	.69	.73	5.00	.00	0.00	100.00	0.00
+20	.80	.78	2.60	5.00	.00	0.00	100.00	0.00
+28	1.10	1.10	.17	5.00	.00	0.00	100.00	0.00
+35	2.60	2.22	14.57	5.00	.00	0.00	100.00	0.00
+48	4.80	3.90	18.77	5.00	.00	0.00	100.00	0.00
+65	5.90	5.64	4.47	5.00	.30	.30	.01	5.00
+100	5.70	5.73	.49	5.00	2.80	2.84	1.56	5.00
+150	9.10	9.26	1.74	5.00	10.80	10.68	1.13	5.00
+200	13.20	13.59	2.97	5.00	14.90	14.95	.35	5.00
+270	14.80	15.00	1.37	5.00	16.40	16.32	.47	5.00
+325	4.90	5.12	4.52	5.00	4.60	4.59	.14	5.00
-325	35.50	36.05	1.54	5.00	50.20	50.31	.22	5.00

STREAMS	SCRFEED				SCROSIZ			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+8	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+10	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+14	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+20	.00	0.00	100.00	0.00	.10	0.00	99.84	5.00
+28	.00	0.00	100.00	0.00	.10	0.00	99.84	5.00
+35	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+48	.10	.10	.36	5.00	.20	.22	9.16	5.00
+65	.40	.42	4.20	5.00	.70	.67	3.67	5.00
+100	.90	.92	1.77	5.00	1.50	1.52	1.36	5.00
+150	2.50	2.47	1.10	5.00	4.10	4.09	.30	5.00
+200	5.70	5.66	.72	5.00	8.50	8.65	1.77	5.00
+270	15.30	15.61	2.04	5.00	22.20	21.53	3.01	5.00
+325	8.70	7.98	8.24	5.00	8.30	8.79	5.92	5.00
-325	66.40	66.84	.66	5.00	54.30	54.52	.41	5.00

STREAMS	SCRUSIZ			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00
+8	.00	0.00	100.00	0.00
+10	.00	0.00	100.00	0.00
+14	.00	0.00	100.00	0.00
+20	.00	0.00	100.00	0.00
+28	.00	0.00	100.00	0.00
+35	.00	0.00	100.00	0.00
+48	.00	0.00	100.00	0.00
+65	.20	.20	1.15	5.00
+100	.40	.40	.41	5.00
+150	1.10	1.10	.19	5.00
+200	3.10	3.11	.45	5.00
+270	10.80	10.58	2.08	5.00
+325	7.10	7.29	2.75	5.00
-325	77.30	77.32	.02	5.00

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NSL5F3.DAT
National Steel Secondary Mill Testing LINE 5-F3


    POWELL ALGORITHM

  N =  3    MAXIT =   10    ESCALE =   .10

 STARTING VALUES (X)      REQUIRED ACCURACIES (E)
   0.32000000E+01            0.63999999E-01
   0.17000000E+01            0.33999999E-01
   0.20000000E+00            0.39999999E-02
A RELATIVE ORE FLOW RATE IS FOUND NEGATIVE
RUN CONTINUES


    POWELL ALGORITHM


ITERATION  1       12  FUNCTION EVALUATIONS,  F = 0.42871995E+04

ESTIMATES :   3.32800  1.34679   .19440


    POWELL ALGORITHM


ITERATION  2       28  FUNCTION EVALUATIONS,  F = 0.41791107E+04

ESTIMATES :   2.68881  1.23032   .25125


    POWELL ALGORITHM


ITERATION  3       36  FUNCTION EVALUATIONS,  F = 0.41778232E+04

ESTIMATES :   2.65687  1.20899   .26128


    POWELL ALGORITHM


ITERATION  4       43  FUNCTION EVALUATIONS,  F = 0.41778044E+04

ESTIMATES :   2.65636  1.20658   .26281


    POWELL ALGORITHM
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ITERATION  5        51  FUNCTION EVALUATIONS.  F = 0.41778040E+04

ESTIMATES :   2.65539  1.20647   .26289


END OF CRITERION MINIMIZATION
       CRITERION VALUE FOR NETWORK 3 DATA :  4177.8040
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                                             4177.8040
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RELATIVE ORE FLOW RATES VALUES :

STREAMS	RELATIVE FLOW RATES
CONC	1.0000
CYCFEED	2.6554
CYCOFLW	1.2065
CYCUFLW	1.4489
MILDISC	1.4489
FINTAIL	.2629
SCRFEED	.9436
SCROSIZ	.2065
SCRUSIZ	.7371

MASS BALANCE RESULTS

ESTIMATES OF NETWORK 3 MASS FRACTIONS

STREAMS	CONC				CYCFEED			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.40	.46	14.05	5.00	1.80	.36	79.97	5.00
+8	1.30	1.60	22.96	5.00	2.10	1.05	49.89	5.00
+10	1.60	1.92	19.85	5.00	2.10	1.15	45.13	5.00
+14	2.50	2.75	10.07	5.00	1.90	1.61	15.06	5.00
+20	3.60	3.57	.79	5.00	1.90	1.94	2.26	5.00
+28	4.40	4.18	4.97	5.00	2.20	2.32	5.50	5.00
+35	5.10	4.98	2.42	5.00	3.20	3.06	4.50	5.00
+48	5.80	5.61	3.27	5.00	4.90	4.32	11.74	5.00
+65	7.50	7.02	6.45	5.00	5.90	5.79	1.81	5.00
+100	6.80	6.57	3.37	5.00	6.20	6.03	2.70	5.00
+150	8.20	8.12	1.00	5.00	9.70	9.01	7.09	5.00
+200	8.00	7.98	.22	5.00	12.90	11.49	10.95	5.00
+270	8.00	8.18	2.30	5.00	12.70	12.57	1.03	5.00
+325	3.60	3.65	1.25	5.00	4.20	4.58	9.11	5.00
−325	33.20	33.42	.66	5.00	28.30	34.70	22.62	5.00

STREAMS	CYCOFLW				CYCUFLW			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00	2.90	.66	77.22	5.00
+8	.00	0.00	100.00	0.00	3.30	1.93	41.56	5.00
+10	.00	0.00	100.00	0.00	2.50	2.11	15.54	5.00
+14	.00	0.00	100.00	0.00	3.10	2.96	4.60	5.00
+20	.00	0.00	100.00	0.00	3.60	3.56	1.09	5.00
+28	.00	0.00	100.00	0.00	4.20	4.25	1.27	5.00
+35	.00	0.00	100.00	0.00	5.20	5.60	7.71	5.00
+48	.00	0.00	100.00	0.00	6.90	7.93	14.86	5.00
+65	.70	.54	23.19	5.00	9.00	10.17	12.99	5.00
+100	1.60	1.65	3.33	5.00	8.90	9.68	8.76	5.00
+150	3.80	4.24	11.61	5.00	12.10	12.98	7.31	5.00
+200	7.40	7.90	6.81	5.00	13.50	14.47	7.19	5.00
+270	16.00	15.96	.28	5.00	10.10	9.75	3.47	5.00
+325	7.30	7.10	2.77	5.00	2.60	2.49	4.31	5.00
−325	63.20	62.61	.93	5.00	12.10	11.46	5.28	5.00

STREAMS	MILDISC				FINTAIL			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.30	.35	15.27	5.00	.00	0.00	100.00	0.00
+8	.70	.83	17.90	5.00	.00	0.00	100.00	0.00
+10	.70	.79	12.57	5.00	.00	0.00	100.00	0.00
+14	1.00	1.06	5.82	5.00	.00	0.00	100.00	0.00
+20	1.10	1.10	.37	5.00	.00	0.00	100.00	0.00
+28	1.40	1.37	2.31	5.00	.00	0.00	100.00	0.00
+35	2.20	2.17	1.54	5.00	.00	0.00	100.00	0.00
+48	4.20	4.05	3.49	5.00	.00	0.00	100.00	0.00
+65	6.00	5.55	7.57	5.00	.60	.63	4.55	5.00
+100	6.50	6.19	4.77	5.00	3.80	3.77	.67	5.00
+150	10.40	10.19	1.99	5.00	11.30	10.72	5.17	5.00

+200	14.10	13.99	.78	5.00	15.10	15.09	.08	5.00
+270	13.40	14.12	5.38	5.00	15.60	15.71	.66	5.00
+325	4.60	4.70	2.25	5.00	4.80	4.77	.68	5.00
-325	33.40	33.56	.47	5.00	47.80	48.31	1.07	5.00

STREAMS	SCRFEED				SCROSIZ			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+8	.00	0.00	100.00	0.00	.10	0.00	98.97	5.00
+10	.00	0.00	100.00	0.00	.10	0.00	98.97	5.00
+14	.00	0.00	100.00	0.00	.20	0.00	99.74	5.00
+20	.00	0.00	100.00	0.00	.20	0.00	99.74	5.00
+28	.00	0.00	100.00	0.00	.10	0.00	98.97	5.00
+35	.00	0.00	100.00	0.00	.20	0.00	99.74	5.00
+48	.10	0.00	99.87	5.00	.50	0.00	99.86	5.00
+65	.50	.51	2.54	5.00	1.50	1.60	6.97	5.00
+100	1.10	1.06	3.42	5.00	2.30	2.32	.97	5.00
+150	3.10	2.44	21.37	5.00	4.80	5.05	5.31	5.00
+200	7.00	5.90	15.67	5.00	10.40	10.90	4.81	5.00
+270	17.00	15.75	7.38	5.00	22.10	22.92	3.71	5.00
+325	8.20	7.75	5.54	5.00	8.20	8.27	.88	5.00
-325	63.00	66.59	5.70	5.00	49.30	48.92	.77	5.00

STREAMS	SCRUSIZ			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00
+8	.00	0.00	100.00	0.00
+10	.00	0.00	100.00	0.00
+14	.00	0.00	100.00	0.00
+20	.00	0.00	100.00	0.00
+28	.00	0.00	100.00	0.00
+35	.00	0.00	100.00	0.00
+48	.00	0.00	100.00	0.00
+65	.20	.21	3.45	5.00
+100	.70	.71	1.34	5.00
+150	1.60	1.70	6.53	5.00
+200	4.20	4.50	7.21	5.00
+270	13.00	13.74	5.66	5.00
+325	7.50	7.60	1.31	5.00
-325	72.80	71.54	1.73	5.00

NSL5P4.DAT
National Steel Secondary Mill Testing LINE 5 - P4

POWELL ALGORITHM

N = 3   MAXIT = 10   ESCALE = .10

STARTING VALUES (X)	REQUIRED ACCURACIES (E)
0.20000000E+01	0.39999999E-01
0.15000000E+01	0.29999999E-01
0.50000000E+00	0.99999998E-02

POWELL ALGORITHM

ITERATION 1   71 FUNCTION EVALUATIONS, F = 0.17517196E+04

ESTIMATES : 2.60794 1.45010 .33800

POWELL ALGORITHM

ITERATION 2   79 FUNCTION EVALUATIONS, F = 0.17496313E+04

ESTIMATES : 2.64709 1.48999 .30814

POWELL ALGORITHM

ITERATION 3   87 FUNCTION EVALUATIONS, F = 0.17493342E+04

ESTIMATES : 2.67017 1.49958 .31087

POWELL ALGORITHM

ITERATION 4   95 FUNCTION EVALUATIONS, F = 0.17493331E+04

ESTIMATES : 2.66894 1.49950 .31128

END OF CRITERION MINIMIZATION
CRITERION VALUE FOR NETWORK 3 DATA : 1749.3331

1749.3331

RELATIVE ORE FLOW RATES VALUES :

STREAMS	RELATIVE FLOW RATES
CONC	1.0000
CYCFEED	2.6689
CYCOFLW	1.4995
CYCUFLW	1.1694
MILDISC	1.1694
FINTAIL	.3113
SCRFEED	1.1882
SCROSIZ	.4995
SCRUSIZ	.6887

MASS BALANCE RESULTS

ESTIMATES OF NETWORK 3 MASS FRACTIONS

STREAMS	CONC				CYCFEED			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.30	.30	.78	5.00	.20	.24	20.89	5.00
+8	.70	.86	22.98	5.00	.50	.42	16.62	5.00
+10	1.40	1.55	11.03	5.00	.90	.86	4.46	5.00
+14	2.20	2.29	4.04	5.00	1.10	1.17	6.27	5.00
+20	3.20	3.19	.38	5.00	1.60	1.72	7.47	5.00
+28	4.30	4.15	3.48	5.00	2.10	2.29	8.95	5.00
+35	5.30	5.02	5.27	5.00	3.30	3.27	.86	5.00
+48	6.40	6.06	5.24	5.00	5.50	4.65	15.48	5.00
+65	8.20	7.62	7.05	5.00	7.10	6.17	13.09	5.00
+100	7.70	7.23	6.07	5.00	7.70	6.64	13.81	5.00
+150	9.00	8.61	4.39	5.00	11.40	9.43	17.27	5.00
+200	8.40	8.20	2.33	5.00	13.00	11.40	12.29	5.00
+270	8.90	9.15	2.82	5.00	12.00	12.77	6.45	5.00
+325	3.50	3.62	3.44	5.00	4.20	4.65	10.66	5.00
-325	30.50	32.14	5.38	5.00	29.40	34.32	16.75	5.00

STREAMS	CYCOFLW				CYCUFLW			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00	1.40	.55	60.59	5.00
+8	.00	0.00	100.00	0.00	1.50	.95	36.57	5.00
+10	.00	0.00	100.00	0.00	2.40	1.96	18.23	5.00
+14	.00	0.00	100.00	0.00	3.20	2.67	16.63	5.00
+20	.00	0.00	100.00	0.00	4.40	3.92	10.81	5.00
+28	.00	0.00	100.00	0.00	5.70	5.22	8.39	5.00
+35	.00	0.00	100.00	0.00	7.10	7.47	5.17	5.00
+48	.20	.12	41.51	5.00	9.10	10.46	14.93	5.00
+65	1.30	1.31	.92	5.00	10.90	12.40	13.77	5.00
+100	3.00	3.30	10.07	5.00	9.80	10.91	11.35	5.00
+150	5.70	6.75	18.43	5.00	11.90	12.87	8.14	5.00
+200	9.80	11.54	17.72	5.00	11.00	11.23	2.08	5.00
+270	16.50	17.33	5.02	5.00	7.60	6.93	8.78	5.00
+325	6.80	6.73	1.01	5.00	2.10	1.98	5.90	5.00
-325	56.70	52.92	6.66	5.00	11.90	10.48	11.97	5.00

STREAMS	MILDISC				FINTAIL			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.30	.30	.91	5.00	.00	0.00	100.00	0.00
+8	.20	.22	7.68	5.00	.00	0.00	100.00	0.00
+10	.60	.63	5.53	5.00	.00	0.00	100.00	0.00
+14	.70	.71	1.51	5.00	.00	0.00	100.00	0.00
+20	1.20	1.20	.16	5.00	.00	0.00	100.00	0.00
+28	1.70	1.67	1.60	5.00	.00	0.00	100.00	0.00
+35	3.30	3.17	3.83	5.00	.00	0.00	100.00	0.00
+48	5.60	5.30	5.34	5.00	.10	.10	4.38	5.00
+65	7.10	6.60	7.11	5.00	2.20	2.22	1.06	5.00
+100	7.50	6.98	6.88	5.00	6.50	6.46	.64	5.00
+150	11.50	10.75	6.50	5.00	12.90	12.57	2.56	5.00
+200	13.40	12.83	4.29	5.00	15.30	15.22	.53	5.00
+270	11.70	12.21	4.39	5.00	16.40	16.18	1.32	5.00
+325	4.20	4.40	4.85	5.00	5.80	5.66	2.48	5.00
-325	31.00	33.02	6.53	5.00	40.80	41.59	1.92	5.00

STREAMS	SCRFEED				SCROSIZ			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+8	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+10	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+14	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+20	.00	0.00	100.00	0.00	.10	0.00	99.78	5.00
+28	.00	0.00	100.00	0.00	.10	0.00	99.78	5.00
+35	.00	0.00	100.00	0.00	.10	0.00	99.78	5.00
+48	.10	.12	20.27	5.00	.30	.29	4.63	5.00
+65	1.20	1.07	10.57	5.00	2.10	2.27	8.27	5.00
+100	2.70	2.48	8.33	5.00	4.50	4.63	2.89	5.00
+150	5.60	5.23	6.68	5.00	8.10	7.99	1.34	5.00
+200	11.00	10.57	3.89	5.00	14.80	14.47	2.23	5.00
+270	18.30	17.63	3.67	5.00	21.30	21.34	.18	5.00
+325	7.10	7.01	1.23	5.00	7.40	7.28	1.68	5.00
-325	54.00	55.89	3.50	5.00	41.20	41.73	1.30	5.00

STREAMS	SCRUSIZ			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00
+8	.00	0.00	100.00	0.00
+10	.00	0.00	100.00	0.00
+14	.00	0.00	100.00	0.00
+20	.00	0.00	100.00	0.00
+28	.00	0.00	100.00	0.00
+35	.00	0.00	100.00	0.00
+48	.00	0.00	100.00	0.00
+65	.20	.20	1.22	5.00
+100	.90	.91	1.37	5.00
+150	3.20	3.22	.64	5.00
+200	7.70	7.75	.59	5.00
+270	15.20	14.94	1.72	5.00
+325	7.30	6.82	6.54	5.00
-325	65.50	66.16	1.01	5.00

```
NSL5P5.DAT
National Steel Secondary Mill Testing LINE 5 - P5


    POWELL ALGORITHM

  N =  3     MAXIT =    10     ESCALE =    .10

 STARTING VALUES (X)       REQUIRED ACCURACIES (E)
   0.20000000E+01             0.39999999E-01
   0.15000000E+01             0.29999999E-01
   0.50000000E+00             0.99999998E-02
A RELATIVE ORE FLOW RATE IS FOUND NEGATIVE
RUN CONTINUES


    POWELL ALGORITHM


ITERATION  1       181  FUNCTION EVALUATIONS,   F = 0.25686346E+04

ESTIMATES :    2.93945  1.19634   .22800


    POWELL ALGORITHM


ITERATION  2       190  FUNCTION EVALUATIONS,   F = 0.25363861E+04

ESTIMATES :    2.67271  1.22634   .22496


    POWELL ALGORITHM


ITERATION  3       198  FUNCTION EVALUATIONS,   F = 0.25356151E+04

ESTIMATES :    2.72066  1.23764   .21736


    POWELL ALGORITHM


ITERATION  4       205  FUNCTION EVALUATIONS,   F = 0.25356151E+04

ESTIMATES :    2.72066  1.23764   .21736

END OF CRITERION MINIMIZATION
       CRITERION VALUE FOR NETWORK 3 DATA :  2535.6151
                                             ----------
                                             2535.6151


 RELATIVE ORE FLOW RATES VALUES :
```

STREAMS	RELATIVE FLOW RATES
CONC	1.0000
CYCFEED	2.7207
CYCOFLW	1.2376
CYCUFLW	1.4830
MILDISC	1.4830
FINTAIL	.2174
SCRFEED	1.0203
SCROSIZ	.2376
SCRUSIZ	.7826

MASS BALANCE RESULTS

ESTIMATES OF NETWORK 3 MASS FRACTIONS

STREAMS	CONC MEAS. VALUES	CONC ESTIM. VALUES	CONC RESID. VALUES	CONC RELAT. ST.DEV.	CYCFEED MEAS. VALUES	CYCFEED ESTIM. VALUES	CYCFEED RESID. VALUES	CYCFEED RELAT. ST.DEV.
+6	.40	.47	18.57	5.00	1.00	.37	62.84	5.00
+8	.90	1.01	12.37	5.00	1.00	.81	19.27	5.00
+10	1.60	1.69	5.38	5.00	1.10	1.01	7.80	5.00
+14	2.30	2.38	3.40	5.00	1.30	1.32	1.33	5.00
+20	3.30	2.93	11.25	5.00	1.30	1.54	18.77	5.00
+28	4.20	3.54	15.70	5.00	1.60	1.96	22.34	5.00
+35	4.80	4.41	8.10	5.00	2.20	2.65	20.59	5.00
+48	5.90	5.70	3.36	5.00	4.30	4.50	4.73	5.00
+65	7.80	7.55	3.23	5.00	6.30	6.02	4.50	5.00
+100	7.30	7.09	2.93	5.00	6.70	6.39	4.58	5.00
+150	8.90	8.91	.13	5.00	10.20	9.42	7.68	5.00
+200	8.70	8.79	1.01	5.00	13.40	12.01	10.40	5.00
+270	8.40	8.68	3.39	5.00	13.70	13.13	4.15	5.00
+325	3.50	3.72	6.31	5.00	4.90	4.77	2.72	5.00
-325	32.00	33.13	3.52	5.00	31.00	34.10	10.00	5.00

STREAMS	CYCOFLW MEAS. VALUES	CYCOFLW ESTIM. VALUES	CYCOFLW RESID. VALUES	CYCOFLW RELAT. ST.DEV.	CYCUFLW MEAS. VALUES	CYCUFLW ESTIM. VALUES	CYCUFLW RESID. VALUES	CYCUFLW RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00	1.10	.68	38.03	5.00
+8	.00	0.00	100.00	0.00	1.80	1.48	17.72	5.00
+10	.00	0.00	100.00	0.00	1.90	1.86	2.07	5.00
+14	.00	0.00	100.00	0.00	2.60	2.42	7.06	5.00
+20	.00	0.00	100.00	0.00	3.10	2.83	8.63	5.00
+28	.00	0.00	100.00	0.00	3.90	3.59	7.93	5.00
+35	.00	0.00	100.00	0.00	5.70	4.87	14.61	5.00
+48	.10	.10	0.00	5.00	8.00	8.18	2.23	5.00
+65	.50	.43	13.36	5.00	9.70	10.68	10.07	5.00
+100	1.60	1.59	.93	5.00	9.50	10.41	9.53	5.00
+150	4.00	4.26	6.61	5.00	13.00	13.72	5.50	5.00
+200	7.60	7.91	4.08	5.00	14.80	15.43	4.22	5.00
+270	16.00	16.04	.27	5.00	11.20	10.70	4.46	5.00
+325	7.70	7.55	1.93	5.00	2.60	2.44	6.07	5.00
-325	62.50	62.11	.62	5.00	11.10	10.73	3.37	5.00

STREAMS	MILDISC MEAS. VALUES	MILDISC ESTIM. VALUES	MILDISC RESID. VALUES	MILDISC RELAT. ST.DEV.	FINTAIL MEAS. VALUES	FINTAIL ESTIM. VALUES	FINTAIL RESID. VALUES	FINTAIL RELAT. ST.DEV.
+6	.30	.36	20.61	5.00	.00	0.00	100.00	0.00
+8	.70	.80	14.15	5.00	.00	0.00	100.00	0.00
+10	.70	.72	3.37	5.00	.00	0.00	100.00	0.00
+14	.80	.81	1.61	5.00	.00	0.00	100.00	0.00
+20	.90	.86	4.71	5.00	.00	0.00	100.00	0.00
+28	1.30	1.20	7.44	5.00	.00	0.00	100.00	0.00
+35	2.00	1.89	5.36	5.00	.00	0.00	100.00	0.00
+48	4.60	4.38	4.70	5.00	.10	.10	.01	5.00
+65	6.00	5.71	4.75	5.00	.50	.51	2.45	5.00
+100	6.90	6.53	5.34	5.00	3.80	3.84	1.16	5.00
+150	10.50	10.33	1.64	5.00	11.30	11.08	1.96	5.00
+200	14.10	14.09	.08	5.00	15.00	15.00	.03	5.00
+270	13.70	14.49	5.75	5.00	17.10	17.08	.11	5.00
+325	4.40	4.88	10.97	5.00	5.60	5.52	1.36	5.00
-325	33.10	32.93	.51	5.00	46.60	46.86	.55	5.00

STREAMS	SCRFEED				SCROSIZ			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+8	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+10	.00	0.00	100.00	0.00	.10	0.00	99.13	5.00
+14	.00	0.00	100.00	0.00	.10	0.00	99.13	5.00
+20	.00	0.00	100.00	0.00	.10	0.00	99.13	5.00
+28	.00	0.00	100.00	0.00	.10	0.00	99.13	5.00
+35	.00	0.00	100.00	0.00	.10	0.00	99.13	5.00
+48	.10	.10	0.00	0.00	.30	.21	30.26	5.00
+65	.40	.42	4.09	5.00	1.40	1.46	3.93	5.00
+100	1.40	1.10	21.15	5.00	2.40	2.61	8.86	5.00
+150	3.30	2.81	14.77	5.00	5.60	5.85	4.44	5.00
+200	6.80	6.40	5.90	5.00	12.30	12.56	2.08	5.00
+270	16.60	15.82	4.68	5.00	22.90	23.38	2.08	5.00
+325	8.30	7.98	3.81	5.00	8.30	8.44	1.71	5.00
-325	63.10	65.36	3.58	5.00	46.40	45.60	1.73	5.00

STREAMS	SCRUSIZ			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00
+8	.00	0.00	100.00	0.00
+10	.00	0.00	100.00	0.00
+14	.00	0.00	100.00	0.00
+20	.00	0.00	100.00	0.00
+28	.00	0.00	100.00	0.00
+35	.00	0.00	100.00	0.00
+48	.10	.07	33.16	5.00
+65	.10	.10	.98	5.00
+100	.60	.65	7.61	5.00
+150	1.80	1.89	5.05	5.00
+200	4.40	4.53	2.95	5.00
+270	13.20	13.53	2.49	5.00
+325	8.20	7.84	4.33	5.00
-325	71.60	71.39	.29	5.00

NSL5P6.DAT
National Steel Secondary Mill Testing LINE 5-P6

POWELL ALGORITHM

N = 3   MAXIT = 10   ESCALE = .10

STARTING VALUES (X)	REQUIRED ACCURACIES (E)
0.32000000E+01	0.63999999E-01
0.17000000E+01	0.33999999E-01
0.20000000E+00	0.39999999E-02

POWELL ALGORITHM

ITERATION 1   10 FUNCTION EVALUATIONS, F = 0.11746486E+04

ESTIMATES : 3.26400 1.66975 .19841

POWELL ALGORITHM

ITERATION 2   20 FUNCTION EVALUATIONS, F = 0.11730492E+04

ESTIMATES : 3.17201 1.63391 .20885

POWELL ALGORITHM

ITERATION 3   27 FUNCTION EVALUATIONS, F = 0.11730489E+04

ESTIMATES : 3.17472 1.63497 .20854

END OF CRITERION MINIMIZATION
CRITERION VALUE FOR NETWORK 3 DATA : 1173.0489

1173.0489

RELATIVE ORE FLOW RATES VALUES :

