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FURTHER EVALUATION OF COPPER-ORE FLOTATION TESTS BY REGRESSION ANALYSIS

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W. R. Honeywell
Extraction Metallurgy Division

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SUMMARY

A flotation investigation was done to determine how the rate of flotation of copper from a chalcopyrite-bearing ore was affected by variations in the pulp density in the flotation cell and the amount of Z-200 collector added. In addition, the effects of these two variables on the recovery of copper and grade of the copper concentrate were determined. All correlations were done by regression analysis techniques. The test work resulted in the following three statistically significant mathematical relationships between the pulp density (X_1) and the amount of Z-200 (X_2) and the three responses considered; recovery grade and flotation rate constant.

$$\text{Rate Constant} = -0.238 - 0.0351\ X_1 + 2.0\ X_2$$

$$\text{Recovery, (\%)} = 96.1 + 0.105\ X_1 - 13.3\ X_2$$

$$\text{Conc. Grade, (\% Cu)} = 28.0 - 0.27\ X_1$$

In the above equations X_1 is expressed as per cent solids, and X_2 as lb/ton of ore treated.

INTRODUCTION

In a previous study [1] a flotation investigation was done to investigate the effects of nine operating variables on the recovery of copper and the grade of the copper concentrate when two chalcopyrite-bearing ores from Opemiska Copper Mines (Quebec) Limited were treated. The results of the work showed that only two variables, the pulp density and the amount of Dow Z-200 collector, had significant effects on the two responses measured, concentrate grade and copper recovery.

Because of the test procedure used in the previous investigation [1], it was not possible to determine how varying the operating variables affected the rate of copper flotation. It was decided, therefore, to conduct a second investigation to determine how varying the pulp density and amount of Z-200 collector used affected the flotation rate. This report describes this work.

PROCEDURE

The ore used in this work analysed 1.44% Cu and was one of those used in the previous investigation [1] from Opemiska Copper Mines (Quebec) Limited. A mineralogical examination showed that the ore contained chalcopyrite, commonly as small blebs less than -½ mm across, in massive pyrite. Lesser amounts of magnetite molybdenite and pyrrhotite were also observed. The gangue was chiefly biotite and amphibole with minor amounts of quartz, feldspar, calcite, sphene, chlorite, apatite and sericite.

The tests were done using a Fagergren flotation machine equipped with a glass cell, on 1000-gm batches of ore. Six tests were run in which all conditions were held constant except for the pulp density and the amount of Z-200 reagent used. In the six tests the effects of the pulp density and amount of Z-200 used were investigated by an experimental design in which these two variables were run at two levels each (Table 1). To provide a test for experimental error, two sets of conditions were run in duplicate (Table 1, Tests 1 and 3 and Tests 4 and 6).

TABLE 1

Experimental Conditions

Test No.	Particle Size (%-200M)	Pulp Density (% Solids)	Lime (lb/ton)	Cyanamid R-208 (lb/ton)	Dow Z-200 (lb/ton)	Z-6 (lb/ton)	TEB[1] (lb/ton)
		(X_1)			(X_2)		
1	76	19	1.2	0.03	0.075	0.003	0.06
2	76	19	1.2	0.03	0.15	0.003	0.06
3	76	19	1.2	0.03	0.075	0.003	0.06
4	76	32	1.2	0.03	0.075	0.003	0.06
5	76	32	1.2	0.03	0.15	0.003	0.06
6	76	32	1.2	0.03	0.075	0.003	0.06

(1) Triethoxy-butane

The flotation concentrate was collected in 30-second increments over the total flotation period. Each increment was analysed for copper, and the copper recovery in each increment was calculated. From this data flotation rates were obtained.