STREAMS	RELATIVE FLOW RATES
CONC	1.0000
CYCFEED	3.1747
CYCOFLW	1.6350
CYCUFLW	1.5397
MILDISC	1.5397

FINTAIL	.2085
SCRFEED	1.4254
SCROSII	.6350
SCROSII	.7915

MASS BALANCE RESULTS

ESTIMATES OF NETWORK 3 MASS FRACTIONS

STREAMS	CONC MEAS. VALUES	CONC ESTIM. VALUES	CONC RESID. VALUES	CONC RELAT. ST.DEV.	CYCFEED MEAS. VALUES	CYCFEED ESTIM. VALUES	CYCFEED RESID. VALUES	CYCFEED RELAT. ST.DEV.
+6	.10	.10	1.57	5.00	.50	.50	.99	5.00
+8	.70	.77	10.20	5.00	.70	.64	9.18	5.00
+10	1.20	1.38	14.70	5.00	1.00	.76	24.26	5.00
+14	2.10	2.30	9.54	5.00	1.10	1.08	1.76	5.00
+20	3.20	3.18	.72	5.00	1.30	1.44	10.44	5.00
+28	4.20	3.90	7.06	5.00	1.60	1.88	17.74	5.00
+35	5.00	4.55	8.95	5.00	2.30	2.69	16.79	5.00
+48	6.20	5.99	3.37	5.00	4.50	4.21	6.51	5.00
+65	8.00	7.77	2.89	5.00	5.80	5.40	6.93	5.00
+100	7.60	7.52	1.09	5.00	6.40	5.70	10.91	5.00
+150	9.00	8.88	1.35	5.00	10.00	8.61	13.87	5.00
+200	8.90	8.75	1.69	5.00	13.80	11.16	19.15	5.00
+270	8.80	8.74	.64	5.00	14.20	13.94	1.81	5.00
+325	3.50	3.59	2.45	5.00	4.80	5.10	6.15	5.00
-325	31.50	32.58	3.44	5.00	32.00	36.91	15.34	5.00

STREAMS	CYCOFLW MEAS. VALUES	CYCOFLW ESTIM. VALUES	CYCOFLW RESID. VALUES	CYCOFLW RELAT. ST.DEV.	CYCUFLW MEAS. VALUES	CYCUFLW ESTIM. VALUES	CYCUFLW RESID. VALUES	CYCUFLW RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00	1.70	1.02	39.96	5.00
+8	.00	0.00	100.00	0.00	1.90	1.31	31.01	5.00
+10	.00	0.00	100.00	0.00	1.80	1.56	13.24	5.00
+14	.00	0.00	100.00	0.00	2.70	2.23	17.48	5.00
+20	.00	0.00	100.00	0.00	3.40	2.96	12.93	5.00
+28	.00	0.00	100.00	0.00	4.50	3.88	13.69	5.00
+35	.00	0.00	100.00	0.00	5.90	5.54	6.13	5.00
+48	.10	.09	13.51	5.00	7.80	8.58	10.03	5.00
+65	.50	.45	9.51	5.00	9.80	10.65	8.66	5.00
+100	1.50	1.45	3.35	5.00	9.50	10.22	7.55	5.00
+150	3.90	4.21	8.05	5.00	12.30	13.28	8.00	5.00
+200	7.30	7.84	7.44	5.00	13.40	14.68	9.54	5.00
+270	15.60	17.45	11.87	5.00	10.30	10.22	.82	5.00
+325	7.60	7.48	1.52	5.00	2.70	2.56	5.27	5.00
-325	63.50	61.02	3.91	5.00	12.30	11.31	8.04	5.00

STREAMS	MILDISC MEAS. VALUES	MILDISC ESTIM. VALUES	MILDISC RESID. VALUES	MILDISC RELAT. ST.DEV.	FINTAIL MEAS. VALUES	FINTAIL ESTIM. VALUES	FINTAIL RESID. VALUES	FINTAIL RELAT. ST.DEV.
+6	.80	.95	19.34	5.00	.00	0.00	100.00	0.00
+8	.70	.81	15.68	5.00	.00	0.00	100.00	0.00
+10	.60	.67	11.30	5.00	.00	0.00	100.00	0.00
+14	.70	.73	4.88	5.00	.00	0.00	100.00	0.00
+20	.90	.90	.34	5.00	.00	0.00	100.00	0.00
+28	1.40	1.35	3.66	5.00	.00	0.00	100.00	0.00
+35	2.80	2.58	7.80	5.00	.00	0.00	100.00	0.00
+48	4.90	4.69	4.25	5.00	.00	0.00	100.00	0.00
+65	5.90	5.70	3.47	5.00	.30	.30	.79	5.00
+100	6.20	6.10	1.56	5.00	3.30	3.35	1.58	5.00
+150	10.30	10.02	2.69	5.00	12.50	12.36	1.13	5.00

+200	14.00	13.37	4.51	5.00	15.30	15.42	.78	5.00
+270	14.30	14.01	2.04	5.00	17.80	17.73	.41	5.00
+325	4.50	4.71	4.70	5.00	5.30	5.25	.32	5.00
-325	32.00	33.41	4.39	5.00	45.50	45.58	.18	5.00

STREAMS	SCRFEED				SCROSIZ			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+8	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+10	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+14	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+20	.00	0.00	100.00	0.00	.10	0.00	99.82	5.00
+28	.00	0.00	100.00	0.00	.10	0.00	99.82	5.00
+35	.00	0.00	100.00	0.00	.00	0.00	100.00	0.00
+48	.10	.10	.87	5.00	.20	.22	11.35	5.00
+65	.40	.47	18.60	5.00	1.10	.94	14.27	5.00
+100	1.20	1.17	2.37	5.00	1.80	1.87	3.95	5.00
+150	3.20	3.02	5.52	5.00	4.70	4.78	1.65	5.00
+200	7.30	6.74	7.73	5.00	9.20	9.59	4.24	5.00
+270	17.20	17.41	1.23	5.00	23.00	21.97	4.47	5.00
+325	8.40	7.81	7.02	5.00	8.20	8.40	2.47	5.00
-325	62.20	63.27	1.73	5.00	51.80	52.42	1.20	5.00

STREAMS	SCRUSIZ			
	MEAS. VALUES	ESTIM. VALUES	RESID. VALUES	RELAT. ST.DEV.
+6	.00	0.00	100.00	0.00
+8	.00	0.00	100.00	0.00
+10	.00	0.00	100.00	0.00
+14	.00	0.00	100.00	0.00
+20	.00	0.00	100.00	0.00
+28	.00	0.00	100.00	0.00
+35	.00	0.00	100.00	0.00
+48	.00	0.00	100.00	0.00
+65	.10	.10	1.58	5.00
+100	.60	.61	1.74	5.00
+150	1.60	1.62	.99	5.00
+200	4.30	4.45	3.37	5.00
+270	14.00	13.76	1.75	5.00
+325	7.40	7.34	.87	5.00
-325	72.00	72.14	.19	5.00

APPENDIX III

Experimental Product for Distribution Obtained in Batch Tests

TABLE III-1 TEST B-1

Medium: Wet - 70% Solids
Top Ball Size: 1.5 inches

Cumulative Percent Passing Stated Size		
Particle Size (Mesh)	Specific Energy Input (KWH/T) 4.08	5.10
3	100.00	100.00
4	99.98	100.00
6	99.98	100.00
8	99.95	99.99
10	99.91	99.97
14	99.89	99.96
20	99.82	99.92
28	99.70	99.83
35	99.35	99.59
48	98.50	99.04
65	95.85	97.09
100	86.84	91.41
150	73.60	79.60
200	52.55	58.95
270	37.09	42.10
325	29.75	33.76

ch/hanna

TABLE III-2 TEST B-2

Medium: Wet - 70% Solids
Top Ball Size: 1.0 inches

Cumulative Percent Passing Stated Size		
Particle Size (Mesh)	Specific Energy Input (KWH/T) 4.16	5.20
3	100.00	100.00
4	99.95	99.96
6	99.53	99.71
8	99.17	99.42
10	99.01	99.33
14	98.88	99.28
20	98.80	99.23
28	98.71	99.15
35	98.52	98.89
48	98.21	98.49
65	97.81	97.89
100	92.88	95.68
150	82.04	87.99
200	60.21	68.15
270	42.49	48.72
325	33.99	37.95

ch/hanna

TABLE III-3 TEST B-3

Medium: Wet - 70% Solids
Top Ball Size: 0.75 inches

Cumulative Percent Passing Stated Size		
Particle Size (Mesh)	Specific Energy Input (KWH/T) 4.47	5.59
3	100.00	100.00
4	99.95	99.77
6	99.14	99.00
8	97.72	98.04
10	97.03	97.51
14	96.51	97.13
20	96.21	96.96
28	96.01	96.82
35	95.70	96.61
48	95.34	96.33
65	95.25	96.08
100	93.71	95.57
150	88.55	93.21
200	70.00	79.52
270	50.63	58.06
325	39.29	45.69

ch/hanna

TABLE III-4 TEST B-4

Medium: Wet - 65% Solids
Top Ball Size: 0.75 inches

Cumulative Percent Passing Stated Size		
Particle Size Mesh)	Specific Energy Input (KWH/T)	
	4.47	5.59
3	100.00	100.00
4	99.84	99.76
6	99.13	99.33
8	97.88	98.11
10	97.20	97.57
14	96.62	97.16
20	96.37	97.00
28	96.19	96.91
35	95.90	96.82
48	95.51	96.71
65	95.04	96.55
100	93.67	95.94
150	88.28	92.77
200	69.85	77.05
270	48.80	53.38
325	37.01	41.56

ch/hanna

TABLE III-5 TEST B-5

Medium: Wet - 70% Solids
Top Ball Size: 0.75 inches

Cumulative Percent Passing Stated Size		
Particle Size (Mesh)	Specific Energy Input (KWH/T)	
	4.47	5.59
3	100.00	100.00
4	99.88	99.88
6	99.32	99.43
8	98.33	98.52
10	97.85	98.21
14	97.55	97.95
20	97.34	97.83
28	97.19	97.75
35	96.95	97.64
48	96.58	97.52
65	96.07	97.39
100	95.22	97.08
150	91.77	95.29
200	75.13	81.96
270	51.60	55.38
325	38.81	44.21

ch/hanna

TABLE III-6 TEST B-6

Medium: Wet - 75% Solids

Top Ball Size: 0.75 inches

Cumulative Percent Passing Stated Size		
Particle Size (Mesh)	Specific Energy Input (KWH/T) 5.40	6.76
3	100.00	100.00
4	99.72	99.81
6	99.03	99.27
8	98.06	98.32
10	97.52	97.90
14	97.12	97.69
20	96.91	97.56
28	96.69	97.51
35	96.41	97.46
48	95.96	97.39
65	95.49	97.31
100	94.82	97.08
150	91.81	95.69
200	76.07	83.74
270	52.59	58.62
325	39.69	46.83

ch/hanna

APPENDIX IV

Mill Filling Determination

MILL FILLING DETERMINATIONS

Mill No.	Filling Volume %
1	36.6
2	36.8
3	36.9
4	30.3
5	31.5

APPENDIX V

Computer Print-Out for Simulations

```
TITLE:     SIMULATION FOR .75"BALLS 70%SOLIDS
-----

INPUT DATA:
----------

     1         2         3         4         5         6         7         8         9        10
    11        12        13        14        15        16

      TOP SIZE IN MICRONS

 6680.0   4750.0   3360.0   2380.0   1680.0   1190.0    841.0    595.0    420.0    297.0
  210.0    149.0    105.0     74.0     53.0     45.0

      CIRCUIT FEED

  .0021    .0121    .0215    .0223    .0409    .0379    .0524    .0641    .0706    .0794
  .0908    .1050    .1530    .1059    .0295    .1125

      CLASSIFIER CONSTANTS

  .0000    .0000    .0000    .0000    .0000    .0000    .0000    .0000    .0000    .0000
  .0000    .0000    .0000    .0000    .0000    .0000

      NUMBER OF DIFFERENT BALL SIZES    1

      SELECTION FUNCTION

  .0280    .0821    .2070    .4436    .8084   1.2520   1.6505   1.8504   1.7629   1.4282
  .9861    .5782    .2861    .1227    .0600    .0000

      BREAKAGE FUNCTION

  .0000    .5515    .1090    .0430    .0304    .0253    .0213    .0182    .0154    .0130
  .0109    .0095    .0080    .0065    .0029    .0350

      SELECTION FCN PARAMETERS

          S(1)    =    .0280
          ZETA(1)= -3.3642
          ZETA(2)=  -.6746

      BREAKAGE FCN PARAMETERS

          ALPHA(1)=  .3205    ALPHA(2)=  .4750    ALPHA(3)= 6.2570


OPERATING PARAMETERS
--------------------

          OPEN CIRCUIT SIMULATIONS: 1

          IDEAL MIXERS                   1.65

          SET:
          ---

          ENERGY INPUT NECESSARY TO ACHIEVE
```

DESIRED FINENESS OF THE MILL CIRCUIT PRODUCT

==> SIZE : 149.00 MICRONS
==> CUMULATIVE PASSING: 85.00 %

SIMULATION

SELECTION FUNCTION

.0290 .0321 .2070 .4435 .8084 1.2520 1.6505 1.8504 1.7629 1.4232
.9881 .5792 .2951 .1227 .0600 .0000

ESTIMATED GRIND TIME OR ENERGY INPUT 3.92

SIMULATED MILL DISCHARGE

SIZE (MICRONS)	GRIND TIME / SPECIFIC ENERGY 3.92
- 6680.0	1.0000
- 4760.0	.9981
- 3360.0	.9890
- 2380.0	.9767
- 1680.0	.9669
- 1190.0	.9564
- 841.0	.9474
- 595.0	.9381
- 420.0	.9271
- 297.0	.9124
- 210.0	.8897
- 149.0	.8500
- 105.0	.7757
- 74.0	.6295
- 53.0	.4501
- 45.0	.3439

TITLE: SIMULATION FOR 1.0"BALLS 70%SOLIDS

INPUT DATA:

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16				

TOP SIZE IN MICRONS

6680.0	4760.0	3360.0	2380.0	1680.0	1190.0	841.0	595.0	420.0	297.0
210.0	149.0	105.0	74.0	53.0	45.0				

CIRCUIT FEED

.0021	.0121	.0215	.0223	.0409	.0379	.0524	.0641	.0706	.0794
.0908	.1050	.1530	.1059	.0295	.1125				

CLASSIFIER CONSTANTS

.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	.0000	.0000	.0000	.0000				

NUMBER OF DIFFERENT BALL SIZES 1

SELECTION FUNCTION

.1944	.4035	.7363	1.1730	1.6314	1.9803	2.0996	1.9429	1.5686	1.1059
.5925	.3670	.1709	.0709	.0344	.0000				

BREAKAGE FUNCTION

.0000	.6515	.1090	.0430	.0304	.0253	.0213	.0182	.0154	.0130
.0109	.0095	.0080	.0065	.0028	.0350				

SELECTION FCN PARAMETERS

S(1) = .1944
ZETA(1)= -2.3198
ZETA(2)= -.5653

BREAKAGE FCN PARAMETERS

ALPHA(1)= .3205 ALPHA(2)= .4750 ALPHA(3)= 6.2570

OPERATING PARAMETERS

OPEN CIRCUIT SIMULATIONS: 1

IDEAL MIXERS 1.65

SET:

ENERGY INPUT NECESSARY TO ACHIEVE

[illegible]
DESIRED FINENESS OF THE MILL CIRCUIT PRODUCT

==> SIZE : 149.00 MICRONS
==> CUMULATIVE PASSING: 85.00 %

SIMULATION

SELECTION FUNCTION

.1944	.4025	.7363	1.1730	1.6214	1.9803	2.0996	1.9429	1.5686	1.105[illegible]
.[illegible]	.3670	.1709	.0709	.0344	.0000				

ESTIMATED GRIND TIME OR ENERGY INPUT 4.01

SIMULATED MILL DISCHARGE

SIZE (MICRONS)	GRIND TIME / SPECIFIC ENERGY 4.01
- 6680.0	1.0000
- 4760.0	.9989
- 3360.0	.9947
- 2380.0	.9893
- 1680.0	.9844
- 1190.0	.9787
- 841.0	.9726
- 595.0	.9650
- 420.0	.9540
- 297.0	.9365
- 210.0	.9061
- 149.0	.8500
- 105.0	.7491
- 74.0	.5735
- 53.0	.3954
- 45.0	.3067

TITLE: SIMULATION FOR 1.5"BALLS 70%SOLIDS

INPUT DATA:

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16				

TOP SIZE IN MICRONS

6680.0	4760.0	3360.0	2380.0	1680.0	1190.0	841.0	595.0	420.0	297.0
210.0	149.0	105.0	74.0	53.0	45.0				

CIRCUIT FEED

.0021	.0121	.0215	.0223	.0409	.0379	.0524	.0641	.0706	.0794
.0909	.1050	.1330	.1059	.0295	.1125				

CLASSIFIER CONSTANTS

.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
.0000	.0000	.0000	.0000	.0000	.0000				

NUMBER OF DIFFERENT BALL SIZES   1

SELECTION FUNCTION

1.0899	1.4956	1.8787	2.1533	2.2521	2.1497	1.8724	1.4874	1.0776	.7129
.1313	.2378	.1187	.0550	.0297	.0000				

BREAKAGE FUNCTION

.0000	.6515	.1090	.0430	.0304	.0253	.0213	.0182	.0154	.0130
.0109	.0095	.0080	.0065	.0028	.0350				

SELECTION FCN PARAMETERS

S(1)   = 1.0899
ZETA(1)= -1.0520
ZETA(2)= -.3812

BREAKAGE FCN PARAMETERS

ALPHA(1)= .3205   ALPHA(2)= .4750   ALPHA(3)= 6.2570

OPERATING PARAMETERS

OPEN CIRCUIT SIMULATIONS: 1

IDEAL MIXERS   1.65

SET:

ENERGY INPUT NECESSARY TO ACHIEVE

```
==  SIZE                    :  149.00 MICRONS
==> CUMULATIVE PASSING:    95.00 %
```

SIMULATION

SELECTION FUNCTION

```
1.0899  1.4956  1.8787  2.1533  2.2521  2.1497  1.8724  1.4874  1.0776   .7129
 [illegible]   .2378   .1187   .0550   .0297   .0000
```

ESTIMATED GRIND TIME OR ENERGY INPUT 5.34

SIMULATED MILL DISCHARGE

SIZE (MICRONS)	GRIND TIME / SPECIFIC ENERGY 5.34
- 6680.0	1.0001
- 4760.0	.9999
- 3360.0	.9992
- 2380.0	.9978
- 1680.0	.9960
- 1190.0	.9932
- 841.0	.9892
- 595.0	.9827
- 420.0	.9717
- 297.0	.9519
- 210.0	.9156
- 149.0	.8500
- 105.0	.7405
- 74.0	.5641
- 53.0	.3927
- 45.0	.3063

TITLE: SIMULATION FOR LINE 1

INPUT DATA:

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16				

TOP SIZE IN MICRONS

6680.0	4760.0	3360.0	2380.0	1680.0	1190.0	841.0	595.0	420.0	297.0
210.0	149.0	105.0	74.0	53.0	45.0				

CIRCUIT FEED

.0050	.0068	.0196	.0242	.0324	.0360	.0440	.0400	.0484	.0700
.0676	.0813	.0825	.0809	.0337	.3276				

CLASSIFIER CONSTANTS

1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	.9680
.9210	.8150	.7750	.5580	.3830	.2210				

NUMBER OF DIFFERENT BALL SIZES 1

SELECTION FUNCTION

2.2053	2.0225	1.8129	1.5894	1.3629	1.1433	.9378	.7521	.5897	.4525
.3401	.2497	.1787	.1261	.0965	.0000				

BREAKAGE FUNCTION

.0000	.6515	.1090	.0430	.0304	.0253	.0213	.0182	.0154	.0130
.0109	.0095	.0080	.0065	.0028	.0350				

SELECTION FCN PARAMETERS

S(1) = 2.2053
ZETA(1)= .2201
ZETA(2)= -.0924

BREAKAGE FCN PARAMETERS

ALPHA(1)= .3205 ALPHA(2)= .4750 ALPHA(3)= 6.2570

OPERATING PARAMETERS

REVERSED CLOSED CIRCUIT SIMULATIONS: 1

IDEAL MIXERS 1.65

SET:

A DESIRED FINENESS OF THE MILL CIRCUIT PRODUCT

==> SIZE : 105.00 MICRONS
==> CUMULATIVE PASSING: 95.00 %

SIMULATION

SELECTION FUNCTION

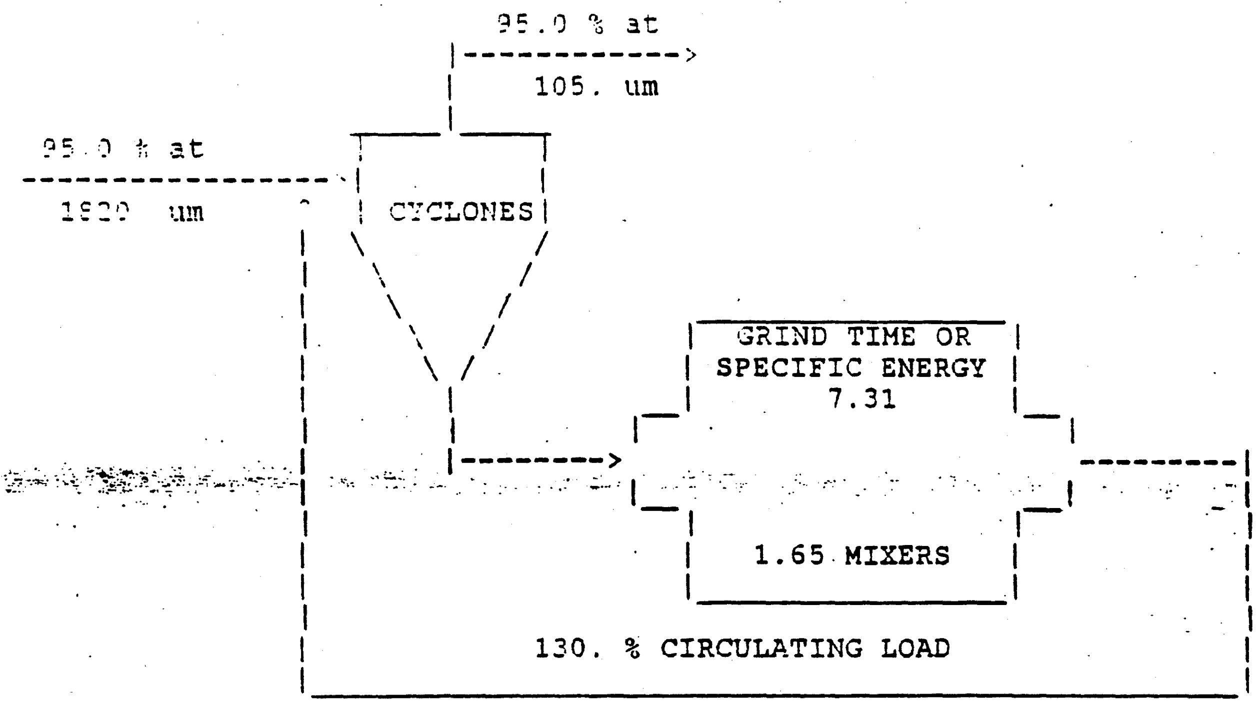
2.2053 2.0225 1.8129 1.5894 1.3629 1.1433 .9378 .7521 .5897 .4525
.3401 .2497 .1787 .1261 .0965 .0000

ESTIMATED GRIND TIME OR ENERGY INPUT 7.31

STEADY-STATE CLOSED CIRCUIT SIMULATION:

--REVERSED CLOSED CIRCUIT : FRESH FEED TO CLASSIFIER--
FEED RATIO = 1.302 (MILL/FRESH)
RELATIVE GRINDABILITY = .105 (WT/MIN)/(HOLD-UP)
CIRCULATING LOAD = 130.18 PERCENT
CUMULATIVE DISTRIBUTION:

SIZE (MICRONS)	FRESH FEED	MILL FEED	MILL PRODUCT	CLASSIFIER FEED	CLASSIFIER OVERSIZE	CLASSIFIER UNDERSIZE
- 6680.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
- 4760.0	.9950	.9961	.9999	.9978	.9961	1.0000
- 3360.0	.9882	.9907	.9997	.9947	.9907	1.0000
- 2380.0	.9686	.9750	.9991	.9858	.9750	1.0000
- 1680.0	.9444	.9550	.9977	.9746	.9550	1.0000
- 1190.0	.9120	.9275	.9951	.9590	.9275	1.0000
- 841.0	.8760	.8953	.9906	.9408	.8953	1.0000
- 595.0	.8320	.8537	.9828	.9173	.8537	1.0000
- 420.0	.7920	.8106	.9703	.8929	.8106	1.0000
- 297.0	.7436	.7531	.9501	.8604	.7531	1.0000
- 210.0	.6736	.6674	.9152	.8103	.6674	.9963
- 149.0	.6060	.5686	.8599	.7496	.5686	.9853
- 105.0	.5247	.4494	.7761	.6669	.4494	.9500
- 74.0	.4422	.3069	.6556	.5629	.3069	.8962
- 53.0	.3613	.1975	.5218	.4521	.1975	.7834
- 45.0	.3276	.1482	.4188	.3792	.1482	.6799


95.0 % at
105. um
95.0 % at
1920 um
CYCLONES
GRIND TIME OR
SPECIFIC ENERGY
7.31
1.65 MIXERS
130. % CIRCULATING LOAD

TITLE: SIMULATION FOR LINE 2

INPUT DATA:

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16				

TOP SIZE IN MICRONS

6680.0	4760.0	3360.0	2380.0	1680.0	1190.0	841.0	595.0	420.0	297.0
210.0	149.0	105.0	74.0	53.0	45.0				

CIRCUIT FEED

.0050	.0068	.0196	.0242	.0324	.0360	.0440	.0400	.0484	.0700
.0676	.0813	.0825	.0809	.0337	.3276				

CLASSIFIER CONSTANTS

1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	.9680
.9210	.8150	.7750	.5580	.3830	.2210				

NUMBER OF DIFFERENT BALL SIZES 1

SELECTION FUNCTION

2.3139	2.1063	1.8753	1.6342	1.3938	1.1640	.9511	.7604	.5949	.4558
.3423	.2512	.1799	.1271	.0974	.0000				

BREAKAGE FUNCTION

.0000	.6515	.1090	.0430	.0304	.0253	.0213	.0182	.0154	.0130
.0109	.0095	.0080	.0065	.0028	.0350				

SELECTION FCN PARAMETERS

S(1) = 2.3139
ZETA(1)= .2429
ZETA(2)= -.0893

BREAKAGE FCN PARAMETERS

ALPHA(1)= .3205 ALPHA(2)= .4750 ALPHA(3)= 6.2570

OPERATING PARAMETERS

REVERSED CLOSED CIRCUIT SIMULATIONS: 1

IDEAL MIXERS 1.65

SET:

A DESIRED FINENESS OF THE MILL CIRCUIT PRODUCT

```
==  SIZE                 :  105.00 MICRONS
==> CUMULATIVE PASSING:     95.00 %
```

SIMULATION

SELECTION FUNCTION

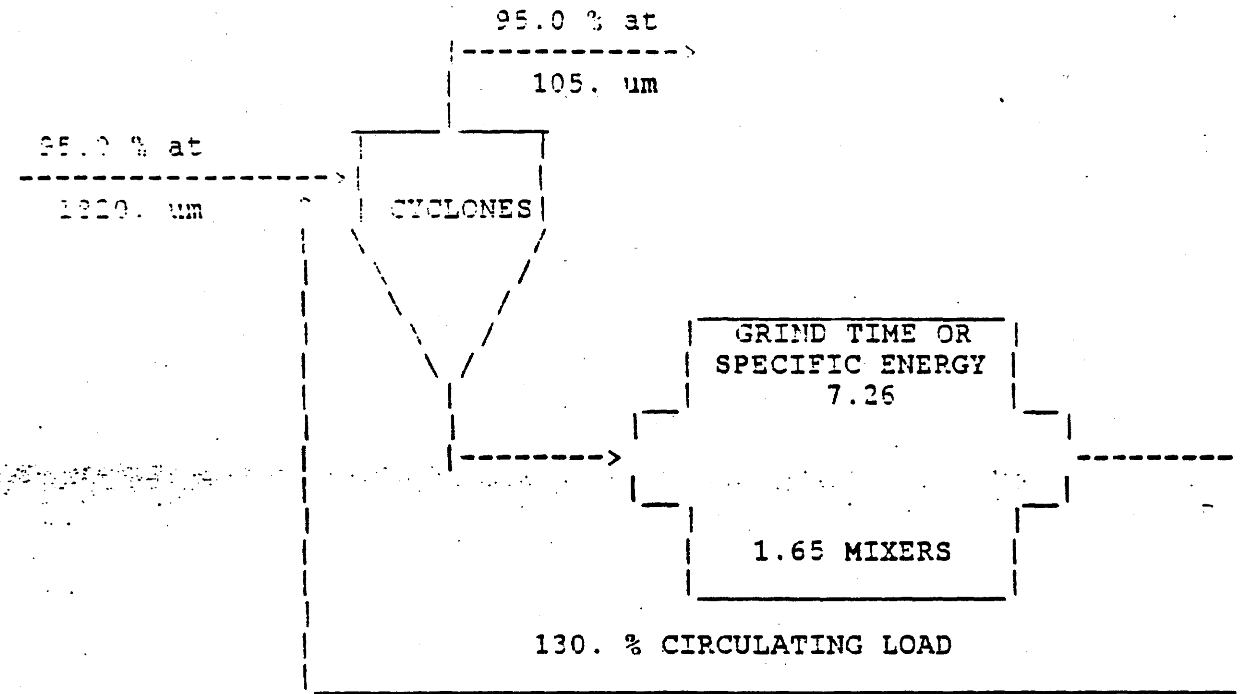
```
2.3139  2.1063  1.8753  1.6342  1.3938  1.1640   .9511   .7604   .5949   .4558
 .3423   .2512   .1799   .1271   .0974   .0000
```

ESTIMATED GRIND TIME OR ENERGY INPUT   7.26

STEADY-STATE CLOSED CIRCUIT SIMULATION:

```
--REVERSED CLOSED CIRCUIT : FRESH FEED TO CLASSIFIER--
        FEED RATIO              =    1.301 (MILL/FRESH)
        RELATIVE GRINDABILITY   =     .106 (WT/MIN)/(HOLD-UP)
        CIRCULATING LOAD        = 130.10   PERCENT
        CUMULATIVE DISTRIBUTION:
```

SIZE (MICRONS)	FRESH FEED	MILL FEED	MILL PRODUCT	CLASSIFIER FEED	CLASSIFIER OVERSIZE	CLASSIFIER UNDERSIZE
- 6680.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
- 4760.0	.9950	.9961	.9999	.9978	.9961	1.0000
- 3360.0	.9882	.9907	.9997	.9947	.9907	1.0000
- 2380.0	.9686	.9750	.9991	.9859	.9750	1.0000
- 1680.0	.9444	.9551	.9978	.9746	.9551	1.0000
- 1190.0	.9120	.9276	.9953	.9591	.9276	1.0000
- 841.0	.8760	.8955	.9908	.9409	.8955	1.0000
- 595.0	.8320	.8539	.9831	.9174	.8539	1.0000
- 420.0	.7920	.8108	.9707	.8930	.8108	1.0000
- 297.0	.7436	.7534	.9505	.8606	.7534	1.0000
- 210.0	.6736	.6676	.9157	.8105	.6676	.9963
- 149.0	.6060	.5688	.8604	.7498	.5688	.9853
- 105.0	.5247	.4495	.7765	.6670	.4495	.9500
- 74.0	.4422	.3070	.6559	.5631	.3070	.8962
- 53.0	.3613	.1977	.5222	.4523	.1977	.7836
- 45.0	[illegible]	.1483	.4193	.3794	.1483	.6801


95.0 % at
105. um
95.0 % at
1820. um
CYCLONES
GRIND TIME OR
SPECIFIC ENERGY
7.26
1.65 MIXERS
130. % CIRCULATING LOAD

TITLE: SIMULATION FOR LINE 3

INPUT DATA:

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16				

TOP SIZE IN MICRONS

6680.0	4760.0	3360.0	2380.0	1680.0	1190.0	841.0	595.0	420.0	297.0
210.0	149.0	105.0	74.0	53.0	45.0				

CIRCUIT FEED

.0050	.0068	.0196	.0242	.0324	.0360	.0440	.0400	.0484	.0700
.0676	.0813	.0825	.0809	.0337	.3276				

CLASSIFIER CONSTANTS

1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	.9680
.9210	.8150	.7750	.5580	.3830	.2210				

NUMBER OF DIFFERENT BALL SIZES 1

SELECTION FUNCTION

4.7942	3.7594	2.9276	2.2688	1.7498	1.3437	1.0264	.7798	.5896	.4438
.3330	.2483	.1837	.1362	.1093	.0000				

BREAKAGE FUNCTION

.0000	.6515	.1090	.0430	.0304	.0253	.0213	.0182	.0154	.0130
.0109	.0095	.0080	.0065	.0028	.0350				

SELECTION FCN PARAMETERS

S(1) = 4.7942
ZETA(1)= .7008
ZETA(2)= -.0201

BREAKAGE FCN PARAMETERS

ALPHA(1)= .3205 ALPHA(2)= .4750 ALPHA(3)= 6.2570

OPERATING PARAMETERS

REVERSED CLOSED CIRCUIT SIMULATIONS: 1

IDEAL MIXERS 1.65

SET:

A. DESIRED FINENESS OF THE MILL CIRCUIT PRODUCT

==> SIZE : 105.00 MICRONS
==> CUMULATIVE PASSING: 95.00 %

SIMULATION

SELECTION FUNCTION

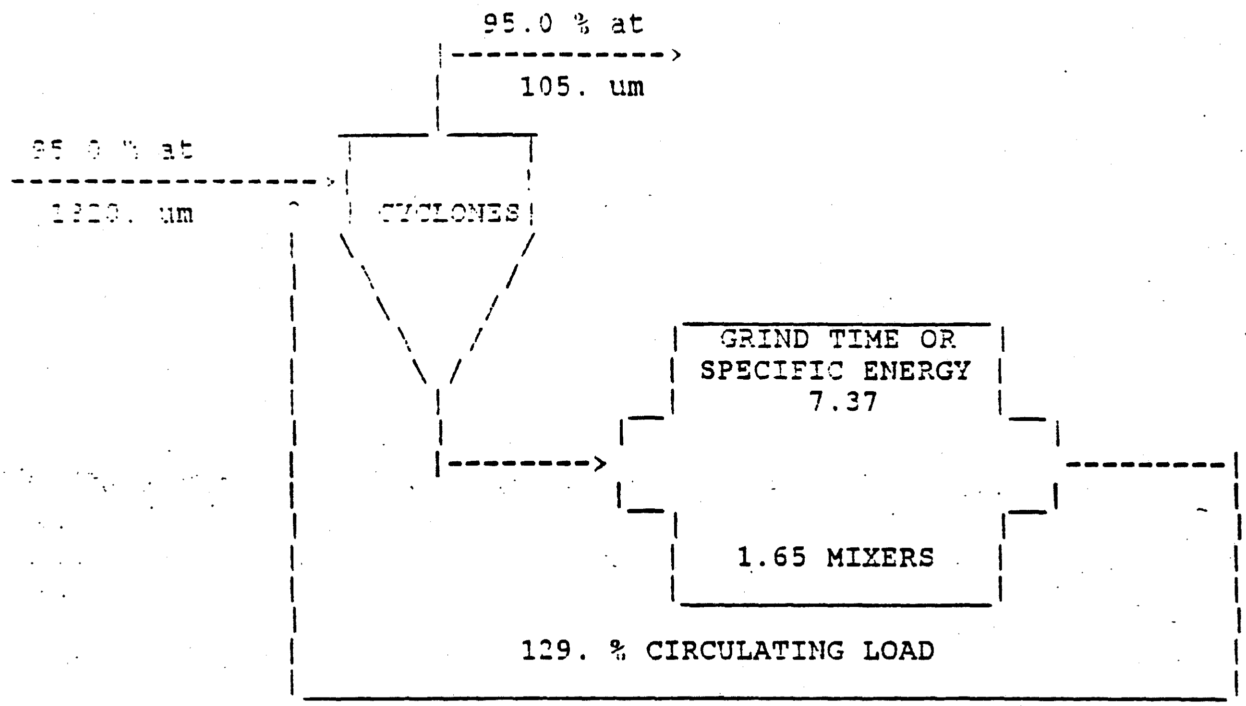
4.7942 3.7594 2.9276 2.2688 1.7498 1.3437 1.0264 .7798 .5896 .4438
.3330 .2483 .1837 .1362 .1093 .0000

ESTIMATED GRIND TIME OR ENERGY INPUT 7.37

STEADY-STATE CLOSED CIRCUIT SIMULATION:

--REVERSED CLOSED CIRCUIT : FRESH FEED TO CLASSIFIER--
FEED RATIO = 1.286 (MILL/FRESH)
RELATIVE GRINDABILITY = .106 (WT/MIN)/(HOLD-UP)
CIRCULATING LOAD = 128.63 PERCENT
CUMULATIVE DISTRIBUTION:

SIZE (MICRONS)	FRESH FEED	----- MILL ------ FEED	PRODUCT	------- CLASSIFIER -------- FEED	OVERSIZE	UNDERSIZE
- 6680.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
- 4760.0	.9950	.9961	1.0000	.9978	.9961	1.0000
- 3360.0	.9882	.9907	.9999	.9948	.9907	1.0000
- 2380.0	.9686	.9752	.9996	.9860	.9752	1.0000
- 1680.0	.9444	.9556	.9988	.9750	.9556	1.0000
- 1190.0	.9120	.9286	.9970	.9598	.9286	1.0000
- 841.0	.8760	.8971	.9935	.9421	.8971	1.0000
- 595.0	.8320	.8561	.9867	.9190	.8561	1.0000
- 420.0	.7920	.8133	.9750	.8949	.8133	1.0000
- 297.0	.7436	.7555	.9549	.8625	.7555	1.0000
- 210.0	.6736	.6684	.9193	.8118	.6684	.9963
- 149.0	.6060	.5679	.8627	.7504	.5679	.9852
- 105.0	.5247	.4475	.7782	.6673	.4475	.9500
- 74.0	.4422	.3064	.6603	.5649	.3064	.8974
- 53.0	.3613	.2000	.5325	.4576	.2000	.7890
- 45.0	[illegible]	.1521	.4336	.3873	.1521	.6897



95.0 % at
105. um
CYCLONES
GRIND TIME OR
SPECIFIC ENERGY
7.37
1.65 MIXERS
129. % CIRCULATING LOAD

TITLE: SIMULATION FOR LINE 4

INPUT DATA:

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16				

TOP SIZE IN MICRONS

6680.0	4760.0	3360.0	2380.0	1680.0	1190.0	841.0	595.0	420.0	297.0
210.0	149.0	105.0	74.0	53.0	45.0				

CIRCUIT FEED

.0050	.0068	.0196	.0242	.0324	.0360	.0440	.0400	.0484	.0700
.0673	.0813	.0825	.0809	.0337	.3276				

CLASSIFIER CONSTANTS

1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	.9680
.9210	.8150	.7750	.5580	.3830	.2210				

NUMBER OF DIFFERENT BALL SIZES 1

SELECTION FUNCTION

2.2241	2.0256	1.8043	1.5730	1.3422	1.1212	.9165	.7329	.5734	.4394
.3300	.2422	.1735	.1226	.0939	.0000				

BREAKAGE FUNCTION

.0000	.6515	.1090	.0430	.0304	.0253	.0213	.0182	.0154	.0130
.0109	.0095	.0080	.0065	.0028	.0350				

SELECTION FCN PARAMETERS

S(1) = 2.2241
ZETA(1)= .2413
ZETA(2)= -.0895

BREAKAGE FCN PARAMETERS

ALPHA(1)= .3205 ALPHA(2)= .4750 ALPHA(3)= 6.2570

OPERATING PARAMETERS

REVERSED CLOSED CIRCUIT SIMULATIONS: 1

IDEAL MIXERS 1.65

ENERGY INPUT NECESSARY TO ACHIEVE
A DESIRED FINENESS OF THE MILL CIRCUIT PRODUCT

==> SIZE   : 105.00 MICRONS
==> CUMULATIVE PASSING: 95.00 %

SIMULATION

SELECTION FUNCTION

2.2241 2.0256 1.8043 1.5730 1.3422 1.1212 .9165 .7329 .5734 .4394
.3300 .2422 .1735 .1226 .0939 .0000

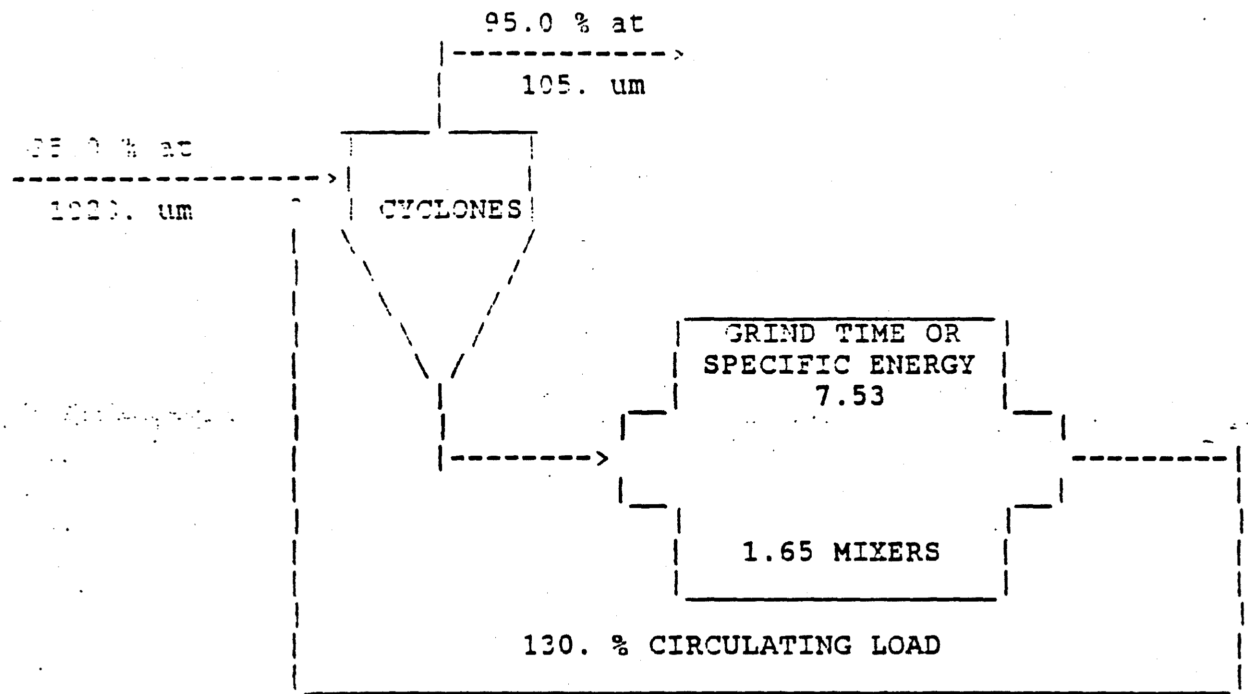
ESTIMATED GRIND TIME OR ENERGY INPUT   7.53

STEADY-STATE CLOSED CIRCUIT SIMULATION:

--REVERSED CLOSED CIRCUIT : FRESH FEED TO CLASSIFIER--
FEED RATIO = 1.301 (MILL/FRESH)
RELATIVE GRINDABILITY = .102 (WT/MIN)/(HOLD-UP)
CIRCULATING LOAD = 130.11 PERCENT
CUMULATIVE DISTRIBUTION:

SIZE (MICRONS)	FRESH FEED	----- MILL ------ FEED	PRODUCT	------- CLASSIFIER -------- FEED	OVERSIZE	UNDERSIZE
- 6680.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
- 4760.0	.9950	.9961	.9999	.9978	.9961	1.0000
- 3360.0	.9882	.9907	.9997	.9947	.9907	1.0000
- 2380.0	.9686	.9750	.9991	.9859	.9750	1.0000
- 1680.0	.9444	.9551	.9978	.9746	.9551	1.0000
- 1190.0	.9120	.9276	.9953	.9591	.9276	1.0000
- 841.0	.8760	.8955	.9908	.9409	.8955	1.0000
- 595.0	.8320	.8539	.9830	.9174	.8539	1.0000
- 420.0	.7920	.8108	.9707	.8930	.8108	1.0000
- 297.0	.7436	.7534	.9505	.8606	.7534	1.0000
- 210.0	.6736	.6676	.9156	.8105	.6676	.9963
- 149.0	.6060	.5688	.8603	.7498	.5688	.9853
- 105.0	.5247	.4495	.7764	.6670	.4495	.9500
- 74.0	.4422	.3070	.6559	.5630	.3070	.8962
- 53.0	[illegible]	.1976	[illegible]	[illegible]	.1976	.7836

-	45.0	.3276	.1483	.4192	.3794	.1483	.6801



SECONDARY BALL MILL CIRCUIT OPTIMIZATION
HRC PILOT PLANT TESTING

MINNESOTA DEPARTMENT OF NATURAL RESOURCES

SECONDARY BALL MILL OPTIMIZATION

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SECONDARY BALL MILL CIRCUIT OPTIMIZATION
HRC PILOT PLANT TESTING

1.0 EXECUTIVE SUMMARY

1.1 Purpose and Scope

As originally proposed, the scope of work called for M. A. Hanna Research center to conduct secondary pilot plant grinding/classification studies with a taconite ore, employing optimum mill operating conditions established by computer simulation in prior laboratory and plant grinding studies.

Some thirty-one pilot plant tests were conducted using a conventional hydrocyclone, static and vibrating screens as well as a modified cyclone equipped with a JD spigot valve. All tests were conducted utilizing a 3'Ø X 3' Marcy ball mill operated at 70-72% solids and with a top ball size of 1-1/4 inches. Both of these operating parameters were the major findings of the computer simulation programs run on a series of batch and commercial plant grinding test results.

The main objective in the overall program was to reduce grinding power consumption.

1.2 Conclusions and Recommendations

1. All Lake Superior taconite operations continue to use hydrocyclones for either primary or secondary mill classification. Over 20 years ago, R. L. Bliefuss(1) suggested cyclone replacement for grade improvement by eliminating manufactured middlings. This current testing demonstrates the magnetude of benefits that a no-cyclone secondary grinding circuit has over existing configurations. These are:

(a) Product silica decrease of 0.6% - 0.9% SiO_2

(b) Product grind decrease of 12-14% -325 mesh

(c) Potential power reduction of 6 to 16%

2. The use of a patented JD cyclone apex valve(2) does not offer any benefits in cyclone classification efficiency.

3. The logical flowsheet modifications for existing secondary grinding installations would be:

(a) Replacement of existing static screens with more efficient high frequency sandwich deck units followed by;

(b) Replacement of existing hydrocyclones with low frequency scalping screens.

2.0 SAMPLE DESCRIPTION & PREPARATION

The feed materials for this program were taken at the National Steel Pellet Company's concentrator during the weeks of January 30 and May 1, 1989. A predetermined ore blend (see attached mine blend schedule, Table 1) was fed to the plant for a 3-day period prior to sampling.

Following three days of purging the plants crude ore systems with these blends, cobber concentrate was bulk sampled on a two shift per day schedule for 5-days for each period. The point in NSPC's flowsheet sampled represented a mixture of 50% of the total plants' cobber concentrate production.

The two barrelled wet cobber concentrate samples were transported to HRC's covered ore storage building and allowed to air dry to about 7% moisture prior to homogenating and storage. The two accumulated samples approximated 75 tons each.

The average plant metallurgical response to these materials in regard to secondary grinding power and final concentrate parameters for the two periods were as follows:

NATIONAL STEEL PELLET COMPANY
CONCENTRATOR METALLURGICAL DATA

	Secondary Power Net KWH/LT		Final Concentrate Fine Screen Undersize			
Period	Crude	Cobb.Conc.	%-325 Mesh	cm^2/gm	% Fe	% SiO_2
1/30-2/1, 1989	5.2	10.8	73.9	1720	68.17	4.65
5/1-5/05, 1989	5.1	10.6	76.2	1850	68.25	4.75

As noted in Table 1, one component of the May blend had a higher than normal silica liberation index of 5.20.

The above plant data was utilized as a base for all subsequent pilot plant test result comparisons and conclusions.

3.0 TEST PROGRAM

3.1 Introduction

The main objective in this secondary ball mill circuit optimization program was to reduce grinding power consumption and/or improve final grade. This was to be investigated by 1) utilizing the recommended grinding % solids and ball size as determined in the prior optimization program and 2) by improved classification techniques.

3.2 Flowsheets

The NSPC commercial plant flowsheet is shown on attached Figure 1. Figures 2 and 3 show the five basic pilot plant flowsheets investigated. These were as follows:

Flowsheet A - A duplication of the NSPC secondary grinding circuit employing a conventional hydrocyclone with a Dorr-Oliver Rapifine screen treating the finisher concentrate product.

Flowsheet B - A Derrick sandwich screen substituted in place of the Dorr-Oliver unit. Screen surfaces DF-120 (170 mesh) and DF-165 (230 mesh) tested. In addition, a modified cyclone with a "JD" apex valve tested.

Flowsheet C - Same as flowsheet B but tested a DF-145 Derrick screen surface. Hydrocyclone operated to produce a coarser separation than in flowsheets A and B.

Flowsheet D - Same as flowsheet B but with Derrick screen oversize returned to the ball mill via a dewatering magnetic separator. NSPC flowsheet (Figure 1) returns this product to the cyclone feed sump.

Flowsheet E - Hydrocyclone replaced by 28 mesh Denver screen and Derrick screen with DF-165 surface operating in series.

3.3 Equipment Description

The major items of equipment used in this flowsheet were:

a) Secondary Ball Mill

Make:	Marcy Ball Mill with trunnion o'flow discharge		
Size:	3'Ø X 3' long		
Speed:	81% C.S.		
Power:	10 HP		
Ball Charge:	1500 lbs. (30% mill volume)	28.6%	1.25"
		47.5%	1.00"
		18.8%	0.75"
		5.1%	0.50"

b) Hydrocyclone

Make:	Dorr-Oliver
Size:	3"Ø
Vortex Finder:	1.0, 1.5, 1.8 & 2.0"Ø
Apex Valve:	7/8" and 1.0"Ø
	1.0" J.D.
Pressure:	5, 8 and 10 psig

c) Rapifine Screen

Make:	Dorr-Oliver
Size:	18 inches wide X 4 feet long
Cloth:	Sieve bend panels - 0.004" & 0.006" avg. slot openings

d) Derrick Screen

Type:	Vibrating screen with sandwich decks
Size:	2 feet wide by 3 feet long
Cloth:	DF120 - 170 mesh
	DF145 - 200 mesh
	DF165 - 230 mesh

e) Denver Screen

Type:	Vibrating screen with conventional screen cloth
Size:	15 inches wide X 3 feet long
Cloth:	28 mesh Tyler

f) Dewatering Separator

Make:	Stearns
Size:	18"Ø X 10"
Strength:	700 gauss

g) Hydroseparator

Make:	Denver
Size:	6'Ø X 4' deep

h) Finisher Magnetic Separator (2 Drum)

Make:	Indiana General
Size:	30"Ø X 20" face width.
Strength:	600 gauss

3.4 Test Procedures

The new feed rate to the flowsheet was accurately determined based on 10 second cuts of the table feeder discharge every 15 minutes. For the sampling period, these readings were averaged to give each test's new feed rate. The sampling period was normally 2-hours in length and followed a 2-4 hour circuit stabilization period.

The power drawn by the mill was measured by a wattmeter. The no-load power or mill tare was determined before the test project over a period of 6 hours.

Water addition to the mill was measured with a Brooks Rotameter. Adjustments were made based on mill discharge slurry density determined manually with a Marcy balance at 20 minute intervals. For all tests, mill discharge density was maintained between 70 and 72% solids by weight.

All circuit points were sampled during the two-hour sampling period and processed for structures and percent solids data. Appropriate time weight samples were taken just prior to circuit shutdown.

4.0 PILOT PLANT RESULTS

4.1 General

Overall, thirty-one tests were conducted utilizing the NSPC cobber concentrates as new feed material to the secondary grinding circuit. All tests were conducted maintaining 70-72% grinding solids by weight. The ball charge and new feed rates were adjusted to maintain the same approximate net power/ton as the NSPC plant averaged during the January and May, 1989 sampling periods. The majority of the following flowsheet conclusions were therefore made on the basis of final product grind/grade levels and ball mill circulating loads, compared to plant and baseline pilot plant tests. For the "no cyclone" tests (Flowsheet E), circuit feed rates were increased to illustarate the potential power reduction (or increased grinding capacity) that exists for this configuration.

4.2 Flowsheet A - Base Line Tests with Dorr-Oliver Rapifine Screen.

The initial tests (Table 2) utilizing a 0.004" slot opening seive bend panel produced a final product that was considerably finer in structure and lower in silica that the the NSPC final concentrate. Changing to a 0.006" opening panel produced the following results, closely paralleling plant data for the two periods.

	Secondary Power Net KWH/LT			Final Concentrate Fine Screen Undersize			
	Crude	Cobb. Conc.	% C.L.	%-325 Mesh	cm^2 /gm	%Fe	$\%SiO_2$
NSPC Plant 1/30-2/1 '89	5.2	10.8	150-250	73.9	1720	68.17	4.65
Pilot Plant - Flowsheet A	5.2	10.8	302	83.7	1754	68.00	4.69
NSPC Plant 5/1-5/5 '89	5.1	10.6	150-250	76.2	1850	68.25	4.75
Pilot Plant - Flowsheet A	4.9	10.1	364	78.7	1631	68.03	4.75

It is virtually impossible to match the plants 26-inch diameter cyclone performance with a small pilot size 3-inch diameter unit. It is for this reason that the above circulating loads, grinds and blaine surface areas are in somewhat disagreement while product grade and power input are for all practical purposes identical.