RESULTS

The results obtained in Tests 1 and 4, Table 1 are given in Table 2. The results of these two tests are also shown graphically on Figure 1 where the logarithm of the amount of copper remaining in the cell is plotted vs time for the first 2.5 to 3 minutes of the flotation period; that is up until about 90 per cent of the copper had been floated. It is apparent from Figure 1 that when the data is plotted in this way, the plot is a straight line for all practical purposes. In other words

TABLE 2

Detailed Flotation Results for Tests 1 and 4

Time (min)	Test No. 1 19% Solids; 0.075 lb/t Z-200				Test No. 4 32% Solids; 0.075 lb/t Z-200			
	Conc Wt (%)	Conc Cu Analysis (%)	Cu Recov in Conc (%)	Cum Recovery (%)	Conc Wt (%)	Conc Cu Analysis (%)	Cu Recov in Conc (%)	Cum Recovery (%)
0.5	1.78	28.0	35.0	35.0	3.03	27.2	55.6	55.6
1.0	0.99	26.1	18.1	53.1	1.26	24.0	20.3	75.9
1.5	0.91	25.0	16.0	69.1	0.50	22.6	7.6	83.5
2.0	0.71	21.8	10.9	80.0	0.37	21.0	5.3	88.8
2.5	0.38	20.9	5.6	85.6	0.34	14.4	3.3	92.1
3.0	0.32	16.8	3.8	89.4	0.25	10.6	1.8	93.9
3.5	0.32	14.1	3.2	92.6	0.21	11.4	1.6	95.5
4.0	0.28	9.92	2.0	94.6	0.11	8.35	0.6	96.1
4.5	0.20	9.46	1.3	95.9	0.41	3.55	1.0	97.1
5.0	0.33	3.37	0.8	96.7	0.22	2.77	0.4	97.5
5.5	0.26	1.83	0.4	97.1	0.20	1.83	0.3	97.8
6.0	0.22	1.69	0.3	97.4	0.29	1.28	0.3	98.1
Conc	6.70	20.66	97.4		7.19	20.22	98.1	
Tailings	93.30	0.04	2.6		92.81	0.03	1.9	
Head	100.00	1.42	100.00		100.00	1.48	100.00	