4.3 Flowsheets B and C - Derrick Sandwich Screen Replacing Dorr-Oliver Rapifine Screens.

For this series of tests, a 2' X 3' Derrick screen was substituted for the Dorr-Oliver Rapifine unit, again treating finisher concentrate. Three different opening sandwich screen panels were tested which gave the following average results compared to the above Flowsheet A baseline data, for each of the two cobber concentrate samples:

		Secondary Power			Final Concentrate Screen Undersize				
		Net KWH/LT		%	%	cm^2		%	%
Flowsheet	Screen	Crude	Conc.	C.L.	-325	/gm	%Fe	SiO_2	SiO_2
		January 30 - February 1, 1989 Sample							
A	D-O, 0.006"	5.2	10.8	302	83.7	1754	68.00	4.69	Base
B	Derr., DF-120*	5.0	10.4	140	79.4	1668	68.39	4.13	-0.56
B	Derr., DF-145	4.7	9.7	187	81.6	1681	68.49	3.93	-0.76
B	Derr., DF-165	4.8	10.0	197	79.8	1707	68.61	3.78	-0.91
		May 1-5, 1989 Sample							
A	D-O, 0.006"	4.9	10.1	364	78.7	1631	68.03	4.75	Base
B	Derr., DF-120	5.0	10.3	260**	76.5	1654	68.10	4.58	-0.17
C	Derr., DF-145	5.0	10.3	144	74.0	1649	68.27	4.35	-0.40
C	Derr., DF-165	4.9	10.1	189	76.9	1612	68.72	3.87	-0.88

*DF-120 (170 mesh)
DF-145 (200 mesh)
DF-165 (230 mesh)

**Value high due to leakage of screen undersize to oversize product at bottom end of screen panel.

As expected, total ball mill circulating loads increased with the use of successive finer ball mill closure screens. For both samples however, the circulating loads for all Derrick screen tests were lower than the base line flowsheet A tests utilizing a Dorr-Oliver rapifine screen.

Interestingly, final product grind in terms of %-325 mesh or Blaine surface area remained relatively constant while product silica decreased with successive finer closure screens. A reduction of final silica of about 0.9% appears easily attainable (DF-165 screen) as a result of increased secondary ball mill classification efficiency utilizing Derrick screens in lieu of the Dorr-Oliver rapifine units. No loss of present grinding capacity would result; on the contrary, the tests with the January plant cobber concentrate sample indiate a 7-8% potential power reduction.

A 1.0" diameter JD spigot valve[2] was constructed and tested (Test No. NS-29) in the 3-inch diameter Dorr-Oliver cyclone. In comparing the results of Test NS-29 to Test NS-28, containing a conventional spigot valve, no improvement in classification was noted. As the appended article cites, higher underflow densities (80-81%) are attainable without roping compared to conventional apex values. For dewatering applications this would be of obvious benefit, but appears to offer nothing for improved classification circuits.

4.4 Flowsheet D - Screen Oversize to Ball Mill

The National Steel Pellet Companys' present flowsheet returns to the Dorr-Oliver rapifine screen oversize product to the secondary ball mill cyclone feed sump. As this material has already exited the secondary circuit via the cyclone overflow product, it was felt improved grind/grade results might be attainable if this oversize product were to be returned to the ball mill, precluding any short circuiting. The following results indicate only marginal grade improvement by this approach compared to the present flowsheet.

		Secondary Power			Final Concentrate Screen Undersize				
		Net KWH/LT		%	%	cm^2		%	%
Flowsheet	Screen	Crude	Conc.	C.L.	-325	/gm	%Fe	SiO_2	SiO_2
C	Derr., DF-145	5.0	10.3	144	74.0	1649	68.27	4.35	Base
D	Derr., DF-145	5.1	10.6	135	73.8	1698	68.29	4.28	-0.07

These marginal grade improvement results would not justify making this flow revision to the present NSPC concentrator. In a similar greenfield application, it would be the preferred configuration.

4.5 Flowsheet E - Screens Replacing Cyclone

Cyclone replacement in a taconite flowsheet was suggested over twenty years ago by R. L. Bliefuss[1] to eliminate or reduce the inherent problems of misplaced material in the cyclone products. No Lake Superior taconite operation has to date converted to this flowsheet configuration which appears to offer the combined benefits of lower product silica, coarser product grind and a significant increase in secondary grinding capacity as shown in the following tabulation:

Flowsheet Screen	KWH/LT Crude	KWH/LT Reduction	% C.L.	Final Concentrate % -325	cm^2/gm	%Fe	$\%SiO_2$	$\%SiO_2$
Plant(5/1-5/5)	5.1	-	150-250	76.2	1850	68.25	4.75	-
A. Cyclone-D-O Screen 0.006" Surface	4.9	Base	364	78.7	1631	68.03	4.75	Base
B. Cyclone-Derr.Screen DF-165 Surface	4.9	-	189	76.9	1612	68.72	3.87	-0.88
E. No Cyclone 28 Mesh Denver Derr.Screen DF-165 Surface	4.6	-6%	122	66.7	1562	68.85	3.84	-0.91
E. No Cyclone 28 Mesh Denver Derr.Screen DF-165 Surface	4.1	-16%	190	64.0	1512	68.19	4.17	-0.58

For the NSPC concentrator, elimination of the cyclone would appear to offer the following magnitude of benefits:

1.) Power reduction or increased secondary grinding capacity of 6 to 16%.

2.) Decrease of concentrate grind by;

a. 12-14% minus 325 mesh, and
b. Blaine surface area reduction of 100 units, minimum.

3.) Concentrate silica decrease of approximately 0.6 - 0.9% SiO_2.

Sideline benefits resulting from a coarser product grind would be 1) decreased filtering problems and 2) a possible reduction in tailing flocculant usage.

To illustrate why these benefits occur, silica analysis of individual screen fractions of the final concentrates were made of a base line test (cyclone and Dorr-Oliver screen, NS-9) and a test (NS-30) employing screens for cyclone replacement.

FINAL CONCENTRATES

Tyler Mesh	TEST NS-9 Cyclone + D-O Screen			TEST NS-30 No Cyclone - 2 Stage Screens		
	%Wt.	$\%SiO_2$	SiO2 Units	%Wt.	$\%SiO_2$	SiO2 Units
+200	5.04	20.60	1.04	8.48	4.25	0.36
+270	7.43	10.80	0.80	15.16	6.85	1.04
+325	7.86	5.68	0.45	9.71	4.85	0.47
-325	79.67	2.52	2.01	66.65	2.96	1.97
TOTALS	100.00	4.30	4.30	100.00	3.84	3.84

Please note the extreme differences in silica content of the +200 and -200 + 270 mesh fractions of these two flowsheet final products. Approximately 25% of the total product silica is contained in the plus 200 mesh fraction (NS-9) compared to only 9% for Test NS-30. At cumulative +270 mesh, the difference is 43% versus 36%. The silica units contained in the final two fractions are essentially equal.

5.0 RECOMMENDATIONS

1. Replace existing static screens with more efficient high frequency sandwich deck units.

2. For maximum power savings, flowsheet E (no cyclone - 2 stage screens) is the preferred configuration.

FIGURE 1

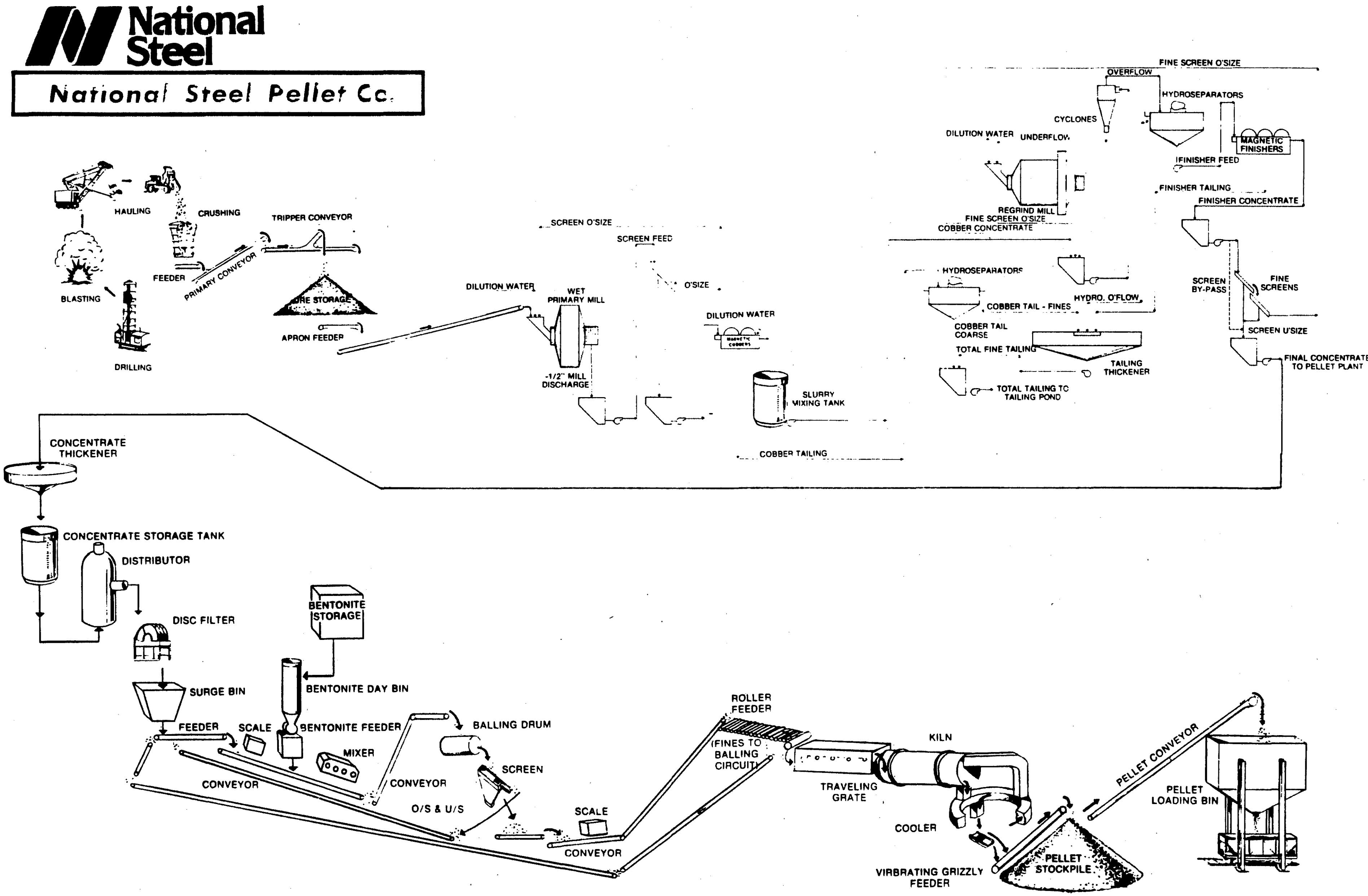
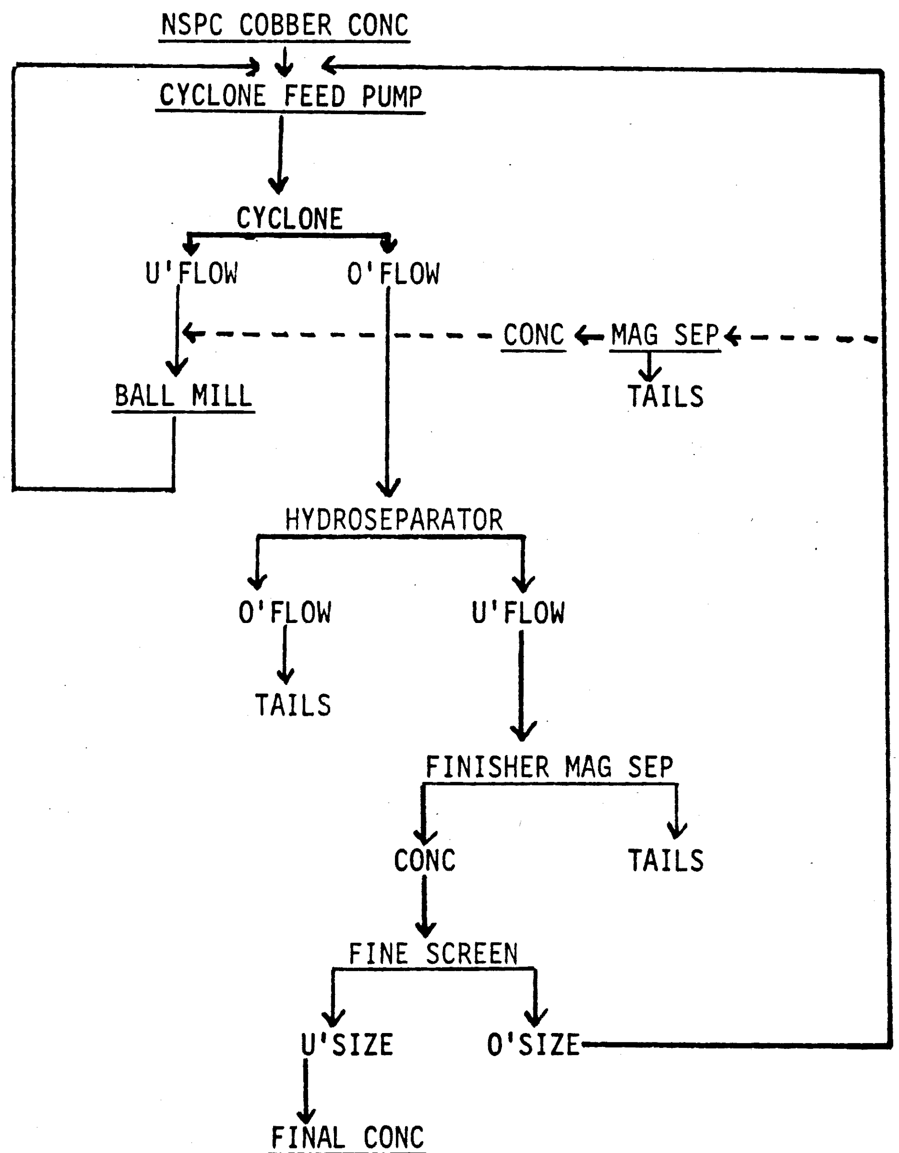

National Steel
National Steel Pellet Co.
HAULING
CRUSHING
TRIPPER CONVEYOR
BLASTING
FEEDER
PRIMARY CONVEYOR
ORE STORAGE
APRON FEEDER
DRILLING
SCREEN O'SIZE
SCREEN FEED
O'SIZE
DILUTION WATER
WET PRIMARY MILL
-1/2" MILL DISCHARGE
DILUTION WATER
SLURRY MIXING TANK
COBBER TAILING
FINE SCREEN O'SIZE
OVERFLOW
HYDROSEPARATORS
CYCLONES
DILUTION WATER
UNDERFLOW
MAGNETIC FINISHERS
FINISHER FEED
FINISHER TAILING
FINISHER CONCENTRATE
REGRIND MILL
FINE SCREEN O'SIZE
COBBER CONCENTRATE
HYDROSEPARATORS
HYDRO. O'FLOW
COBBER TAIL - FINES
COBBER TAIL COARSE
TOTAL FINE TAILING
TAILING THICKENER
TOTAL TAILING TO TAILING POND
SCREEN BY-PASS
FINE SCREENS
SCREEN U'SIZE
FINAL CONCENTRATE TO PELLET PLANT
CONCENTRATE THICKENER
CONCENTRATE STORAGE TANK
DISTRIBUTOR
DISC FILTER
BENTONITE STORAGE
SURGE BIN
BENTONITE DAY BIN
FEEDER
SCALE
BENTONITE FEEDER
MIXER
BALLING DRUM
SCREEN
CONVEYOR
CONVEYOR
O/S & U/S
SCALE
CONVEYOR
ROLLER FEEDER
(FINES TO BALLING CIRCUIT)
TRAVELING GRATE
KILN
COOLER
VIRBRATING GRIZZLY FEEDER
PELLET STOCKPILE
PELLET CONVEYOR
PELLET LOADING BIN

FIGURE 2



FLOWSHEETS:

Flowsheet A - Baseline; present NSPC flowsheet with D/O Rapifine screen.

Flowsheet B - Same but with Derrick screen replacing Rapifine screen.

Flowsheet C - Same as "B" flowsheet with coarser cyclone split. Shift more load to Derrick Screen.

Flowsheet D - Same as "B" flowsheet but screen o'size returned to ball mill via dewatering mag separator.

FIGURE 3

FLOWSHEET E - SCREENS REPLACING CYCLONE

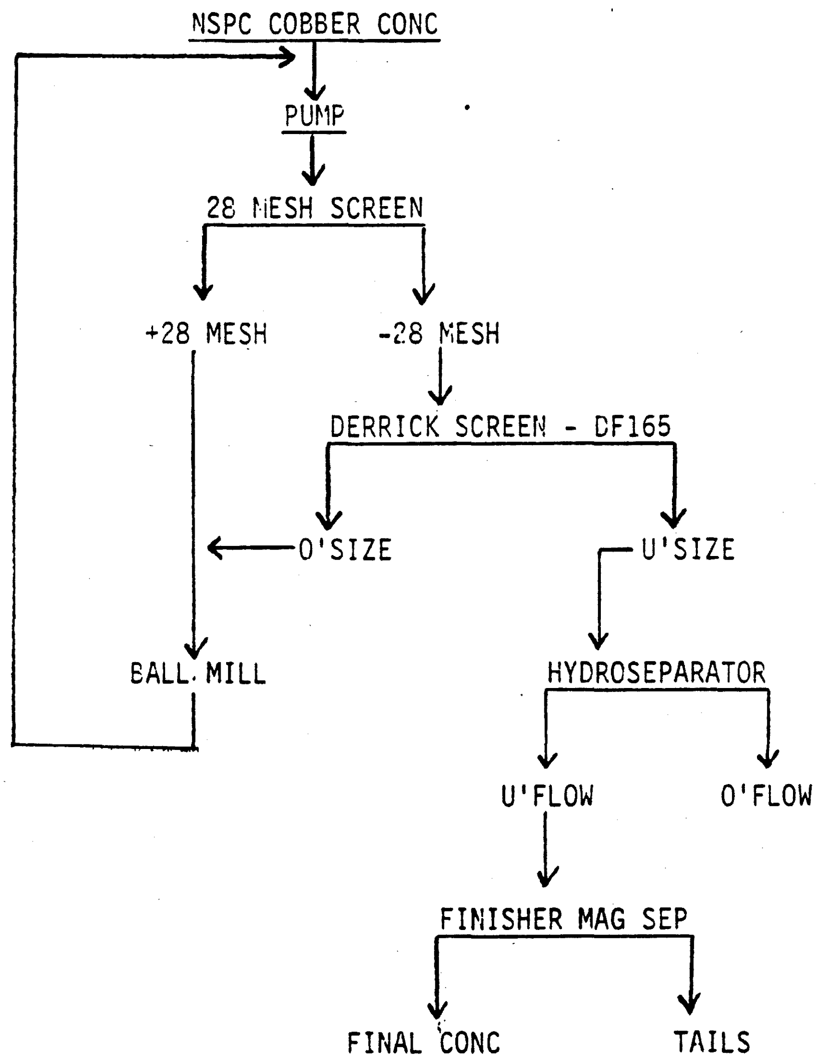


TABLE 1

SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

National Steel Pellet Company
Mine Ore Blend April 28 - May 5, 1989

PROPERTY	COMPOSITE	SHOVEL NO.	% MINED	% WGT	LIBERATION INDEX
ONTARIO ANNEX	1511-012	4157	16	32.6	5.20
STEVENSON ANNEX	1425-1951	4154	13	26.6	2.00
STEVENSON	1330-040	4155	38	24.0	2.00
STEVENSON ANNEX	1425-1952	4154	30	29.0	2.10
ONTARIO ANNEX	1511-022	4157	3	32.2	4.70
AVERAGE:			100%	27.4	2.60
TARGET BLEND				27.5	2.62

Mine Ore Blend January 27 - February 1, 1989

PROPERTY	COMPOSITE	SHOVEL NO.	% MINED	% WGT	LIBERATION INDEX
ONTARIO ANNEX	1510-301/281	4157	36	35.5	3.30
RUSSELL	1230-16/15	4155	30	25.8	2.00
STEVENSON ANNEX	1425-1931	4154	25	34.0	2.40
AVERAGE:			100%	32.1	2.60
TARGET BLEND				31.9	2.63

TABLE 2

SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

NSPC Plant Cobber Concentrate Sample: May 1 - 5, 1989

FS	Date	Test No.	DRY FEED RATE lb/hr	DRY FEED RATE LT/hr	3-INCH Ø CYCLONE psig	3-INCH Ø CYCLONE VF-Ø	3-INCH Ø CYCLONE Apex-Ø	POWER NET KWH/LT Crude	POWER NET KWH/LT Cobb. Conc	CYCLONE %-325M U'Flow	CYCLONE %-325M O'Flow	FINE SCREEN Make	FINE SCREEN Opening	FINE SCREEN PRODUCTS O'Size %-325	FINE SCREEN PRODUCTS UNDERSIZE %-325	UNDERSIZE cm²/gm	UNDERSIZE %Fe	UNDERSIZE %SiO	Ball Mill Cir. Loads** %
	5/1 - 5/5/89		NATIONAL STEEL PLANT AVERAGE					5.1*	10.6*						76.2	1850	68.25	4.75	150-250%
									*Gross X 0.85										
					FLOWSHEET A - BASE LINE w/D-O FINE SCREEN														
A	5/23/89	NS-1	758	0.34	10	1.0"	7/8"	8.9	18.6	39.2	94.6	D-O	0.004"	-	98.5	-	69.76	2.65	
A	5/24/89	NS-2	1184	0.53	10	1.0"	7/8"	7.1	14.8	41.9	96.6	D-O	0.004"	-	96.2	2177	69.94	2.58	
A	5/30/89	NS-3	1466	0.65	10	1.5"	1.0"	4.7	9.7	16.9	87.2	D-O	0.004"	42.1	84.4	1765	68.63	3.56	
A	6/01/89	NS-4	1466	0.65	10	1.5"	7/8"	4.9	10.2	18.9	78.0	D-O	0.004"	41.3	84.7	1761	68.63	3.98	
A	6/06/89	NS-5	1469	0.66	10	1.8"	7/8"	4.9	10.1	17.7	78.2	D-O	0.004"	49.1	86.2	1782	68.85	3.82	
A	6/07/89	NS-6	1451	0.65	10	1.8"+2.0"	7/8"	4.9	10.1	19.5/ 19.5	79.2/ 73.2	D-O	0.004"	-	91.9/ 84.7	1982/ 1876	69.00/ 68.63	3.44/ 3.48	
A	6/08/89	NS-7	1444	0.64	5	1.8"	1.0"	4.9	10.1	19.9	74.4	D-O	0.006"	36.2	78.2	1618	67.88	5.07	
A	6/09/89	NS-8	1447	0.65	5	1.8"	1.0"	4.9	10.1	19.5	74.4	D-O	0.006"	55.1	78.2	1603	67.73	4.87	
A	6/13/89	NS-9	1477	0.66	8	1.8"	1.0"	4.9	10.1	20.9	74.0	D-O	0.006"	60.8	79.7	1672	68.48	4.30	
	AVE.	7, 8 & 9						4.9	10.1	20.1	74.2	D-O	0.006"	50.7	78.7	1631	68.03	4.75	364%
					FLOWSHEET B - DERRICK SCREEN REPLACING DORR-OLIVER														
B	6/14/89	NS-10	1458	0.65	8	1.8"	1.0"	4.9	10.1	20.2	72.8	Derr.	DF-120	57.7	76.5	1605	68.18	4.45	
B	6/14/89	NS-11	1450	0.65	8	1.8"	1.0"	4.9	10.1	22.0	74.6	Derr.	DF-120	61.5	77.3	1536	67.88	4.73	
B	6/15/89	NS-12	1458	0.65	5	1.8"	1.0"	4.9	10.1	19.1	74.7	Derr.	DF-120	60.8	76.8	1634	67.90	4.91	
B	6/15/89	NS-13	1450	0.65	5	2.0"	7/8"	5.1	10.4	20.0	70.3	Derr.	DF-120	20.4	72.3	1576	67.57	5.22	
B	6/29/89	NS-20	1430	0.64	10	2.0"	7/8"	5.1	10.6	20.8	81.7	Derr.	DF-120	16.3	85.4	1825	68.64	3.96	
B	6/29/89	NS-21	1442	0.64	8	2.0"	7/8"	5.1	10.6	19.1	77.7	Derr.	DF-120	24.2	71.0	1753	68.42	4.18	
	AVE.							5.0	10.3	20.2	75.3	Derr.	DF-120	40.1	76.5	1654	68.10	4.58	260%
B	8/03/89	NS-28	1488	0.66	5	2.0"	7/8"	4.9	10.1	18.0	71.9	Derr.	DF-165	34.3	76.9	1612	68.72	3.87	189%
B	8/04/89	NS-29	1486	0.66	8	2.0"	JD(1")	4.9	10.1	16.0	75.8	Derr.	DF-165	50.9	79.8	1605	68.55	3.89	198%
					FLOWSHEET C - DERRICK SCREEN WITH COARSER CYCLONE SPLIT														
C	6/20/89	NS-14	1518	0.67	5	2.0"	7/8"	4.9	10.1	18.7	64.6	Derr.	DF-145	10.5	72.4	1610	68.63	4.10	
C	6/22/89	NS-17	1467	0.65	5	2.0"	7/8"	5.0	10.3	14.5	53.9	Derr.	DF-145	11.2	70.1	1616	67.59	4.93	
C	6/27/89	NS-18	1427	0.64	5	2.0"	7/8"	5.1	10.6	18.9	74.9	Derr.	DF-145	23.6	79.5	1763	68.58	4.01	
	AVE.							5.0	10.3	17.4	64.5	Derr.	DF-145	15.1	74.0	1649	68.27	4.35	144%
					FLOWSHEET D - SCREEN O'SIZE TO BALL MILL														
D	6/20/89	NS-15	1474	0.66	5	2.0"	7/8"	4.9	10.1	18.4	61.5	Derr.	DF-145	12.4	71.6	1644	68.63	4.13	
D	6/22/89	NS-16	1444	0.64	5	2.0"	7/8"	5.1	10.5	16.9	66.6	Derr.	DF-145	11.5	73.5	1735	68.00	4.35	
D	6/28/89	NS-19	1368	0.61	5	2.0"	7/8"	5.4	11.3	19.4	72.0	Derr.	DF-145	18.7	76.3	1715	68.25	4.36	
	AVE.							5.1	10.6	17.3	66.7	Derr.	DF-145	14.2	73.8	1698	68.29	4.28	135%
					FLOWSHEET E - SCREENS REPLACING CYCLONE					Denver Screen @ 28 Mesh % -325 Mesh O'Size	Denver Screen @ 28 Mesh % -325 Mesh U'Size				Finisher Conc.				
E	8/07/89	NS-30	1476	0.66	-	-	-	4.6	9.6	10.2	47.9	Derr.	DF-165	20.4	66.7	1562	68.85	3.84	122%
E	8/08/89	NS-31	1688	0.75	-	-	-	4.1	8.5	9.7	39.6	Derr.	DF-165	26.0	64.0	1512	68.19	4.17	190%