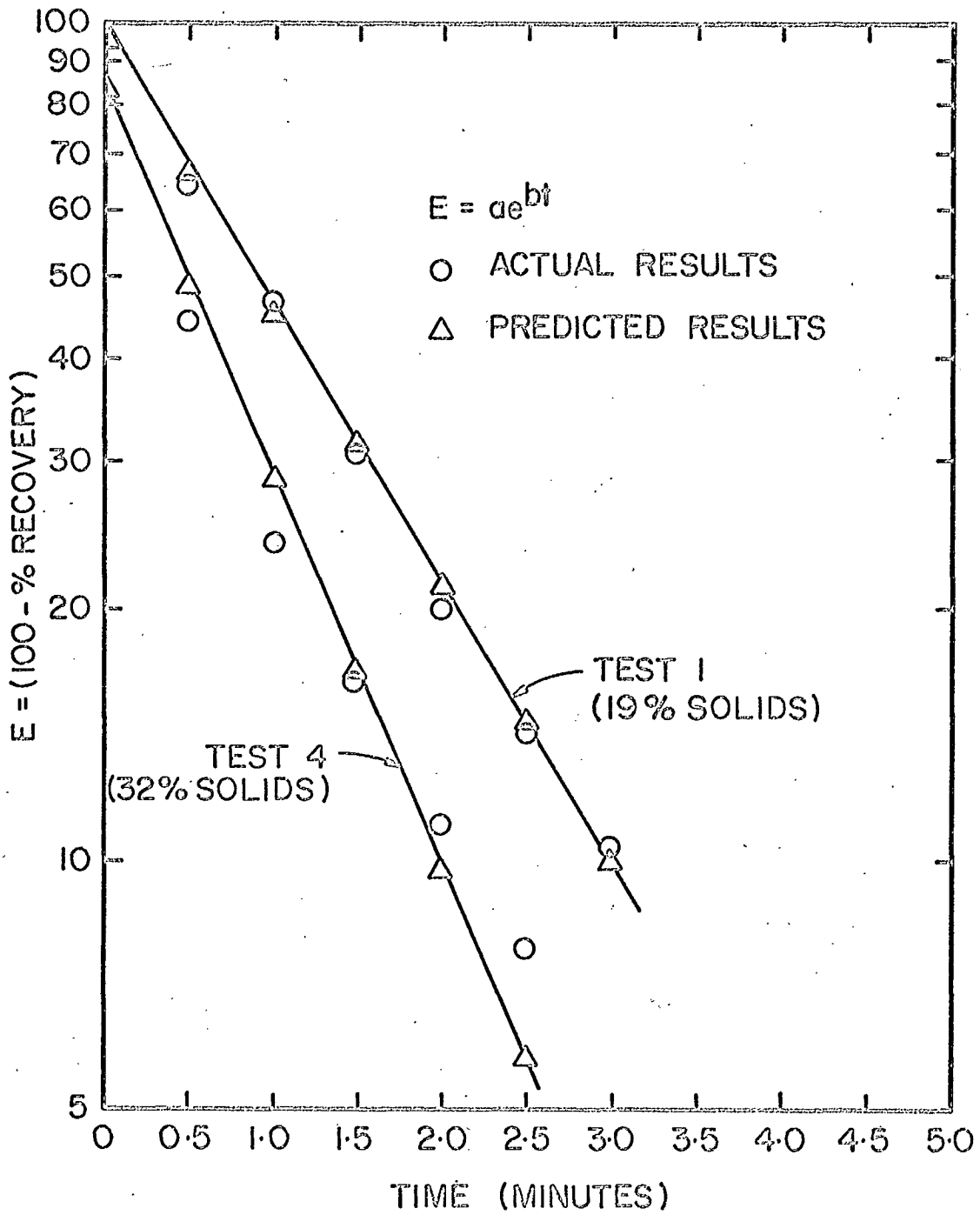

Figure 1. Flotation Rate Curves

the relationship between (100 - % recovery) and time is exponential and has the general form:

$$E = (100 - \% \text{ recovery}) = ae^{-bt}$$

where a is the value of the y intercept, and b is the slope of the straight-line plot shown on Figure 1 and is referred to as the rate constant.

It follows that the greater the absolute value of b, the greater is the rate at which copper is floated.

It was found that in all of the flotation tests done in this study (Table 1) it was possible to determine a rate constant in the same way as was done for Tests 1 and 4. All of these calculated rate constants, based on the first 2.5 to 3.0 minutes of flotation, along with the copper recovery and grade obtained at the end of 6.0 minutes of flotation are shown on Table 3.

The responses shown in Table 3 were correlated with the test conditions (Table 1) by multi-variable regression methods to determine first order linear equations. The resulting equations relating recovery (%R), concentrate grade (% Cu), and rate constant to pulp density (% solids) and amount of Z-200 added (lb/ton ore) were as follows:

$$\text{Rate constant} = -0.238 - 0.035\ (\% \text{ solids}) + 2.0\ (\text{lb Z-200/lb})$$

$$\%R = 96.1 + 0.105\ (\% \text{ solids}) - 13.3\ (\text{lb Z-200/ton})$$

$$\% \text{ Cu} = 28.0 - 0.27\ (\% \text{ solids}).$$

Since it can be shown that over two thirds of the variations observed in the dependent variables are due to changes in the operating variables, the equations may be used to predict responses for any levels of the operating variables providing they are within the ranges investigated.

An inspection of the three regression equations derived from the test data shows that increasing the pulp density within the range of 19-32% solids results in higher recovery of copper at a faster flotation rate. On the other hand increasing the amount of Z-200 added in the range of 0.075 to 0.15 lb/ton ore results in lower recovery and lower flotation rates. Also, increasing the pulp density is seen to decrease the grade of the copper concentrate while the amount of Z-200 added has no effect on the grade.

TABLE 3

Overall Flotation Responses and Variables

Test No.	RESPONSES			VARIABLES	
	Recovery (%)	Grade Cu (%)	Rate Constant	Solids (%)	Z-200 (lb/ton)
	Y_1	Y_2	Y_3	X_1	X_2
1	97.4	20.7	-0.76	19	0.075
2	95.4	24.3	-0.49	19	0.15
3	97.4	23.6	-0.87	19	0.075
4	98.1	20.2	-1.07	32	0.075
5	98.1	18.5	-1.18	32	0.15
6	98.1	19.4	-1.25	32	0.075

Note: Tests 1 and 3, and also 4 and 6 are duplicates

A further inspection of Table 2 shows that the higher flotation rate results in higher recovery but lower grade during the first 1.0 to 1.5 minutes of flotation than when a lower flotation rate is effected by a lowering of the pulp density (Table 1). However a comparison of the recoveries and grades from the two tests after 6 minutes of flotation showed only very small differences in the results obtained.

In both tests the grade of the concentrates are high during the early part of the flotation period. Mineralogical examination of the concentrate shows that during the early part of the flotation period, the concentrate is composed mainly of chalcopyrite particles containing little or no gangue. As the flotation proceeds the concentrate contains more chalcopyrite-gangue middling particles and gangue particles.

DISCUSSION AND CONCLUSIONS

Two techniques used in this work make it possible for a flotation investigator to obtain a great deal of information about the system being studied with a minimum of test work. Conventionally, flotation tests are conducted using a procedure where the concentrate is collected as a bulk concentrate over the whole flotation period which lasts until the investigator decides by visual inspection that all the valuable mineral has been floated. Also it is usual for only one variable to be investigated at a time.

The procedure used in this study which involved a designed experiment, regression analysis of the data, and incremental collection of the concentrate has the following advantages.

(a) The test work involves only six flotation tests in which the effect of two variables are determined.

(b) The data obtained provides information as to how the variables affect flotation rate as well as overall recovery and grade.

(c) The data provides information which could be used to optimize reagent cost with capital cost of the flotation cells required for the conditions used.

(d) The results obtained allow for the specification of how a plant should be run to obtain the best combination of finished concentrate grade and recovery at the head of a rougher circuit.

(e) The results obtained provide information as to the relative floatability of the minerals present.

Specifically this work allows for the following observations to be made regarding the effect of pulp density in the range of 19 to 32 per cent solids, and of the amount of Z-200 added in the range of 0.075 to 0.15 lb/ton ore on the flotation of chalcopyrite ore from Opemiska Copper Mines (Quebec) Limited.

(a) Increasing the pulp density results in increased flotation rate, decreased overall grade, and increased overall recovery. Increasing the amount of Z-200 added decreases overall recovery and flotation rate and has no significant effect on concentrate grade. The effects of Z-200 addition on grade and recovery are unexpected but the observed effects are significant statistically.

(b) The flotation results as exemplified by Table 2 show that the recovery and grade of the concentrate recovered at the head of a rougher step can be controlled by varying the pulp density or amount of Z-200 added. However, such changes could result in significant variations in overall recovery and grade (Table 3).

(c) As would be expected the fastest floating particles are pure or almost pure particles of chalcopyrite.

These results suggest that the Opemiska plant would operate most efficiently at a pulp density of 32% (or perhaps higher) and a Z-200 addition of 0.075 lb/ton (or perhaps lower), along with other conditions as shown on Table 1. Plant experimentation has led to the plant being operated at 31% solids and 0.034 lb Z-200/ton. Under these conditions the plant recovers over 80% of the copper at a shipping grade at the head end of the rougher circuit. This is in agreement with the results of the laboratory work reported here.

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REFERENCE

1. W.R. Honeywell and H.H. McCreedy, "Factorial Design and Regression Analysis of Copper-Ore Flotation Tests", Mines Branch Investigation Report IR 68-50, Department of Energy, Mines and Resources, Ottawa, (1968).