**By time weight samples.

TABLE 3
SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

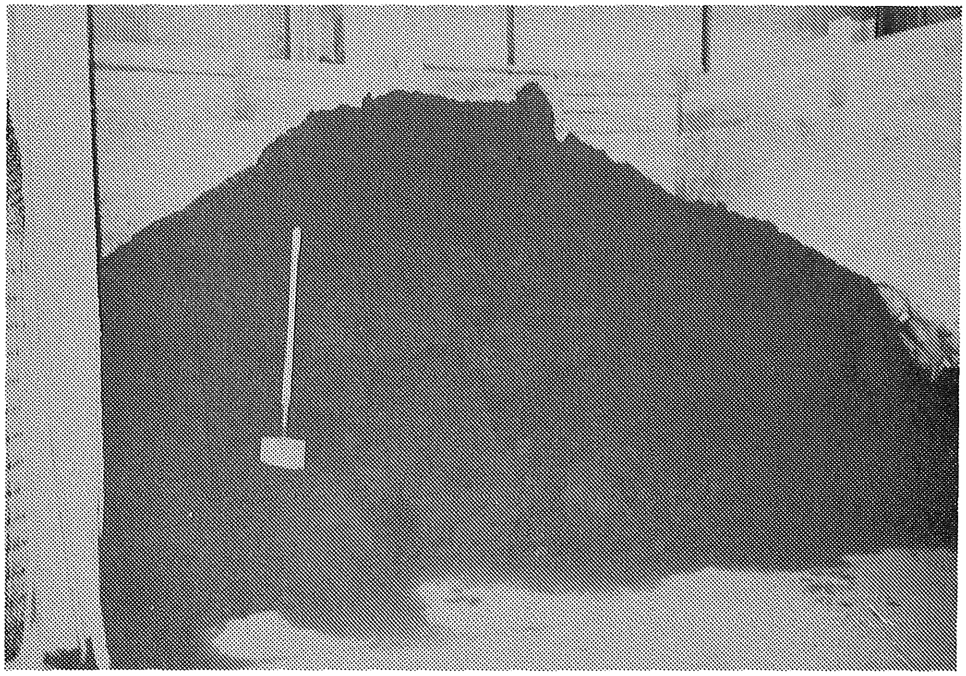
Plant Cobber Concentrate Sample: January 30, 31 & February 1, 1989

F.S.	Date	Test No.	DRY FEED RATE lb/hr	DRY FEED RATE LT/hr	3-INCH Ø CYCLONE psig	3-INCH Ø CYCLONE VF-Ø	3-INCH Ø CYCLONE Apex-Ø	POWER NET KWH/LT Crude	POWER NET KWH/LT Cobb. Conc	CYCLONE %-325M U'Flow	CYCLONE %-325M O'Flow	FINE SCREEN Make	FINE SCREEN Opening	FINE SCREEN PRODUCTS O/Size %-325	FINE SCREEN PRODUCTS UNDERSIZE %-325	UNDERSIZE cm^2/gm	UNDERSIZE %Fe	UNDERSIZE $\%SiO_2$	Ball Mill Cir. Loads %
	1/30-2/1	NATIONAL STEEL PLANT AVERAGE						5.2*	10.8* *Gross X 0.85						73.9	1720	68.17	4.65	150-250
		FLOWSHEET A - BASELINE w/D-O FINE SCREEN																	
A	7/05/89	NS-22	1392	0.62	5	1.8"	7/8"	5.2	10.8	19.7	80.4	D-O	0.006"	59.3	83.7	1754	68.00	4.69	302
		FLOWSHEET B - DERRICK SCREEN REPLACING DORR-OLIVER																	
B	7/07/89	NS-24	1407	0.63	5	2.0"	7/8"	5.0	10.4	20.6	77.2	Derr.	DF-120	41.2	79.4	1668	68.39	4.13	140
	8/01/89	NS-26	1536	0.69	5	2.0"	7/8"	4.7	9.7	23.7	76.4	Derr.	DF-145	51.4	81.6	1681	68.49	3.93	187
	7/31/89	NS-25	1512	0.68	5	2.0"	7/8"	4.8	10.0	22.4	76.8	Derr.	DF-165	46.9	79.8	1707	68.61	3.78	197
	8/02/89	NS-27*	1543	0.69	5	2.0"	7/8"	4.7	9.7	21.9	67.8	Derr.	DF-145	35.4	77.1	1610	68.60	3.93	187

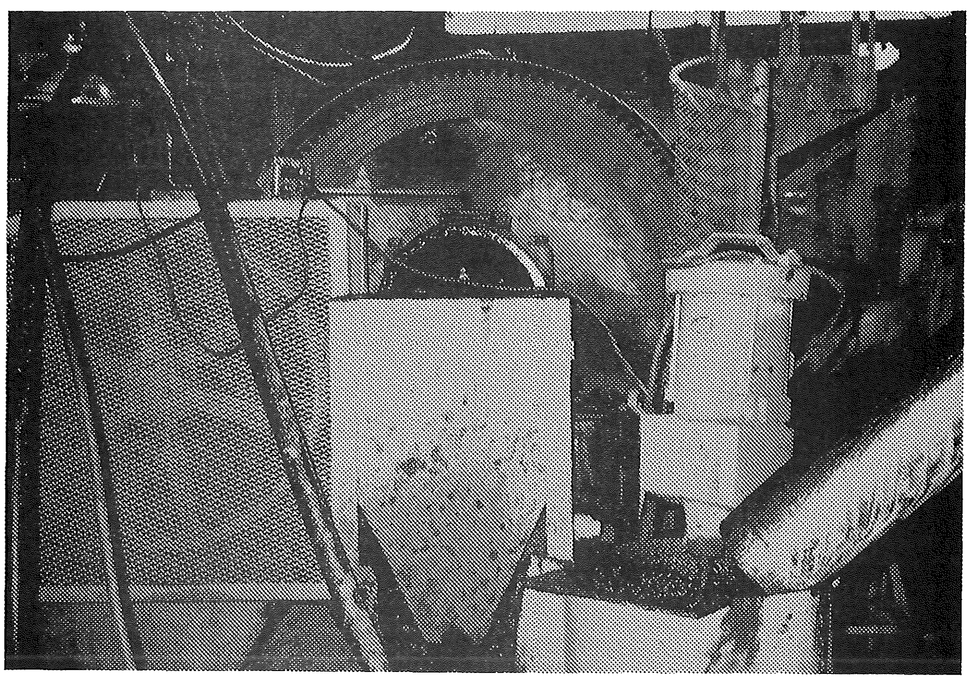
*Increased Derrick Screen Loading - Used only 5-inches of 22" screen width. Compare to Test NS-26.

*By time weight samples.

<u>SECONDARY BALL MILL CIRCUIT OPTIMIZATION</u>
<u>HRC PILOT PLANT TESTING</u>

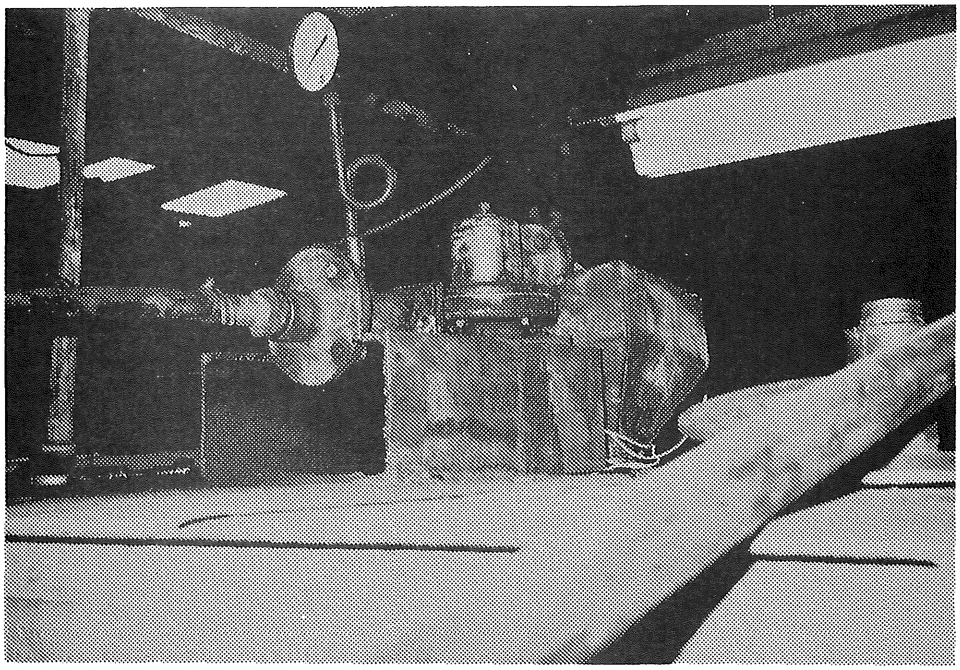


N.S.P.C. Cobber Concentrate Feed Material

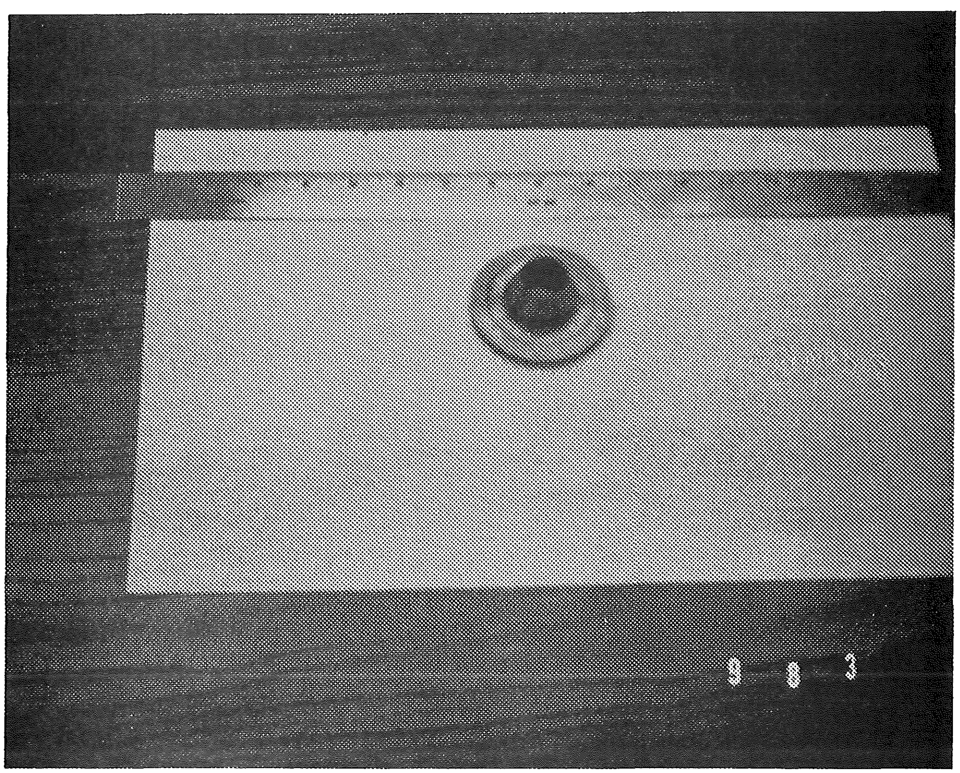


Marcy 3'Ø X 3' Long Ball Mill

SECONDARY BALL MILL CIRCUIT OPTIMIZATION
HRC PILOT PLANT TESTING

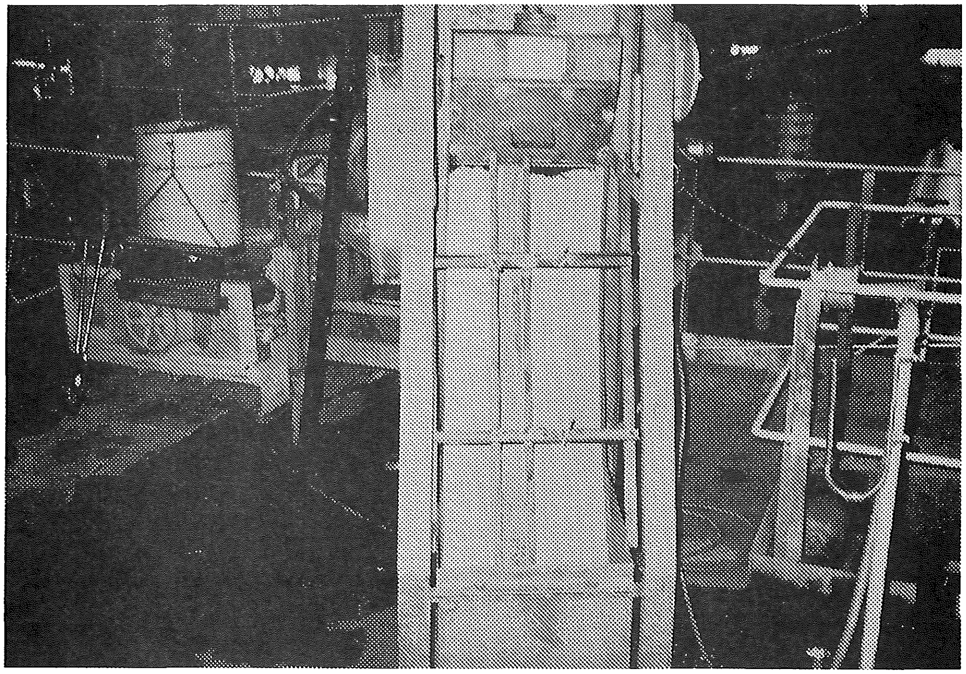


3"Ø Dorr Oliver Hydrocyclone

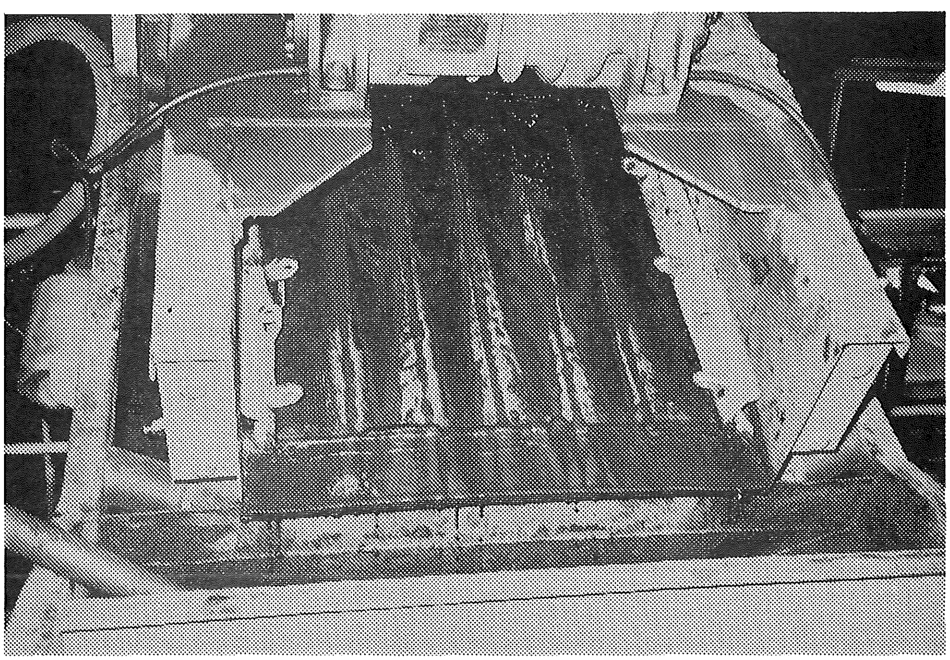


Machined "JD" Apex Valve

SECONDARY BALL MILL CIRCUIT OPTIMIZATION
HRC PILOT PLANT TESTING

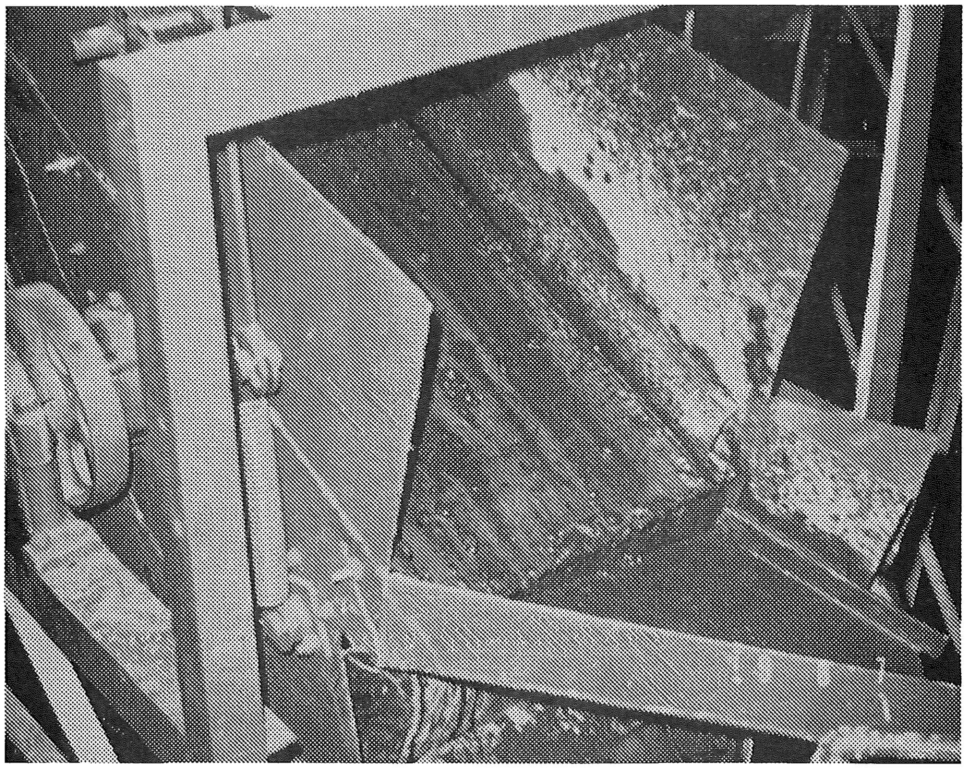


Dorr Oliver Rapifine Screen

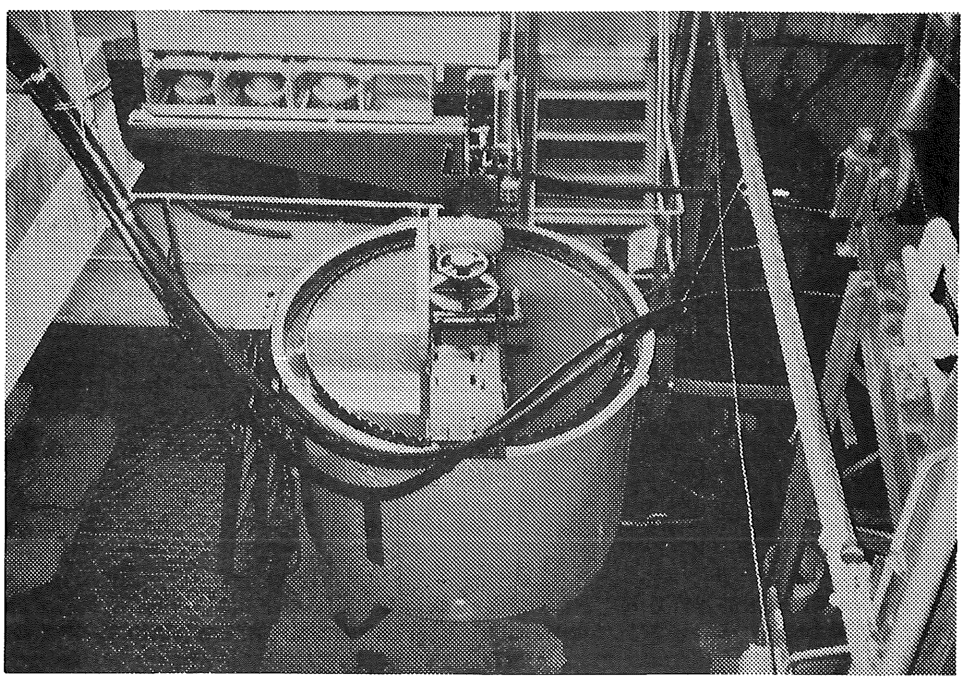


Derrick Sandwich Screen Unit

SECONDARY BALL MILL CIRCUIT OPTIMIZATION
HRC PILOT PLANT TESTING



Denver 28 Mesh Scalping Screen



Denver 6'Ø X 4' Hydroseparator

SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

Test No. NS-7

Sample	% Fe	% SiO_2	% Solids
Cobber Conc.	48.16		93.4
Cyclone Feed	52.22		42.3
Cyclone U'Flow	53.73		72.5
Ball Mill Disch.	52.22		70.9
Cyclone O'Flow	48.91		19.4
Hydro U'Flow	50.42		24.1
Hydro O'Flow	14.20		1.2
Finisher Conc.	67.50		54.4
Finisher Tails	14.82		5.9
Fine Screen O'Size	55.46		14.0
Fine Screen U'Size	67.88	5.07	20.1

	Cumulative % Wt. Retained					
Mesh	Cobber Conc	Cyclone U'Flow	Ball Mill Disch.	Cyclone O'Flow	F.S. O'Size	F.S. U'Size
+4	0.25	0.37	0.30			
+6	1.71	1.95	1.11			
+8	3.47	3.69	2.07			
+10	6.43	5.53	2.83			
+14	10.45	7.27	3.43			
+20	15.88	9.54	3.88			
+28	21.36	11.75	4.28			
+35	28.29	14.60	4.88			
+48	35.43	18.13	5.94	0.08	3.33	
+65	42.87	22.71	8.41	0.24	9.20	0.18
+100	50.06	29.45	13.10	0.88	17.87	0.57
+150	56.94	40.25	23.33	3.16	29.09	1.67
+200	64.28	56.69	41.42	9.39	45.16	6.54
+270	70.01	71.55	58.04	18.53	57.66	15.58
+325	73.28	80.03	64.39	25.56	63.78	21.81
-325	26.72	19.97	35.61	74.44	36.22	78.19

SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

Test No. NS-8

Sample	% Fe	% SiO_2	% Solids
Cobber Conc.	49.14		93.1
Cyclone Feed	52.15		39.8
Cyclone U'Flow	53.13		71.8
Ball Mill Disch.	52.60		72.0
Cyclone O'Flow	49.51		18.9
Hydro U'Flow	51.47		23.9
Hydro O'Flow	15.95		0.9
Finisher Conc.	67.35		61.8
Finisher Tails	15.35		5.9
Fine Screen O'Size	62.08		27.8
Fine Screen U'Size	67.73	4.87	32.3

	Cumulative % Wt. Retained					
Mesh	Cobber Conc	Cyclone U'Flow	Ball Mill Disch.	Cyclone O'Flow	F.S. O'Size	F.S. U'Size
+4	0.12	0.09	0.28			
+6	1.27	1.58	1.52			
+8	3.37	3.07	2.47			
+10	6.37	4.88	3.31			
+14	10.28	6.55	3.93			
+20	15.38	8.49	4.38			
+28	21.38	10.75	4.77			
+35	28.00	13.50	5.39		0.10	
+48	34.74	16.89	6.40		0.61	
+65	42.31	21.59	8.70	0.20	2.23	0.11
+100	48.85	27.82	13.75	0.75	5.53	0.45
+150	57.32	40.96	23.46	2.61	11.97	1.62
+200	63.53	56.31	41.37	9.61	24.50	5.90
+270	69.33	72.56	56.31	19.93	36.67	13.93
+325	72.91	80.55	64.56	25.57	44.94	21.28
-325	27.09	19.45	35.44	74.43	55.06	78.72

SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

Test No. NS-9

Sample	% Fe	% SiO_2	% Solids
Cobber Conc.	49.59		92.8
Cyclone Feed	55.08		46.02
Cyclone U'Flow	54.18		74.5
Ball Mill Disch.	54.18		72.1
Cyclone O'Flow	51.09		16.7
Hydro U'Flow	52.98		23.4
Hydro O'Flow	15.80		1.0
Finisher Conc.	67.80		46.9
Finisher Tails	15.50		4.9
Fine Screen O'Size	64.03		12.9
Fine Screen U'Size	68.48	4.30	38.5

	Cumulative % Wt. Retained					
Mesh	Cobber Conc	Cyclone U'Flow	Ball Mill Disch.	Cyclone O'Flow	F.S. O'Size	F.S. U'Size
+4	0.61	0.30	0.38			
+6	1.32	1.77	1.61			
+8	3.69	3.48	2.53			
+10	6.51	4.95	3.49			
+14	10.42	6.48	3.99			
+20	15.52	8.25	4.41			
+28	20.94	10.17	4.79			
+35	27.45	12.47	5.40	0.05		
+48	34.51	15.16	6.51	0.10	0.41	0.05
+65	42.16	19.20	8.81	0.31	1.71	0.10
+100	49.49	24.80	14.07	1.03	4.38	0.31
+150	56.36	37.70	24.09	3.03	10.26	1.48
+200	64.10	52.87	43.64	9.61	18.95	5.04
+270	69.33	71.15	59.88	18.60	31.19	12.47
+325	72.83	79.11	68.79	26.00	39.19	20.33
-325	27.17	20.89	31.21	74.00	60.81	79.67

SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

Test No. NS-12

Sample	% Fe	% SiO_2	% Solids
Cobber Conc.	49.36		92.7
Cyclone Feed	51.02		42.1
Cyclone U'Flow	51.27		70.9
Ball Mill Disch.	51.64		70.5
Cyclone O'Flow	48.76		21.0
Hydro U'Flow	52.77		23.3
Hydro O'Flow	15.73		0.9
Finisher Conc.	67.12		24.4
Finisher Tails	15.28		5.8
Fine Screen O'Size	59.30		13.9
Fine Screen U'Size	67.80	4.91	26.8

	Cumulative % Wt. Retained					
Mesh	Cobber Conc.	Cyclone U'Flow	Ball Mill Disch.	Cyclone O'Flow	F.S. O'Size	F.S. U'Size
+4	0.41	0.64	0.11			
+6	1.06	2.56	0.60			
+8	2.81	4.83	1.75			
+10	5.58	7.20	2.68			
+14	9.82	10.30	3.17			
+20	15.03	13.95	3.50			
+28	20.98	17.45	3.83			
+35	27.62	21.89	4.27			
+48	34.30	26.82	5.04	0.06	0.63	
+65	41.92	32.68	6.73	0.18	3.35	
+100	48.60	40.02	10.39	0.85	12.60	0.06
+150	57.07	49.73	17.44	3.21	21.58	1.21
+200	63.87	61.80	28.59	9.26	25.66	4.44
+270	69.98	74.37	43.67	18.21	33.18	15.28
+325	73.12	80.92	52.74	25.34	39.25	23.18
-325	26.88	19.08	47.26	74.66	60.75	76.82

SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

Test No. NS-13

Sample	% Fe	% SiO_2	% Solids
Cobber Conc.	49.21		92.8
Cyclone Feed	50.42		23.8
Cyclone U'Flow	50.19		70.3
Ball Mill Disch.	49.36		70.1
Cyclone O'Flow	48.91		23.1
Hydro U'Flow	50.79		17.2
Hydro O'Flow	15.88		0.7
Finisher Conc.	66.60		14.9
Finisher Tails	15.05		0.6
Fine Screen O'Size	45.15		9.0
Fine Screen U'Size	67.57	5.22	24.2

	Cumulative % Wt. Retained					
Mesh	Cobber Conc.	Cyclone U'Flow	Ball Mill Disch.	Cyclone O'Flow	F.S. O'Size	F.S. U'Size
+4	0.54	0.22	0.35			
+6	1.81	1.87	1.12			
+8	3.67	4.05	2.17			
+10	6.56	6.92	2.94	0.06	7.62	
+14	10.57	10.00	3.50	0.12	13.47	
+20	15.66	13.88	3.85	0.24	19.60	
+28	20.94	18.45	4.13	0.42	26.08	
+35	27.44	23.66	4.48	0.79	28.54	
+48	34.58	29.13	5.11	1.28	32.95	
+65	42.11	35.98	6.58	2.14	41.08	
+100	49.30	43.26	9.60	3.73	55.87	
+150	56.24	54.74	17.38	6.91	68.48	2.84
+200	62.06	65.47	28.74	12.05	72.72	9.40
+270	69.30	75.83	41.43	21.50	77.19	20.45
+325	72.92	80.03	58.57	29.73	79.60	27.73
-325	27.08	19.97		70.27	20.40	72.27

SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

Test No. NS-14

Sample	% Fe	% SiO_2	% Solids
Cobber Conc.	49.97		95.2
Cyclone Feed	50.95		28.7
Cyclone U'Flow	48.84		72.6
Ball Mill Disch.	49.44		70.9
Cyclone O'Flow	49.21		16.7
Hydro U'Flow	51.47		24.1
Hydro O'Flow	15.35		1.2
Finisher Conc.	64.49		19.5
Finisher Tails	15.50		6.2
Derrick Screen O'Size	50.12		18.0
Derrick Screen U'Size	60.63	4.10	20.0

	Cumulative % Wt. Retained						
Mesh	Cobber Conc	Cyclone Feed	Cyclone U'Flow	Ball Mill Disch.	Cyclone O'Flow	Derrick O'Size	Derrick U'Size
+4	0.17		0.71				
+6	1.36	0.62	3.59	1.65			
+8	3.23	1.17	7.02	2.88			
+10	5.91	1.95	10.45	3.63			
+14	10.11	2.85	13.54	4.14	0.14	0.19	
+20	15.42	4.37	17.09	4.50	0.33	0.65	
+28	20.94	6.32	21.35	4.77	0.56	2.00	
+35	27.65	8.81	26.11	5.13	1.12	5.18	
+48	34.87	11.85	31.08	5.70	2.05	10.36	
+65	42.64	16.06	37.14	7.14	3.67	20.21	
+100	50.11	20.97	43.66	10.51	6.45	35.50	0.05
+150	57.03	31.10	55.32	17.85	11.54	69.40	0.47
+200	64.33	41.04	65.73	28.79	16.40	82.36	5.30
+270	70.66	52.22	75.72	44.79	29.30	87.54	18.42
+325	74.44	58.53	81.32	52.46	35.45	89.55	27.61
-325	25.56	41.47	18.68	47.54	64.55	10.45	72.39

SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

Test No. NS-15

Sample	% Fe	% SiO_2	% Solids
Cobber Conc.	49.59		93.8
Cyclone Feed	50.72		36.2
Cyclone U'Flow	48.46		72.2
Ball Mill Disch.	48.76		70.5
Cyclone O'Flow	49.14		17.0
Hydro U'Flow	51.92		24.1
Hydro O'Flow	15.43		5.5
Finisher Conc.	65.62		22.0
Finisher Tails	15.43		4.3
Derrick Screen O'Size	50.04		19.4
Derrick Screen U'Size	68.63	4.13	19.7
Dewater Sep. Conc.	50.57		65.6
Dewater Sep. Tail	28.60		0.1

	Cumulative % Wt. Retained						
Mesh	Cobber Conc	Cyclone Feed	Cyclone U'Flow	Ball Mill Disch.	Cyclone O'Flow	Derrick O'Size	Derrick U'Size
+4	0.04		0.55				
+6	0.77	0.31	4.20	1.41			
+8	2.98	0.90	8.29	2.56			
+10	5.96	1.74	12.05	3.16			
+14	10.43	2.75	16.03	3.59		1.02	
+20	15.85	4.60	21.00	3.85		2.22	
+28	22.26	6.77	26.41	4.06		4.93	
+35	29.02	9.85	31.93	4.32	1.95	9.83	
+48	35.93	13.56	37.56	4.83	3.12	16.95	
+65	43.72	18.35	44.08	5.98	4.92	27.94	
+100	50.21	24.22	50.27	8.33	7.78	42.10	0.12
+150	58.61	31.84	60.62	16.15	12.49	69.76	0.98
+200	65.29	41.42	70.41	26.11	18.07	80.51	6.67
+270	71.21	52.57	79.69	40.43	32.54	85.37	21.38
+325	74.57	58.97	84.59	46.54	38.46	87.59	28.45
-325	25.43	41.03	15.41	53.46	61.54	12.41	71.55

SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

Test No. NS-16

Sample	% Fe	% SiO_2	% Solids
Cobber Conc.	49.23		93.5
Cyclone Feed	51.11		33.0
Cyclone U'Flow	51.96		71.8
Ball Mill Disch.	49.16		71.7
Cyclone O'Flow	49.01		17.0
Hydro U'Flow	51.86		22.7
Hydro O'Flow	15.31		0.1
Finisher Conc.	64.69		19.1
Finisher Tails	15.31		5.2
Derrick Screen O'Size	49.83		19.7
Derrick Screen U'Size	68.00	4.35	21.7
Dewater Sep. Conc.	49.83		67.5
Dewater Sep. Tail	26.94		0.1

	Cumulative % Wt. Retained						
Mesh	Cobber Conc	Cyclone Feed	Cyclone U'Flow	Ball Mill Disch.	Cyclone O'Flow	Derrick O'Size	Derrick U'Size
+4	0.25	0.07	0.47	0.08			
+6	1.69	0.54	2.76	0.79			
+8	3.38	1.07	6.00	1.79	0.04		
+10	6.43	2.14	9.44	2.29	0.08		
+14	10.47	3.54	13.08	2.54	0.16		
+20	15.63	5.34	17.59	2.75	0.32	1.47	
+28	21.53	7.67	22.69	2.92	0.61	3.92	
+35	28.09	10.54	27.99	3.13	1.10	8.91	
+48	34.77	13.87	33.48	3.59	1.92	16.30	
+65	42.65	18.07	39.92	4.63	3.28	27.46	
+100	49.29	22.60	46.17	7.08	5.26	43.41	0.12
+150	57.58	31.00	56.64	12.77	10.00	67.37	0.59
+200	64.80	40.80	67.35	22.29	16.68	79.35	5.63
+270	70.78	52.93	77.90	37.00	27.23	85.92	17.00
+325	74.25	58.73	83.08	45.69	33.37	88.47	26.55
-325	25.75	41.27	16.92	54.31	66.63	11.53	73.45

SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

Test No. NS-17

Sample	% Fe	% SiO_2	% Solids
Cobber Conc.	48.21		93.2
Cyclone Feed	50.62		45.9
Cyclone U'Flow	48.21		70.8
Ball Mill Disch.	48.51		70.5
Cyclone O'Flow	49.19		19.7
Hydro U'Flow	50.47		30.3
Hydro O'Flow	15.32		0.8
Finisher Conc.	62.03		24.6
Finisher Tails	15.17		6.1
Derrick Screen O'Size	48.14		25.7
Derrick Screen U'Size	67.59	4.93	23.0

	Cumulative % Wt. Retained						
Mesh	Cobber Conc	Cyclone Feed	Cyclone U'Flow	Ball Mill Disch.	Cyclone O'Flow	Derrick O'Size	Derrick U'Size
+4	0.26		0.20	0.19			
+6	1.29	0.11	2.16	1.13			
+8	3.05	0.64	5.07	2.15			
+10	5.69	1.33	8.49	2.91			
+14	9.57	2.29	12.76	3.33			
+20	14.62	3.79	17.64	3.63	0.91	2.96	
+28	20.66	5.55	23.16	3.86	1.62	5.42	
+35	27.03	8.33	29.05	4.16	2.75	10.10	
+48	33.77	11.96	35.38	4.69	4.59	17.32	
+65	41.65	16.77	43.34	5.97	7.67	28.14	0.05
+100	48.46	23.34	51.37	8.54	11.92	44.72	0.10
+150	57.03	33.07	64.54	16.51	21.28	68.14	0.90
+200	63.99	42.64	74.09	27.09	30.04	79.81	8.39
+270	70.44	53.92	82.05	39.79	41.51	86.18	20.76
+325	73.63	60.60	85.50	46.25	46.06	88.79	29.89
-325	26.37	39.40	14.50	53.75	53.94	11.21	70.11

SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

Test No. NS-18

Sample	% Fe	% SiO_2	% Solids
Cobber Conc.	49.11		92.9
Cyclone Feed	52.11		34.4
Cyclone U'Flow	50.08		75.8
Ball Mill Disch.	51.44		70.9
Cyclone O'Flow	48.73		12.8
Hydro U'Flow	52.79		22.6
Hydro O'Flow	15.27		1.2
Finisher Conc.	67.23		17.2
Finisher Tails	15.34		4.5
Derrick Screen O'Size	49.33		10.3
Derrick Screen U'Size	68.58	4.01	18.5

	Cumulative % Wt. Retained						
Mesh	Cobber Conc	Cyclone Feed	Cyclone U'Flow	Ball Mill Disch.	Cyclone O'Flow	Derrick O'Size	Derrick U'Size
+4	0.06		0.43	0.11			
+6	1.17	0.17	2.22	1.13			
+8	3.11	0.51	4.74	2.09			
+10	5.76	1.13	7.38	2.88			
+14	9.74	1.92	9.90	3.39			
+20	14.88	3.16	13.18	3.79			
+28	20.96	4.80	16.51	4.07	0.16	0.48	
+35	27.65	6.95	20.69	4.47	0.40	2.39	
+48	34.40	9.49	25.21	5.09	0.72	7.40	
+65	42.09	12.94	30.58	6.39	1.35	16.71	
+100	48.78	17.29	37.70	9.39	2.54	33.18	0.06
+150	57.41	26.39	47.42	15.91	5.86	62.30	0.84
+200	64.16	36.79	60.21	24.02	11.00	70.18	3.58
+270	69.97	49.40	74.28	42.78	18.91	74.71	12.98
+325	73.18	57.03	81.10	52.64	25.08	76.38	20.53
-325	26.82	42.97	18.90	47.36	74.92	23.62	79.47

SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

Test No. NS-19

Sample	% Fe	% SiO_2	% Solids
Cobber Conc.	49.29		92.8
Cyclone Feed	51.47		34.3
Cyclone U'Flow	50.12		75.4
Ball Mill Disch.	50.49		71.0
Cyclone O'Flow	48.91		13.2
Hydro U'Flow	52.75		24.6
Hydro O'Flow	15.20		0.1
Finisher Conc.	66.67		19.5
Finisher Tails	15.43		5.8
Derrick Screen O'Size	49.51		13.3
Derrick Screen U'Size	68.25	4.36	18.8
Dewater Sep. Conc.	50.49		62.9
Dewater Sep. Tail	28.29		0.1

	Cumulative % Wt. Retained						
Mesh	Cobber Conc	Cyclone Feed	Cyclone U'Flow	Ball Mill Disch.	Cyclone O'Flow	Derrick O'Size	Derrick U'Size
+4			0.48	0.62			
+6	0.70	0.29	2.27	1.36			
+8	2.53	0.70	4.84	2.23			
+10	5.43	1.11	7.12	2.91			
+14	9.40	1.69	9.88	3.47			
+20	14.66	2.62	13.42	3.78			
+28	20.89	4.01	17.10	3.97		2.62	
+35	27.60	5.86	21.61	4.28		5.98	
+48	34.52	8.24	26.60	4.84	0.77	11.77	
+65	42.14	11.54	32.43	6.02	1.55	22.17	
+100	48.74	15.60	39.45	8.86	3.17	40.67	0.12
+150	57.01	24.17	48.66	15.17	6.27	67.46	1.33
+200	63.50	34.31	57.58	22.53	9.05	71.82	7.51
+270	68.98	47.52	73.62	40.90	21.46	79.23	16.60
+325	72.74	54.70	80.60	50.42	27.99	81.29	23.69
-325	27.26	45.30	19.40	49.58	72.01	18.71	76.31

SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

Test No. NS-21

Sample	% Fe	% SiO_2	% Solids
Cobber Conc.	49.19		93.9
Cyclone Feed	54.00		43.6
Cyclone U'Flow	53.47		73.3
Ball Mill Disch.	53.17		71.8
Cyclone O'Flow	48.97		14.3
Hydro U'Flow	51.67		19.4
Hydro O'Flow	15.92		1.0
Finisher Conc.	68.34		18.5
Finisher Tails	15.40		5.0
Derrick Screen O'Size	60.08		10.1
Derrick Screen U'Size	68.42	4.18	20.3

	Cumulative % Wt. Retained						
Mesh	Cobber Conc	Cyclone Feed	Cyclone U'Flow	Ball Mill Disch.	Cyclone O'Flow	Derrick O'Size	Derrick U'Size
+4	0.16						
+6	1.57	0.33	2.29	1.55			
+8	3.57	0.93	4.11	2.58			
+10	6.22	1.26	5.93	3.57			
+14	10.06	1.93	7.71	4.18			
+20	15.47	2.93	9.72	4.70			
+28	21.31	4.19	11.73	5.12			
+35	27.90	5.79	14.25	5.73	0.09	0.24	
+48	35.04	7.92	17.38	6.67	0.18	1.19	
+65	42.72	11.12	21.54	8.65	0.27	6.53	
+100	50.07	15.45	27.75	12.22	0.71	30.40	0.10
+150	57.26	25.57	37.56	22.24	2.11	56.41	2.15
+200	63.31	38.22	50.92	36.26	5.17	63.06	8.11
+270	70.72	55.86	70.17	56.77	13.90	72.20	20.43
+325	74.88	64.45	80.96	65.24	22.28	75.76	29.03
-325	25.12	35.55	19.04	34.76	77.72	24.24	70.97

SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

Test No. NS-22

Sample	% Fe	% SiO_2	% Solids
Cobber Conc.	50.42		92.8
Cyclone Feed	54.33		35.5
Cyclone U'Flow	53.95		73.8
Ball Mill Disch.	54.18		70.1
Cyclone O'Flow	49.97		19.0
Hydro U'Flow	52.98		24.5
Hydro O'Flow	15.35		1.3
Finisher Conc.	67.88		18.1
Finisher Tails	14.75		5.1
Fine Screen O'Size	55.84		21.2
Fine Screen U'Size	68.00	4.69	20.1

	Cumulative % Wt. Retained						
Mesh	Cobber Conc	Cyclone Feed	Cyclone U'Flow	Ball Mill Disch.	Cyclone O'Flow	F.S. O'Size	F.S. U'Size
+4	0.09		0.11				
+6	0.59	0.24	0.70	0.59			
+8	1.50	0.72	1.88	1.07			
+10	3.04	1.01	2.95	1.28			
+14	5.63	1.58	4.66	1.49			
+20	9.40	2.63	7.07	1.65			
+28	14.35	3.92	10.01	1.81			
+35	20.34	5.82	13.70	2.02			
+48	27.06	8.34	18.03	2.45			
+65	34.87	11.77	23.43	3.52			
+100	42.31	16.48	29.74	6.15	0.23	2.39	0.07
+150	52.07	23.57	41.73	12.26	1.48	15.79	0.72
+200	59.65	32.18	55.43	22.50	4.13	25.26	2.90
+270	66.78	49.22	72.66	41.86	12.62	32.22	8.72
+325	70.37	57.12	80.26	52.48	19.63	40.70	16.28
-325	29.63	42.88	19.74	47.52	80.37	59.30	83.72

SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

Test No. NS-24

Sample	% Fe	% SiO_2	% Solids
Cobber Conc.	49.94		92.2
Cyclone Feed	53.41		46.1
Cyclone U'Flow	53.69		74.0
Ball Mill Disch.	53.63		71.0
Cyclone O'Flow	50.24		24.4
Hydro U'Flow	52.88		32.5
Hydro O'Flow	15.29		1.2
Finisher Conc.	67.94		25.2
Finisher Tails	14.84		5.5
Derrick Screen O'Size	62.82		8.0
Derrick Screen U'Size	68.39	4.13	22.0

	Cumulative % Wt. Retained						
Mesh	Cobber Conc	Cyclone Feed	Cyclone U'Flow	Ball Mill Disch.	Cyclone O'Flow	Derrick O'Size	Derrick U'Size
+4	0.09						
+6	0.63	0.54	0.61	0.33			
+8	1.44	0.66	1.48	0.56			
+10	2.57	1.02	2.52	0.79			
+14	5.05	1.62	4.39	0.98			
+20	8.83	2.34	6.99	1.12			
+28	13.20	3.30	10.24	1.26			
+35	19.10	4.80	14.27	1.40			
+48	26.12	6.84	18.87	1.72			
+65	34.45	9.54	25.29	2.55	0.15		
+100	42.91	13.56	32.19	4.77	0.56	2.10	0.07
+150	51.24	19.62	44.08	10.14	2.46	16.20	0.92
+200	56.82	25.50	58.05	17.88	6.61	22.91	2.61
+270	66.59	43.73	74.28	37.38	16.60	29.70	12.02
+325	70.73	52.72	79.44	47.29	22.80	58.80	20.57
-325	29.27	47.28	20.56	52.71	77.20	41.20	79.43

SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

Test No. NS-25

Sample	% Fe	% SiO_2	% Solids
Cobber Conc.	49.07		94.4
Cyclone Feed	54.03		73.6
Cyclone U'Flow	54.93		74.5
Ball Mill Disch.	55.35		71.9
Cyclone O'Flow	49.52		18.2
Hydro U'Flow	53.05		28.4
Hydro O'Flow	15.48		1.2
Finisher Conc.	67.63		28.1
Finisher Tails	14.73		5.7
Derrick Screen O'Size	58.09		10.3
Derrick Screen U'Size	68.61	3.78	26.9

	Cumulative % Wt. Retained						
Mesh	Cobber Conc	Cyclone Feed	Cyclone U'Flow	Ball Mill Disch.	Cyclone O'Flow	Derrick O'Size	Derrick U'Size
+4			0.05				
+6	0.26	0.35	0.52	0.68			
+8	1.29	0.49	1.41	1.23			
+10	2.88	0.70	2.58	1.54			
+14	5.55	1.27	4.21	1.72			
+20	9.40	2.05	6.27	1.84			
+28	14.58	3.11	8.47	2.02			
+35	20.74	4.52	11.55	2.33			
+48	27.62	6.50	15.33	2.88	0.08	0.47	0.68
+65	36.03	9.40	19.95	4.30	0.25	1.47	0.88
+100	43.73	13.15	26.30	7.44	0.66	4.54	1.01
+150	53.58	21.91	35.97	14.77	2.31	15.35	1.34
+200	60.92	32.86	49.56	28.69	5.78	31.91	4.46
+270	68.82	49.47	66.05	45.70	14.79	43.86	13.63
+325	72.31	58.02	77.59	57.41	23.22	53.01	20.20
-325	27.69	41.98	22.41	42.59	76.78	46.99	79.80

SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

Test No. NS-26

Sample	% Fe	% SiO_2	% Solids
Cobber Conc.	51.29		94.0
Cyclone Feed	54.22		44.1
Cyclone U'Flow	54.90		72.9
Ball Mill Disch.	54.45		71.3
Cyclone O'Flow	50.32		21.7
Hydro U'Flow	52.65		35.0
Hydro O'Flow	15.47		1.2
Finisher Conc.	67.89		36.4
Finisher Tails	14.57		5.0
Derrick Screen O'Size	54.22		7.5
Derrick Screen U'Size	68.49	3.93	44.3

	Cumulative % Wt. Retained						
Mesh	Cobber Conc	Cyclone Feed	Cyclone U'Flow	Ball Mill Disch.	Cyclone O'Flow	Derrick O'Size	Derrick U'Size
+4	0.05		0.12				
+6	0.40	0.05	0.59	0.14			
+8	1.41	0.53	1.18	0.42			
+10	2.52	1.07	2.00	0.61			
+14	4.88	1.88	3.33	0.89			
+20	8.20	2.85	5.09	1.03			
+28	13.08	4.20	7.01	1.17			
+35	18.92	5.92	9.95	1.41		0.07	
+48	25.91	8.18	13.63	1.98	0.06	0.42	
+65	34.26	11.41	18.37	3.35	0.18	1.67	
+100	42.16	15.67	24.87	6.52	0.66	5.14	0.06
+150	52.42	24.88	34.70	13.58	2.33	19.76	0.35
+200	60.37	35.49	47.47	25.52	5.79	29.95	2.53
+270	68.22	53.65	67.60	47.64	15.69	42.15	9.66
+325	71.84	60.55	76.30	55.74	23.63	48.59	18.45
-325	28.16	39.45	23.70	44.26	76.37	51.41	81.55

SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

Test No. NS-27

Sample	% Fe	% SiO_2	% Solids
Cobber Conc.	50.43		93.6
Cyclone Feed	53.74		49.9
Cyclone U'Flow	54.41		71.0
Ball Mill Disch.	54.19		70.6
Cyclone O'Flow	51.56		38.3
Hydro U'Flow	54.04		43.7
Hydro O'Flow	15.91		0.9
Finisher Conc.	66.87		45.4
Finisher Tails	14.11		5.2
Derrick Screen O'Size	57.86		22.1
Derrick Screen U'Size	68.60	3.93	60.5

	Cumulative % Wt. Retained						
Mesh	Cobber Conc	Cyclone Feed	Cyclone U'Flow	Ball Mill Disch.	Cyclone O'Flow	Derrick O'Size	Derrick U'Size
+4	0.25	0.31					
+6	0.69	1.00	0.42	0.16			
+8	1.57	1.77	1.07	0.47			
+10	2.89	2.54	2.10	0.86			
+14	5.16	3.46	3.59	1.13			
+20	8.69	4.77	5.74	1.32			
+28	13.35	6.46	8.21	1.48			
+35	19.02	8.69	11.71	1.71			
+48	25.82	11.54	16.15	2.25	0.07	0.27	
+65	34.26	15.23	21.71	3.72	0.34	1.22	0.06
+100	41.88	19.85	29.41	7.17	1.08	4.47	0.12
+150	52.02	29.54	40.47	14.78	4.66	14.98	0.24
+200	59.70	41.08	55.60	27.74	11.69	34.23	3.13
+270	67.89	57.31	73.57	49.04	24.80	58.23	15.70
+325	70.91	61.46	78.15	55.48	32.16	64.60	22.90
-325	29.09	38.54	21.85	44.52	67.84	35.40	77.10

SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

Test No. NS-28

Sample	% Fe	% SiO_2	% Solids
Cobber Conc.	49.27		93.8
Cyclone Feed	54.40		40.3
Cyclone U'Flow	54.30		71.7
Ball Mill Disch.	52.87		70.9
Cyclone O'Flow	49.34		18.6
Hydro U'Flow	53.09		32.0
Hydro O'Flow	16.37		1.3
Finisher Conc.	66.99		35.2
Finisher Tails	15.39		5.6
Derrick Screen O'Size	55.50		11.1
Derrick Screen U'Size	68.72	3.87	35.7

	Cumulative % Wt. Retained						
Mesh	Cobber Conc	Cyclone Feed	Cyclone U'Flow	Ball Mill Disch.	Cyclone O'Flow	Derrick O'Size	Derrick U'Size
+4	0.17	0.12					
+6	0.75	1.53	1.74	1.13			
+8	2.66	2.76	3.67	3.04			
+10	4.97	4.05	5.72	4.11			
+14	8.90	5.58	7.46	4.77			
+20	13.81	7.28	9.58	5.19			
+28	19.88	9.28	11.70	5.61			
+35	26.47	11.45	14.44	6.15		0.06	
+48	33.58	14.04	17.80	7.04	0.16	0.31	
+65	41.44	17.62	22.22	9.07	0.32	1.39	
+100	48.38	22.32	28.94	13.42	0.88	5.01	0.05
+150	57.22	32.48	40.20	22.24	3.11	17.34	0.20
+200	64.33	44.47	54.26	35.11	8.12	37.04	3.50
+270	71.96	59.57	73.86	56.98	20.92	57.43	17.30
+325	74.79	66.39	82.01	64.67	28.15	65.63	23.08
-325	25.21	33.61	17.99	35.33	71.85	34.37	76.92

SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

Test No. NS-29

Sample	% Fe	% SiO_2	% Solids
Cobber Conc.	49.35		94.1
Cyclone Feed	51.75		31.6
Cyclone U'Flow	53.10		79.5
Ball Mill Disch.	52.05		70.0
Cyclone O'Flow	49.13		12.8
Hydro U'Flow	54.45		28.9
Hydro O'Flow	15.75		1.0
Finisher Conc.	67.80		26.9
Finisher Tails	15.00		4.6
Derrick Screen O'Size	55.80		12.4
Derrick Screen U'Size	68.55	3.89	26.9

	Cumulative % Wt. Retained						
Mesh	Cobber Conc	Cyclone Feed	Cyclone U'Flow	Ball Mill Disch.	Cyclone O'Flow	Derrick O'Size	Derrick U'Size
+4			0.48	0.20			
+6	0.85	0.66	2.07	1.44			
+8	2.70	1.22	4.33	2.73			
+10	5.10	1.68	6.64	3.82			
+14	8.80	2.75	9.00	4.47			
+20	13.50	4.07	11.65	4.87			
+28	19.45	5.39	14.39	5.22		0.08	
+35	26.10	7.32	17.95	5.67		0.16	
+48	33.25	9.71	22.18	6.52		0.55	
+65	41.25	12.91	27.28	8.31	0.20	1.80	
+100	48.25	17.64	34.16	12.09	0.65	4.86	
+150	56.90	25.78	44.65	20.00	2.95	19.99	0.20
+200	63.35	36.97	57.59	32.28	7.76	32.45	3.72
+270	70.20	52.18	74.95	50.43	17.27	43.42	12.33
+325	73.35	62.25	84.04	61.57	24.23	49.14	20.21
-325	26.65	37.75	15.96	38.43	75.77	50.86	79.79

SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

Test No. NS-30

Sample	% Fe	% SiO_2	% Solids
Cobber Conc.	51.09		94.5
Denver Scr. Feed	45.22		57.7
Denver Scr. O'Size	37.10		81.3
Denver Scr. U'Size	47.56		49.5
Derrick Scr. O'Size	45.52		71.1
Ball MIll Disch.	42.44		71.6
Derrick Scr. U'Size	49.89		38.9
Hydro U'Flow	51.92		28.8
Hydro O'Flow	14.90		1.0
Finisher Conc.	68.85	3.84	31.7
Finisher Tail	15.43		5.8

	CUMULATIVE % WT. RETAINED								
Mesh	Cobb. Conc.	Denver Scr. Feed	Denver Scr. O'Size	Denver Scr. U'Size	Derr. O'Size	Ball Mill Disch.	Derr. U'Size	Hydro U'Flow	Fin. Conc.
+4	0.09	0.47	0.30						
+6	1.19	5.85	5.51						
+8	2.48	9.91	12.11			1.38			
+10	4.96	12.60	20.74			2.17			
+14	9.47	14.68	33.04			2.57			
+20	14.76	16.90	48.17			2.77			
+28	20.19	19.35	63.80	0.04		3.17			
+35	27.14	21.90	79.03	1.03	2.17	3.42			
+48	32.43	24.73	82.70	4.89	9.35	3.82			
+65	40.20	28.08	83.94	9.78	19.01	4.86			
+100	47.88	31.52	84.83	15.65	29.25	7.03			
+150	55.19	38.36	85.82	23.81	48.62	14.93	0.18	0.36	0.40
+200	62.87	45.06	86.86	32.46	66.17	26.68	6.07	7.03	8.48
+270	68.44	54.49	88.70	45.82	75.88	39.03	17.45	19.58	23.64
+325	71.94	59.63	89.79	52.14	79.56	45.89	25.75	28.07	33.35
-325	28.06	40.37	10.21	47.86	20.44	54.11	74.25	71.93	66.65

SECONDARY BALL MILL CIRCUIT OPTIMIZATION TESTS

Test No. NS-31

Sample	% Fe	% SiO_2	% Solids
Cobber Conc.	48.42		94.4
Denver Scr. Feed	45.51		63.5
Denver Scr. O'Size	36.50		82.7
Denver Scr. U'Size	48.74		58.8
Derrick Scr. O'Size	45.29		69.3
Ball Mill Disch.	43.56		71.9
Derrick Scr. U'Size	45.66		43.0
Hydro U'Flow	51.07		34.5
Hydro O'Flow	14.87		1.4
Finisher Conc.	68.19	4.17	38.5
Finisher Tail	14.42		8.6

	CUMULATIVE % WT. RETAINED								
Mesh	Cobb. Conc.	Denver Scr. Feed	Denver Scr. O'Size	Denver Scr. U'Size	Derr. O'Size	Ball Mill Disch.	Derr. U'Size	Hydro U'Flow	Fin. Conc.
+4	0.16	0.62	1.27						
+6	1.45	2.68	10.53			0.87			
+8	3.00	5.20	19.39			2.29			
+10	6.05	7.00	28.98			3.43			
+14	10.13	8.59	38.44			4.19			
+20	15.50	10.34	48.84			4.63			
+28	21.13	12.04	61.17			5.17			
+35	27.74	14.25	73.86	0.38	0.26	5.82			
+48	34.98	16.92	77.67	2.70	3.59	6.96			
+65	42.42	20.42	79.47	6.71	9.21	9.41			
+100	49.60	25.61	80.97	12.35	18.71	14.10	0.01	0.06	0.06
+150	56.53	34.61	83.69	25.88	35.16	27.51	0.50	0.12	0.44
+200	61.39	45.36	86.48	39.84	53.87	44.24	6.32	3.51	7.15
+270	69.04	59.29	89.07	54.18	69.17	58.30	15.39	17.06	23.76
+325	73.48	65.77	90.29	60.38	74.01	63.75	26.50	27.58	36.04
-325	26.52	34.23	9.71	39.62	25.99	36.25	73.50	72.42	63.96

SEMINAR SESSION—NEW CONCEPTS IN UPGRADING CONCENTRATES AND AGGLOMERATION

Chairman: JAMES E. LAWVER, Professor of Metallurgical Engineering and Director

Mines Experiment Station, University of Minnesota, Minneapolis, Minnesota

SECOND SEMINAR—PAPER 1

THE MINERALOGY OF TACONITE PRODUCTS AS RELATED TO THE AUGMENTATION OF MAGNETITE MIDDLINGS

by

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ABSTRACT

The problems relating to the reduction of the silica content of magnetite concentrates have been actively pursued over the past several years. The acceptable silica levels have been significantly lowered, and it has become apparent that some taconite operations will not be able to meet these new specifications without modification of the processing flowsheets. This has led to the consideration of the addition of supplementary concentration units such as flotation, regrind units, screening, and various types of elutriation devices to mention only a few.

The current study has been directed toward making a mineralogical and textural study of the plant products produced to observe the changing nature of the raw material through the various concentration and grinding steps. It was hoped that systematic sampling of the entire flowsheet might provide useful data that could be informative with regard to the more effective rejection of silica. These observations have provided an insight into the manner in which silica has been concentrated in the final products. The observations show that the superabundance of middlings, which are the principal source of silica in the final concentrates, do not represent an inherent property of the ore, but are produced by the nature of the process flowsheet.

INTRODUCTION

Once a taconite plant has been brought into operation and has passed through the break-in stage, it is almost immediately subject to two types of pressure. The first of these is to increase the productivity of the existing units, and the second is to lower the silica in the final concentrates. Although it is relatively easy to obtain one at the expense of the other, it is difficult to obtain both concurrently.

A great deal of research has been conducted in the respective taconite plants to reduce by segregation and additional grinding the amount of silica that occurs in the plus 325-mesh fraction of the final concentrates. In some plants this has involved screening or flotation combined with regrind units. In other plants only extra ball mills in closed circuit with conventional cyclones have been added.

Plant operators have recognized that a cyclone operating in closed circuit with a ball mill tends to increase the percentage of middlings in the overflow because of the gravity effect in this type of classification. The bulk of the free magnetite in the coarse size fractions is returned to the ball mill for additional grinding and consequently the relative percentage of middling-type particles appearing in the cyclone overflow is greatly increased. These same operators, however, are reluctant to think that this type of classification-grinding flowsheet can materially affect the basic concentratability of an ore.

The current study was undertaken to learn more about the coarse middlings in the plus 325-mesh-size fraction and to determine, if possible, whether these are really an inherent characteristic of the ore or rather an inherent characteristic of the process itself. It was hoped that a better understanding of the actual development of middling-type particles, which are the principal source of silica contamination in the final concentrates, could be used advantageously to increase productivity and to lower the silica in the final concentrates.

PROCEDURE

The samples used in this study were obtained by a systematic sampling of two commercial taconite operations supplemented by materials obtained from pilot plant studies at the Mines Experiment Station. The approach used was to trace through the various plant operations to the final concentrate the changes in the nature of the 100/325-mesh material brought into the circuit as rod mill cobber concentrate. Grain slides were prepared for microscopic study, and grain counts made from samples of both commercial plant products and pilot plant products produced at the Mines Experiment Station. A distinction was made in the grain counts between three types of particles: (1) magnetite particles containing over 90% opaque mineral, (2) middling particles containing from 5 to 90% opaque mineral, and (3) gangue particles containing less than 5% opaque mineral. The counts were based on 750 particles and the accuracy is estimated to be within ±5% of the given value. The conclusions in this study are based on major shifts in the relative percentage of magnetite and middlings and are well within the experimental error of the grain counts.

DISCUSSION

Ratios of Free Magnetite to Middlings in Plant Products

The work included a study of all plant products; however, the most significant data were obtained from the cobber concentrate, cyclone overflow, hydroseparator underflow, and finisher magnetic separator concentrate. The distribution of free magnetite, middling particles, and gangue in the rod mill cobber concentrate as a function of the grain size is shown in Figure 1. In the 150/200-mesh fraction about 50% of the particles are free magnetite. This percentage increases progressively with improved liberation

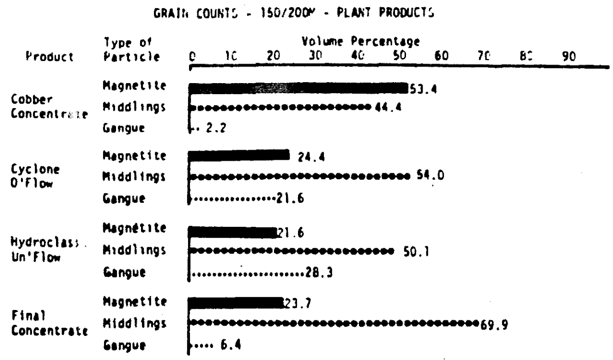


FIGURE 2. Bar graph illustrating the dramatic change in the relative abundance of free magnetite and middlings that takes place in the 150/200-mesh fraction. The ratio of magnetite to middlings changes from about 1:1 in the cobber concentrate to about 0.3:1 in the final concentrate

in the finer size fractions; at 325/500 mesh well over 90% of the particles are free magnetite. Although the percentage of 100 to 500-mesh material in the rod mill cobber concentrate is very small, it is representative of the type of material produced in this size range by the ball mill in closed circuit grinding. This was confirmed by experiments in which samples of the rod mill feed and cobber concentrate were stage crushed through successively smaller top sizes and the new 200/270-mesh material removed at each stage. Davis tube tests run on the "as is" material showed that essentially the same particle type distribution was created at each stage of grinding.

There is a continual evolution in the nature of the individual plus 325-mesh size fractions of the ore in a conventional taconite plant as the cobber concentrate moves through the fine grinding and concentrating circuits. This evolution is illustrated by the data from the 150/200-mesh size fraction shown in Figure 2. When the 150/200-mesh fraction enters the circuit in the cobber concentrate, it contains 53.4% of free magnetite. In the cyclone overflow, however, it contains only 24.4% free magnetite and 54.0%

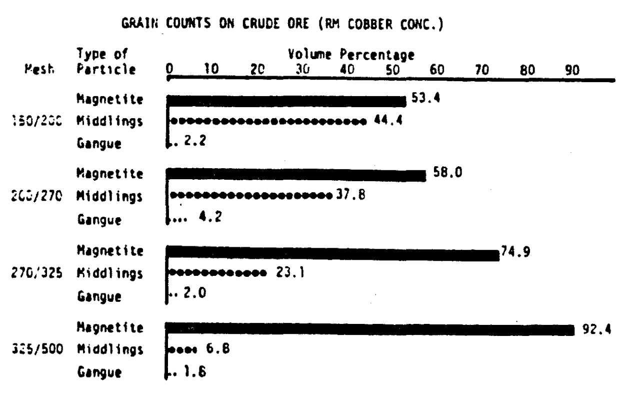


FIGURE 1. Bar graph showing the relative abundance of free magnetite, middlings, and gangue in the cobber concentrate. Over 50% of the 150/200-mesh fraction consists of free magnetite and the percentage increases with finer grinding in response to improved liberation

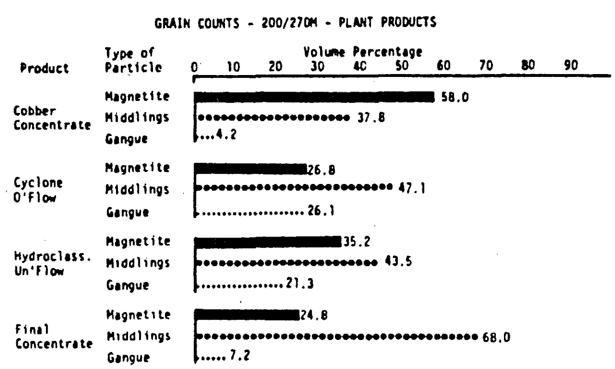
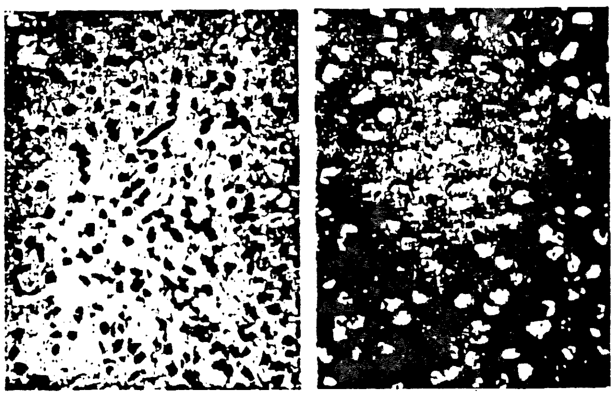


FIGURE 3. The same shift in the relative abundance of magnetite and middlings described in Figure 2 for the 150/200-mesh fraction takes place in the 200/270-mesh fraction. The ratio of magnetite to middlings changes from 1.5:1 in the cobber concentrate to about 0.3:1 in the final concentrate, despite the improved liberation of the ore

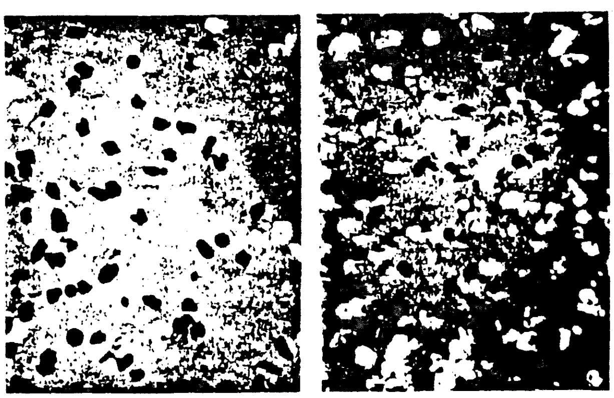
middling particles due to the gravity effect in the cyclone. The same size fraction in successive stages of concentration, i.e., in the hydroclassifier underflow and in the finisher magnetic separator concentrate, shows an increase in the ratio of middlings to free magnetite. The final concentrate contains 23.7% free magnetite and 69.9% middling-type particles. The next smaller size fraction at 200/270 mesh shows much the same distribution (Figure 3). This size fraction of the cobber concentrate comes into the plant containing 58.0% free magnetite with 37.8% middlings and in the final concentrates consists of 24.8% free magnetite and 68.0% middling particles. Again the ratio of free magnetite to middlings is essentially reversed in the process.

The same trends are observed in all of the coarser size fractions and are, as expected, more accentuated in the relatively coarse size ranges and essentially disappear in the fine sizes at 500 mesh. The problem is illustrated in the photomicrographs of Figures 4 and 5 which compare examples of the cobber concentrate as it comes into the grinding circuit with equivalent size fractions in the corresponding final plant concentrate. The relative increase in the percentage of middlings is clearly illustrated.



4a 4b

FIGURE 4. Photomicrographs illustrating the relative abundance of middlings in the 150/200-mesh fraction of the cobber concentrate (4a) and of the final concentrate (4b). These products were obtained from a plant treating a taconite that has relatively good liberation characteristics



5a 5b

FIGURE 5. Photomicrographs illustrating the relative abundance of middlings in the 270/325-mesh fraction of the cobber concentrate (5a) and in the final concentrate (5b). These products were obtained from a plant treating a taconite that has relatively poor liberation characteristics. Figure 5a shows that a substantial percentage of the 270/325-mesh fraction of the cobber concentrate had been liberated

Problems To Be Solved

The first problem is whether this increase in middlings represents a real gain in the absolute percentage of middlings as it goes through the process or whether it is merely developed by the selective comminution of the free magnetite. The second problem is whether the middlings produced in this manner are normal middlings that represent the inherent mineral distribution in the ore or whether they are a type of middling synthesized in the process itself.

Grinding Analysis

Some insight into this problem can be obtained by taking a sample of rod mill cobber concentrates, batch grinding it to 90% minus 325-mesh, and comparing the plus 325-mesh material produced by this means with that found in the corresponding plant concentrate at an equivalent grind. The plus 325-mesh material produced by batch grinding followed by magnetic concentration contains 64.4% iron (Table 1), whereas this same size fraction from the plant concentrates contains only 45.7% iron. There is also a corresponding increase in the percentage of middlings in the plus 325-mesh size fractions of the plant concentrates. The grain counts show only 33.1% middling particles in the batch-ground rod mill cobber concentrate compared with 53.4% in the plant concentrates. By using these data and by making some assumptions as to the specific gravity of the magnetite and gangue based on their iron content, it is possible to calcu-

TABLE 1. Grain Count Data

Mesh	Wt %	Fe %	Magnetite %	Middlings %	Gangue %
Cobber Concentrate (+325 Mesh)					
−150	0.7	53.4	64.8	31.8	3.4
−200	1.5	60.5	53.4	44.4	2.2
+270	4.2	64.9	58.0	37.8	4.2
−325	3.6	67.5	74.9	23.1	2.0
Total +325	10.0	64.4	63.9	33.1	3.0
Final Concentrate (+325 Mesh)					
−150	0.7	39.7	40.4	53.0	6.1
−200	1.5	30.6	23.7	69.9	6.4
+270	4.2	41.9	24.8	68.0	7.2
−325	3.6	57.7	66.9	29.5	3.6
Total +325	10.0	45.7	40.9	53.4	5.7

Results of grain counts on the plus 325-mesh fractions of the final concentrate and on the plus 325-mesh fractions of the corresponding cobber concentrate ground to 90% minus 325 mesh. The data show a superabundance of middlings in corresponding size fractions of the final concentrate.

late the average iron content of the middlings produced in each case. The middlings produced in the batch-ground rod mill cobber concentrates (Table 2) are calculated to contain 55.0% iron and 18.2% silica. The middlings in the corresponding plant concentrates contain only 20.0% iron and 58.9% silica. These calculated middling analyses are relative values, rather than absolute, but there is a clear indication that the type of middling produced in the plant concentrate is much lower in iron than that produced by batch grinding of rod mill cobber concentrate. The distribution of the silica in the plus 325-mesh fraction (Table 2) shows 0.5 to 0.8 silica units tied up in the middling particles in the batch-ground material, whereas in the plant concentrates from the corresponding ore, 2.6 of 3.0 silica units are associated with middlings. The fact that almost five times as much silica is associated with plus 325-mesh middlings produced in the normal plant concentrates, as might be anticipated from looking at the crude ore as it comes into the plant, lends some credence to the contention that some of the middling problems are inherent in the process.

TABLE 2. Distribution of Fe and SiO_2

	Wt %	Fe %	SiO_2	SiO_2 Dist %	SiO_2 Units
Cobber Concentrate (+325 Mesh)					
Magnetite	69.4	70.0	2.0	17.1	0.1
Middlings	28.6	55.0	18.2	63.4	0.5
Gangue	2.0	8.0	80.0	19.5	0.2
	100.0	64.4	8.2	100.0	
Final Concentrate (+325 Mesh)					
Magnetite	52.5	70.0	2.0	3.5	0.1
Middlings	43.1	20.0	58.9	84.7	2.6
Gangue	4.4	8.0	80.0	11.8	0.3
	100.0	45.7	30.0	100.0	

The data from Table 1 have been used to calculate the approximate iron content of the middlings in the plus 325-mesh fractions of the final concentrate and of the cobber concentrate. The calculations show that the middlings in the final concentrate are much lower in iron than the middlings in the cobber concentrate.

Ball Mill-Cyclone Product Analysis

If middlings are synthesized in the process then the critical steps will involve the cyclone-ball mill closed circuit, because this stage determines what type of material goes on to the final concentrating steps. The grain count data, combined with the screen analyses, were used to work out a particle balance around the cyclone. The data show that relative recovery of magnetite and middlings in the cyclone overflow is a function of particle size. In the 325/500-mesh size fraction over 50% of both the free magnetite and middlings coming into the cyclone appear in the overflow. In the progressively coarser fractions the recovery of free magnetite drops off rapidly and in the 200/270-mesh size fraction recovery is less than 5%. Recovery of middlings in the overflow follows a parallel course but does not decrease as rapidly as magnetite recovery and is greater in all size ranges (Figure 6).

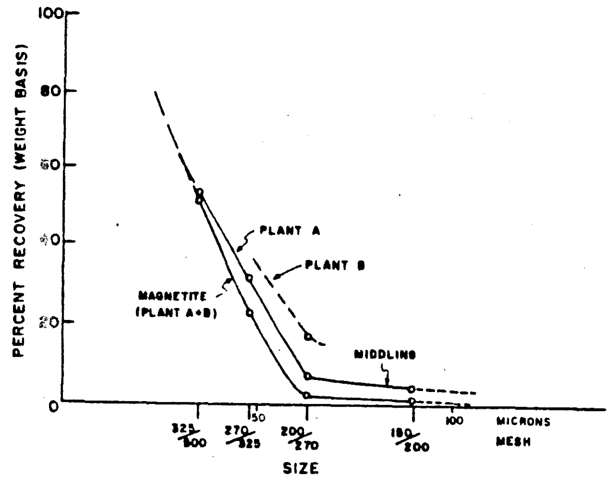


FIGURE 6. Graph showing the recoveries of magnetite and middlings in the cyclone overflow as a function of size. The recoveries were calculated from screen analyses and grain count data on the feed, the cyclone overflow, and the cyclone underflow

A schematic representation of what happens to the 200/270-mesh size fraction is presented in Figure 7. The feed contains 63.8% free magnetite and 33.3% middling particles; 2.4% of the free magnetite is recovered in the cyclone overflow; and 6.6% of the middlings are recovered in the cyclone overflow. The total weight recovery is about 5.0% in this size fraction. The particle balance obtained on this size fraction does not coincide with what would be expected to appear in the overflow of the cyclone because the middling recovery is much too low compared to the magnetite recovery. The reason the middling recovery should have been higher is shown schematically in Figure 8.

The basis for separation of a given size fraction in the cyclone is specific gravity. To obtain free magnetite in the overflow the cyclone should make a separation based on an apparent specific gravity as shown, however, this implies

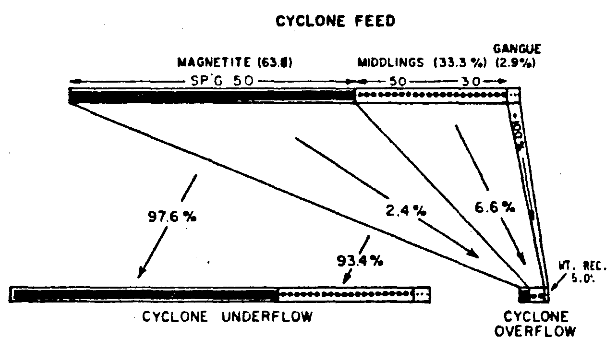


FIGURE 7. The weight recovery in the 200/270-mesh fraction of the cyclone overflow and the relative recovery of free magnetite, middlings and gangue are shown schematically in this figure. The relative recovery of the middlings is too low for the observed magnetite recovery

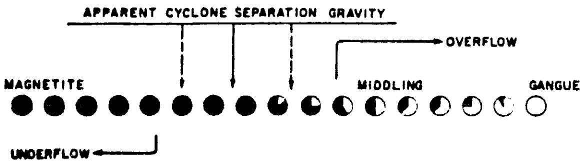


FIGURE 8. This figure illustrates that, with any given size fraction, the basis for separation should be a function of the specific gravity, and that when free magnetite appears in the overflow, the recovery of middlings should be much higher than actually calculated from the grain counts

that a very high percentage of the middling particles associated with free magnetite should appear in the overflow, taken literally it means that some 20 to 30% of the middlings should be recovered with 5% of the free magnetite. This does not coincide with the balance calculated on the basis of the petrographic study which shows much lower middling recovery. A similar situation is observed in the other plus 325-mesh size fractions.

Explanation of Results

Attempts to explain these observations from a theoretical viewpoint encounter some difficulties. It is logical to expect that the cyclone feed carries a complete suite of particle types ranging from high specific gravity free magnetite particles through progressively lighter middling particles which contain lower percentages of magnetite all the way to free gangue particles. Therefore, there should be a progressive increase in the relative probability that the lower-gravity particles will appear in the cyclone overflow. If a single size fraction is considered, and if all other factors, such as surface irregularities, shape, and porosity, are equalized, the principal factor affecting the probability that a given particle will appear in the cyclone overflow is specific gravity.

In a simplified approximation it is possible to relate the probability that a particle will appear in the cyclone overflow to its settling velocity, or its acceleration in the carrier medium by one of the expressions below:

Stokes: $V = K(d_s - d_p)D^2$ $\qquad P \cong V \cong (d_s - d_p)^{-1}$

Rittenger: $V = C[D\,(d_s - d_p)]^{\frac{1}{2}}$ $\qquad P \cong V \cong (d_s - d_p)^{-\frac{1}{2}}$

Fontein[1] $S = \frac{1}{2}\,g\,\frac{(d_s - d_p)}{d_s}\,t^2$ $\qquad P \cong S \cong \frac{(d_s - d_p)^{-1}}{d_s}$

The fact that these expressions on the left simplify into the expressions on the right indicates that the probability for a particle of given size to appear in the overflow is primarily a function of the specific gravity of both the particle and the carrier medium. Using these formulas, the relative probability that a given type of middling particle will appear in the overflow is shown in Figure 9. The two flatter curves are calculated from Stokes' and Rittenger's assumptions. The curves with the sharp inflection points were calculated using the expression from Fontein. It is not possible to apply any of these relative probabilities directly to the cyclone feed and satisfy the requirements for magnetite and middling recovery and maintain the ratio of magnetite to middlings observed in the cyclone overflow. It is possible to obtain the observed recovery, or obtain the observed ratio

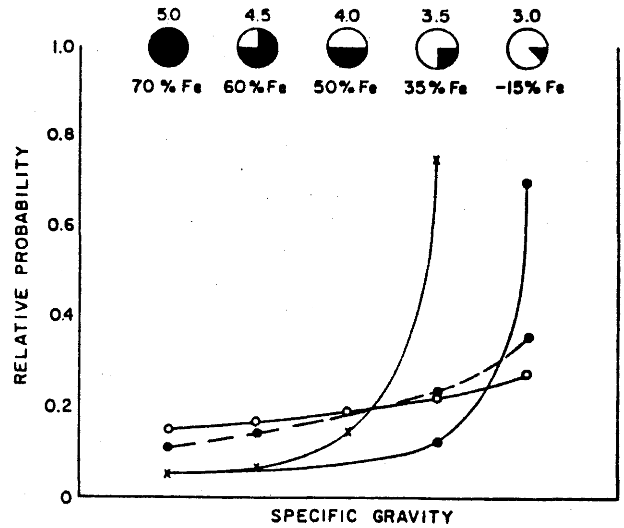


FIGURE 9. Graph showing the relative probability that a particle of a given specific gravity will appear in the overflow, based on the assumption explained in the text. The calculated probabilities do not explain the observed recoveries of magnetite and of middlings in the cyclone overflow

of magnetite to middlings, but not simultaneously. This leads to consideration that perhaps the separation of a given size fraction in the cyclone is a combination of more than one factor and not just a matter of its relative specific gravity. It is proposed that a given size fraction of cyclone feed yields two types of samples in the overflow: (1) a "random" sample consisting of a statistical sampling of the feed coming into the cyclone, something normally associated with short circuiting, and (2) a "design" sample consisting of particles that belong in the overflow because of their specific gravity. This concept is illustrated in Figure 10 where the 200/270-mesh cyclone feed is represented schematically by the shaded circles to indicate the free magnetite and middling particles.

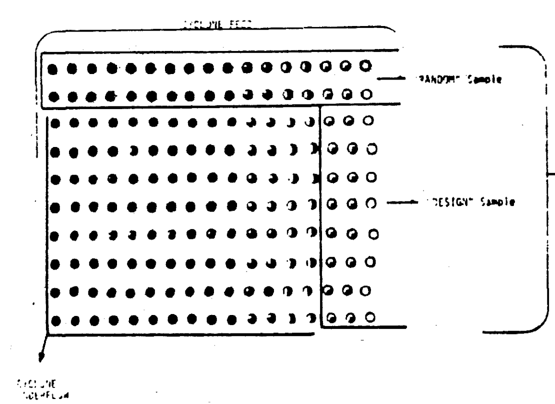


FIGURE 10. This figure illustrates schematically how it is possible to consider that the cyclone overflow is composed of two elements: a "random" sample of the feed that appears because of short circuiting and a "design" sample representing truly-classified middling particles

It is evident that it is possible to account for both magnetite and middling recovery and at the same time to maintain the proper middling to free magnetite ratio by varying the percentages of the "random" sample and the "design" sample components. On this basis it is then possible to modify the relative probability shown earlier in Figure 9, and to add a "random" sample component as shown in Figure 11. This results in a combined probability for each type of particle that will account for both the observed recovery, and the observed ratio of free magnetite to middling in the final overflow product. The preceding observations will apply to the adjacent size fractions but the relative percentage of "random" and "design" middlings will vary. The estimated relative percentage of a "design" sample and of "random" sample for each size fraction calculated from the grain count data is shown in Figure 12. The curves show that the 325/500-mesh size fraction is nearly all "random" on the assumption that material in this size range and finer was not effectively fractionated in the cyclone. In the progressively coarser fractions the percentage of "random" sample decreases and the percentage of "design" sample correspondingly increases.

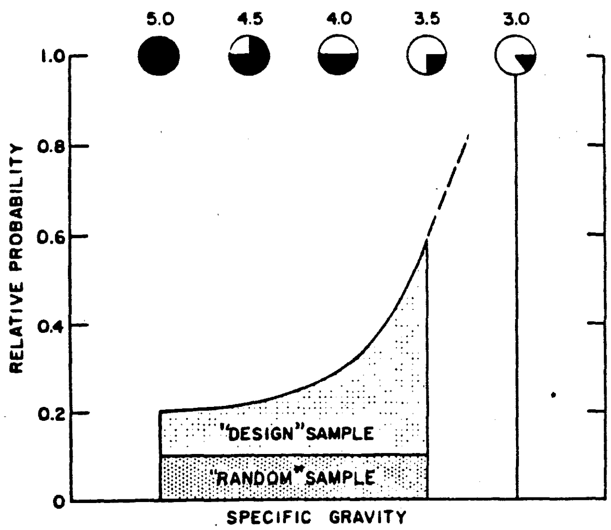


FIGURE 11. Adjusting the relative percentages of the "random" sample and of the "design" sample in the cyclone overflow makes it possible to determine the relative probability that a particle which has a given specific gravity and which fulfills the requirements for both observed abundance and relative recovery will appear in the cyclone overflow

The final make-up of the cyclone overflow is determined by the combined effects shown in Figures 6 and 12. In progressively coarser sizes, from 500 to 100 mesh, the total recovery of middlings drops from over 50% to less than 5% (Figure 6), and the relative percentage of "design" middlings compared to normal middlings increases from less than 10% to over 60%. The effect that this has on the final concentrate grade is shown in Figure 13 where the cobber concentrate grade is plotted against the corresponding final concentrate for two different operations. The fact that the concentrate grades are much lower than the corresponding

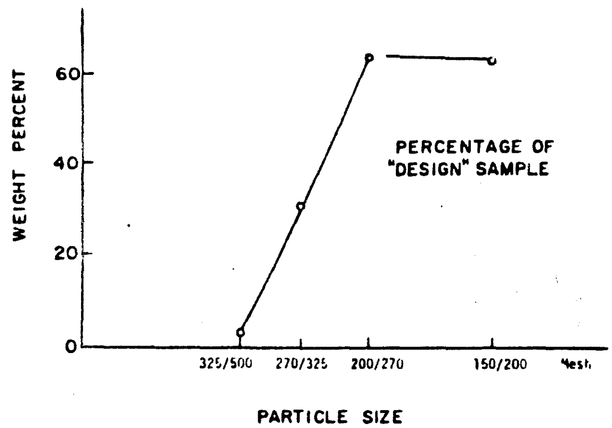


FIGURE 12. This figure shows the relative abundance of the "design" sample in the cyclone overflow, as calculated from the grain count data, as a function of the particle size. At sizes coarser than 150 mesh, the total recovery is so low that the data are not significant

feed material reflects the increased percentage of "design" middlings in the coarser size fractions. The final concentrates contain both free magnetite and middlings in these size fractions, and the "design" middlings have to be significantly lower grade than the analyses of the corresponding size fractions of the final concentrate. All the "design" middlings produced between 100 and 270 mesh fall in the 20 to 35% iron range which can be converted to about a 20% volume percentage. When such particles are examined under the microscope they obviously require grinding through 500 mesh for liberation. These "design" middlings represent as much as 65% of the middlings which report in the cyclone overflow but they represent less than 10% of the middlings in the cyclone feed. Therefore, the middlings that reach the final concentrating stages represent a very small, carefully selected fraction of the incoming middling population which require extremely fine grinding for liberation. The inference from such observations on the plant concentrates that the ore requires grinding through 500 mesh for effective liberation is seriously in error. The middlings which are observed in the plus 325-mesh size fractions are in large part inherent in the process rather than in the ore and are developed by selectively grinding the higher grade middlings and free magnetite and thereby leaving a superabundance of lean, "design" middlings in the cyclone overflow.

GRINDING PRACTICE RELATED TO THE ABUNDANCE OF MIDDLINGS

There are actually two effects involved in the accumulation of a super-abundance of middlings in the final concentrate. The first effect involves the selective classification in the cyclone, just described, that leads to the preferential accumulation of "design" middlings with ultrafine magnetite inclusions in the plus 325-mesh size fractions. The second effect is the ability of the combination of the ball mill and cyclone in closed circuit to actually create a superabundance of middling type particles.

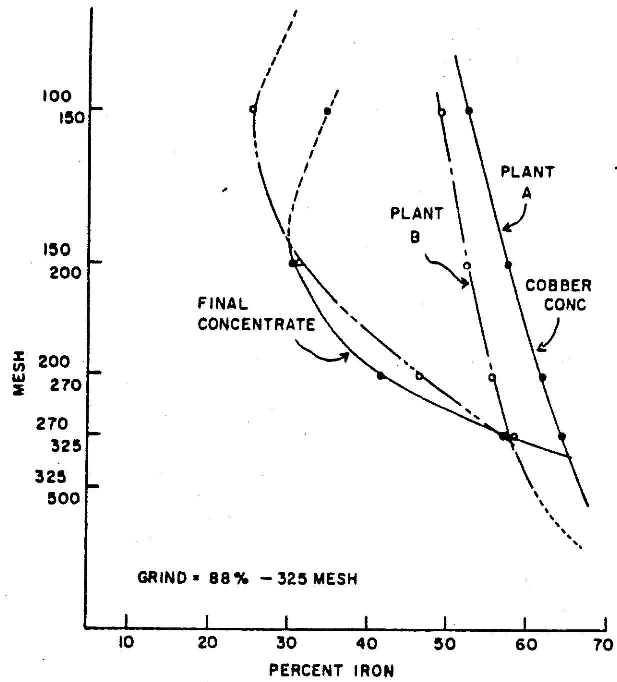


FIGURE 13. The iron contents of the feed (cobber concentrate) and of the final concentrate in the corresponding size range are shown for 2 taconite operations treating different ores. The data show that it is possible to obtain lower-grade products in some size fractions from an ore that has distinctly superior liberation characteristics, depending upon the manner in which the grinding circuit is operated

The fact that this type of circuit is capable of creating a "false" middling problem is illustrated in Figure 13. The figure shows the iron analyses by size fraction for the cobber concentrates and the final concentrates from two plants, A and B. Each plant grinds to about 90% minus 325 mesh and their flowsheets are essentially parallel. The difference in the iron analyses of the cobber concentrates shows that the plants are treating two ores with distinctly different liberation characteristics, i.e., the cobber concentrates from Plant A average about 5% higher in iron content. The individual size fractions, particularly at 200/270 and at 270/325 mesh, show some striking anomalies:

Mesh	% Fe Cobber Concentrate	% Fe Final Concentrate	Difference
Plant A			
200/270	62.1	41.9	−20.2
270/325	64.6	57.7	− 6.9
Plant B			
200/270	55.8	46.2	− 9.6
270/325	58.6	57.1	− 1.5

The negative differential between the final plant concentrate and the incoming material is significantly greater for Plant A than Plant B, despite the fact that the feed to Plant A contains about 6.2% more iron and has a correspondingly lower original middling content. Plant A is producing lower grade middling particles and a lower grade final concentrate in some size fractions from an ore that by all normal tests and criteria should have much superior concentrating characteristics. Microscopic examinations of the concentrates from each plant show a superabundance of particles requiring a 500-mesh grind for liberation. The fact that the treatment of two distinctly different ores produces an equivalent, or even inferior product in the upper size fractions from the ore with the better liberation characteristics can only reflect a condition inherent in the process itself.

The ability of the process to produce a lower, or equivalent grade, final concentrate from higher grade starting material, as illustrated in Figure 13, can be explained by the cyclone operation. If the cyclone is operated to give a sharp split, i.e., to maximize the percentage of 200/270 and 270/325-mesh material, and to minimize the percentage of coarse oversize material, then it makes a less efficient separation in these size ranges. This is shown by comparing the size distribution and weight recovery for each fraction of the cyclone overflow from Plants A and B below:

Cyclone Overflow

Mesh	Plant A Wt %	Plant A Wt Rec %	Mesh	Plant B Wt %	Plant B Wt Rec %
+150	1.2	2.3	+150	0.8	1.8
+200	2.1	2.9	+200	1.9	3.5
+270	3.8	4.2	+270	6.1	8.9
+325	7.0	20.5	+325	5.3	29.6
−325	85.9	64.0	−325	85.9	60.0

The cyclone operation in Plant A is making a closer split and is producing a greater percentage of 270/325-mesh material, compared to the percentage of 200/270-mesh material, than Plant B. Using the figures given it is possible to compare the relative amounts of 200/270 and 270/325-mesh material required in the cyclone feed to produce an equivalent amount of cyclone overflow.

Pounds of cyclone feed required to produce 100 pounds of cyclone overflow in each size fraction

Mesh	Plant A	Plant B
200/270	2380	1120
270/325	488	338

These figures show that Plant A requires twice as much 200/270-mesh material in the cyclone feed as Plant B to produce the same amount of 200/270-mesh material in the overflow. The reason that this is the case is because the cyclone overflow consists of both the "random" and "design" type of sample. The relative percentage of each for a given size fraction is determined by the operating characteristics of the cyclone. However, the feed only contains a limited number of "design" particles which reflect its basic liberation characteristics; the number of such particles is lower for Plant A than for Plant B. Consequently Plant A must present a greater percentage of each of these given size fractions to the cyclone to produce the same overall 86% minus 325 mesh in the overflow. While the operator concentrates on adjusting all of the available parameters in the grinding-cyclone circuit to achieve a grind specified as some percentage passing a nominal screen size, a more damaging accommodation is reached between the cyclone and the ball mill that dictates the number, and type, of middling particles that appear in the cyclone overflow that has little relation to the nature of the primary feed material.

CONCLUSIONS

The use of a cyclone in closed circuit with a ball mill results in the creation of a coarse middling and silica problem in the final concentrates. The problem is far more serious than the simple effect that would be produced by selectively over-grinding coarse magnetite and thereby producing an over-abundance of normal middling type particles. The process actually manufactures an excess of particles in the potential middling size range and then selectively extracts an especially refractory type of particle that requires grinding through 500-mesh and even finer for effective liberation. The middlings produced and recovered in the coarser 10 to 15% of final concentrates, which carry as much as 50% of the total silica in the final concentrates, are in large part synthesized by the process itself. They will be produced regardless of the grind at 90% passing 200 mesh or at 90% passing 500 mesh. Their relative importance increases with progressively finer grinds because they represent an ever increasing percentage of the total silica problem.

The middling problem can be avoided by replacing the cyclones in the ball mill circuit with a screen. The screens are separating largely on the basis of size, there is but little gravity effect, and the circuit is no longer manufacturing the particularly refractory middling particles associated with the cyclone. The effectiveness of such an approach was illustrated in a recent paper[2] in which equivalent concentrate grades were obtained with a screen in the circuit at 82% minus 325 mesh, compared with the normally required 90% minus 325 mesh. The explanation offered was that this was due to a gravity effect on the screen, however; the foregoing analyses and discussion indicate that it is far more likely that the major positive effect was due to the fact that middlings were no longer being manufactured in the circuit.

The other factor which makes it more desirable to place screens in the ball mill circuit is the fact that it is not necessary to attempt a separation at 325 mesh; the effective size of separation can be significantly coarser and still maintain equivalent grade in the final concentrate. The use of the screen in this capacity takes advantage of the natural liberation characteristics of the ore, and the wide grade differential between the coarse size fractions in the concentrate and in the cobber concentrate disappears. The use of screens on the final concentrate, or flotation, to segregate the coarse silica-rich fractions for additional grinding may be expedient in some instances. However, the basic problem stems from the creation of middlings in the grinding circuit, and this is where screening has by far its greatest potential.

The complexity of the concentration problems associated with magnetic taconites requires that the inherent liberation characteristics of the ore be exploited as efficiently as possible. The use of the cyclone in the grinding circuit has tended to bury the natural liberation characteristics of the taconite in a synthesized middling problem. Redesigning the circuit to bring free magnetite grains (Figures 4a and 5a) down into the final concentrating circuit rather than the synthesized middling population (Figures 4b and 5b) has so many obvious potential advantages that they do not need renumeration here. Although it is clear that screening in the ball mill circuit will minimize the tendency to create middlings in the grinding circuit, it is possible that equivalent results can be obtaned without recourse to screening by a judicious modification of the classification system.

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Paper K1

REFERENCE 2

THE IMPROVEMENT OF CYCLONE PERFORMANCE WITH A SPECIAL SPIGOT DESIGN

BY

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ABSTRACT

Simple changes to cyclone spigot design have given improved cyclone performance. At Mt Newman Mining the use of these spigots has allowed the capacity of a dewatering circuit to be increased by over 30%. The spigots are simple, inexpensive and require no operator adjustment. They are suitable for use in both dewatering and sizing circuits.

1.0 INTRODUCTION

The Mt Newman Mining Beneficiation Plant uses a combination of WEMCO drums, DSM heavy medium cyclones and Reichert cones to produce saleable products from low grade iron ores. Hydrcyclones are used in a number of locations in the plant for sizing and dewatering purposes.

The plant was built using conventional Krebs and AKW cyclones fitted with conventional spigots.

There were a number of locations in the plant where improved cyclone performance had the potential to increase profitability. The Mt Newman cyclone development programme has concentrated on improving spigot performance in the Reichert cones plant.

2.0 THEORY

The development of a new cyclone spigot started when production was being affected by a dewatering screen that was not working properly because the cyclone feeding the screen was putting too much water onto the screen. The question asked was "Why do conventional cyclones send so much water to underflow?". Once this question was answered it was possible to develop a new spigot design hereafter referred to as the JD spigot.

2.1 Conventional Spigots

Fig. 2.1 shows the cross section of a cyclone with a conventional spigot operating on water only. The air core contracts at the spigot end of the cyclone. The main reason for this is the reduction in the average angular velocity of the liquid as it moves towards the spigot end of the cyclone.

Thin layers of liquid slow down faster than thick layers. For this reason conventional cyclones operating in the vertical position will always discharge some liquid from the spigot - no matter how small the spigot diameter is.

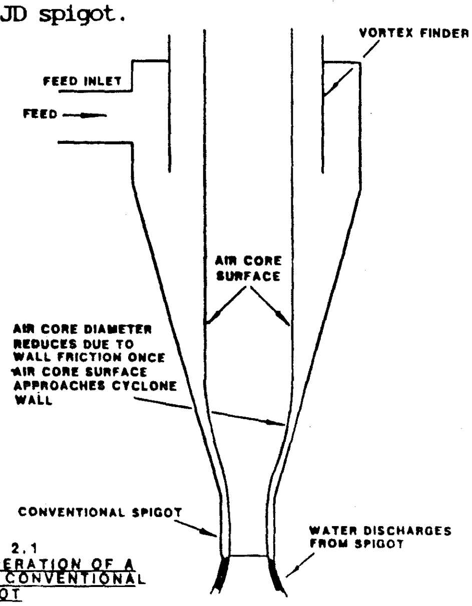


FIGURE 2.1
SCHEMATIC OPERATION OF A CYCLONE WITH CONVENTIONAL SPIGOT

2.2 A New Spigot Design - The JD Spigot

FIGURE 2.2
SCHEMATIC OPERATION OF A CYCLONE WITH A JD SPIGOT

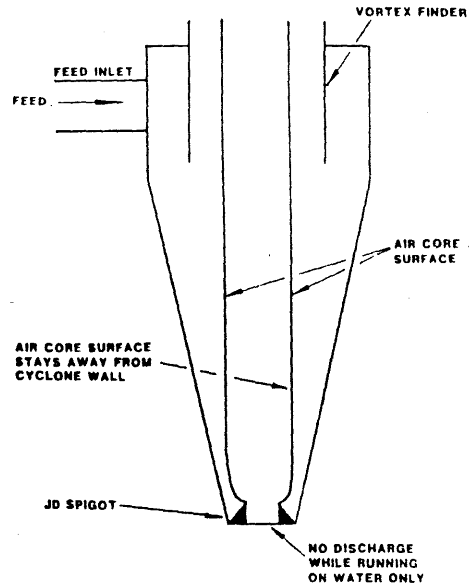


Fig. 2.2 shows the cross section of a cyclone fitted with a small JD spigot. The key feature of the JD spigot is that, unlike conventional spigots, the included angle is greater than 180°. Fig. 2.2 shows that the design allows thin layers of liquid to be avoided. This means that nothing will discharge from a small spigot when the cyclone is running on water only.

When the cyclone is operated on a slurry, coarse particles accumulate at the spigot end. As a result, slurry viscosity at the spigot increases, angular velocity drops and the air core contracts. Slurry discharges from the spigot once the critical viscosity has been reached.

If larger JD spigots are used some liquid will discharge at all times. However, the quantity will be less than that for conventional spigots of the same diameter. This is because the effect of wall friction on angular velocity will be lower for JD spigots, i.e., air core diameter will be greater.

The effect of JD spigots on sizing efficiency is more difficult to predict. Reducing the percentage of water reporting to underflow must help sizing efficiency. However, the thicker slurry layers and different flow patterns at the bottom of the cyclone may have a detrimental affect on the separation of near size material.

3.0 MT NEWMAN MINING CONES PRODUCT DEWATERING CIRCUIT

The cones product dewatering screens used to be the bottleneck at the Mt Newman Mining Iron Ore Beneficiation Plant. At high tonnages water would pour off the end of the screens. The feed to these screens came from 3 x 300mm AKW cyclones fitted with conventional 78mm spigots.

Both a Linatex fishtail and JD spigots were trialled in an attempt to overcome this problem. The Linatex fishtail gave slightly thicker underflows that the JD spigot. (Average underflow moistures of 22.3% vs 23.5% by weight% during trials. The conventional spigot product had moistures in excess of 30%). Despite these results it was decided to persist with JD spigots because they were so much easier to use. The Linatex fishtail required extra pipework for siphoning and was difficult to tune properly. In practice the fishtail had to be run at less than the optimum setting to avoid the risk of cyclone bogging.

The JD spigots had a dramatic effect on plant capacity. The dewatering screen discharge moisture is 16%, i.e., the JD spigots had reduced by more than 40% the amount of water that the dewatering screens had to remove per tonne of product. When the cyclones were fitted with 85mm JD spigots, spigot capacity had become the plant bottleneck.

Further tests were run with larger diameter spigots. Water running off the end of the screen only re-appeared as a limiting factor when 100mm JD spigots were used. 95mm spigots are the current standard. 95mm spigots give underflow moistures below 25% under normal operating conditions. The 100mm spigots were still giving much better results than conventional 78mm spigots. Vortex finder diameter is only 110mm.

4.0 MT NEWMAN MINING DESLIMING CYCLONES

Two nests of 300mm AKW cyclones with 48mm conventional spigots are used to separate -63 micron reject slimes from Reichert cone feed. Underflow pulp density has been found to be less than optimum for Reichert cone operation.

The desliming cyclone circuit allowed timed samples to be taken of cyclone underflow and somewhat less than perfect samples to be taken of cyclone feed and overflow.

4.1 Dewatering Performance

Fig. 4.1 shows the relationship between wt% solids in cyclone underflow and tph solids to underflow. The graphs show that JD spigots give higher underflow pulp densities. Even the 55mm JD spigot was still giving much better results than a 48mm conventional spigot. The graphs also show that JD spigot underflow pulp density is less affected by spigot loading than it is for conventional spigots. This is an attractive feature for situations like ours where a consistent feed pulp density is desirable.

FIGURE 4.1
WEIGHT % SOLIDS U/FLOW vs TONNAGE

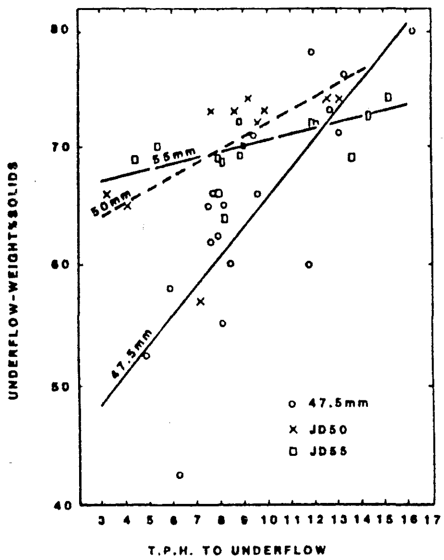
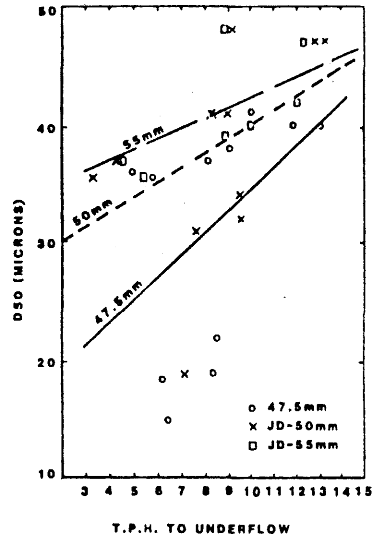


FIGURE 4.2
D50 vs TONNAGE



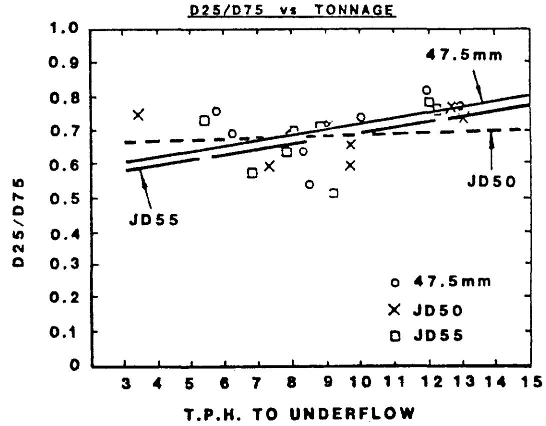
4.2 Sizing Performance

The testwork gave enough information to allow rough partition curves to be drawn. Figs 4.2 and 4.3 plot D50 and the AICHE sharpness index (D25/D75) against tph solids to underflow.

Fig. 4.2 shows that D50 is coarser for cyclones fitted with JD spigots. This is in line with expectations. The JD spigot removes oversize from a point higher in the cyclone. JD spigots are also expected to increase the average pulp density of material in the cyclone.

Fig. 4.3 shows that the testwork was not precise enough to determine whether JD or conventional spigots give the best separation of particles near the size of separation.

FIGURE 4.3
D25/D75 vs TONNAGE



5.0 WEAR RATES

Initial tests using 85mm JD spigots in the Mt Newman Mining cones dewatering cyclones showed that the JD spigots lasted for 9 months compared with 6 months for 78mm conventional spigots. The reason for this surprising result was considered to be that the theory of JD spigots operation implies lower velocities in the spigot region. Spigot life was lower for larger JD spigots because of higher tonnages and high velocities near the spigot. JD 100mm spigots last about 9 weeks.

JD spigots did cause higher wear rates at the bottom of the cyclone conical section. A distinct groove was found to form there. This problem arises because the JD spigot prevent all solids discharging when feed goes off. JD spigots will also tend to retain very coarse particles in the lower cone region. Conventional spigots simply discharge very coarse particles as soon as they reach the spigot. The wear rates were not high enough to be a significant problem.

6.0 OPERATING CONSIDERATIONS

No special pipework or adjustments are required to use JD spigots. Because there is less variation in underflow pulp density JD spigots may remove the necessity for adjustable spigots in some circumstances.

7.0 CONCLUSIONS

Experience at the Mt Newman Beneficiation Plant has shown that JD spigots provide a very simple way of improving cyclone dewatering performance. The results of plant testwork were not precise enough to determine whether JD or conventional spigots gave the best separation of particles near the size of separation. The differences appear to be too small to be a significant factor in cyclone selection.

JD spigots do increase the size of separation. Changes to cyclone length or geometry may be required if this is a problem.

9.0 ACKNOWLEDGEMENTS

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