Development of flotation rate equations for Konkola primary mill cyclone overflow at various pulp densities and thickener underflow at 35% solids

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Introduction

Flotation involves the selective levitation of mineral and its transfer from cell to launder. The flotation rate is the rate of this transfer. It may be defined by the slope of a recovery-time curve for any cell in a bank or at any time in a batch operation. The objective in flotation rate study is an equation expressing the rate in terms of some measurable property of the pulp. This can be either the concentration of floatable mineral in weight per unit volume or a relative concentration, which will be a function of the recovery. A rate equation for an actual flotation pulp will contain at least two constants, both to be determined from the collected data. The data used in this paper were collected from bench-scale flotation tests on Konkola primary mill cyclone overflow at various pulp densities and pre-flotation thickener underflow at a pulp density of 35% solids by weight.

Theory

There are two ways in which rate equations can be developed. One way is by analysis of the mechanism of the process while another is by direct fitting of equations to recovery-time data. In this paper the latter method was used. Assuming that under constant operating conditions the flotation rate is proportional to the actual or relative concentration, say recovery for instance, of floatable mineral in the pulp, a generalized rate equation may be expressed as follows:

$$\text{Rate} = Kc^n \qquad [1]$$

Where K is the rate constant, C is some measure of the quantity of floatable mineral in the pulp at time t, and n is a positive number.

If the exponent in Equation [1] is 2, then after integration the equation becomes

$$R = \frac{A^2Kt}{1 + AKt} \qquad [2]$$

where A is the maximum possible recovery with prolonged time under the conditions used, while R is cumulative recovery.

Rearranging Equation [2] gives

$$\frac{t}{R} = \frac{t}{A} + \frac{1}{A^2K} \qquad [3]$$

Compare this to an equation of a straight line, $y = mx + c$.

If the second order equation is valid, a plot of (cumulative flotation time) / cumulative recovery) against time should result in a straight line. It will be convenient to redefine a rate constant in terms of the recovery relative to the maximum possible recovery A. This constant then becomes A^2K and will be the reciprocal of the intercept on a plot according to Equation [3].

Test work

Bench-scale flotation tests were conducted on samples of Konkola primary mill cyclone overflow at solids contents of 15, 25 and 35% by weight. Comparative tests were also carried out on samples of preflotation thickener underflow stream at 35% solids by weight. The tests were conducted over a period of 5 days using the flowsheet given in Figure 1. Timed concentrates were collected in the sulphide flotation stage while a bulk concentrate was collected in the oxide flotation stage.

Results

The averaged results for tests on Konkola cyclone overflow and thickener underflow are presented in Tables I and II respectively. Time–recovery plots have been made in Figure 2.

Using the cumulative flotation time and %TCu recoveries the values of *t/R* at various pulp densities were computed and these are shown in Table III.

Plots of *t/R* against cumulative flotation time have been shown in Figure 3 at various flotation feed densities.

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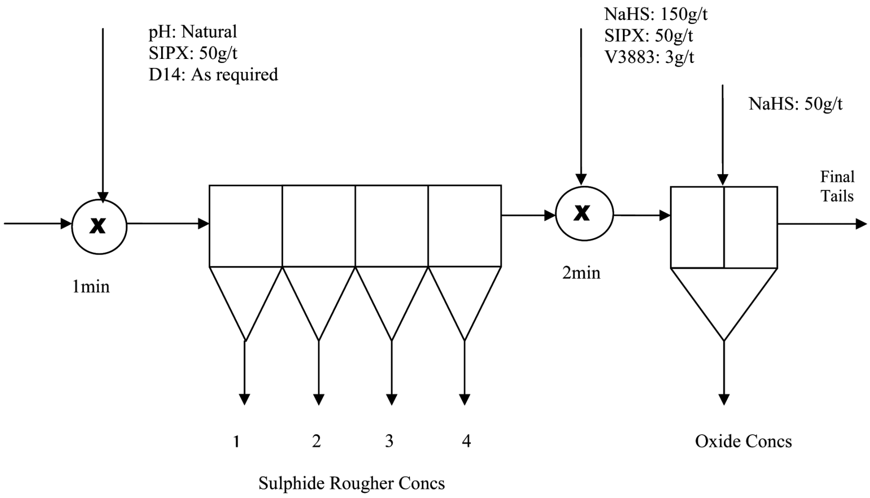

Figure 1—Konkola standard laboratory flotation flowsheet

Table I

Konkola laboratory flotation test work results (cyclone overflow)

% Solids	Fraction	Wt %	Grade %			Recovery			Cum Grade					Cum Recov
			TCu	ASCu	AlCu	TCu	ASCu	AlCu	TCu	ASCu	AlCu	TCu	ASCu	TCu
15	Cu rougher conc 1	5.18	28.11	0.81	27.30	54.8	18.3	58.3	28.11	0.81	27.3	54.8	18.3	54.8
	2	2.81	21.70	0.69	21.01	22.9	8.4	8.4	25.86	0.77	25.09	77.7	26.7	77.7
	3	1.75	7.91	0.55	7.36	5.2	4.2	5.3	22.63	0.73	21.90	83.0	30.9	82.9
	4	2.21	3.36	.0.74	2.62	2.3	7.1	2.4	19.07	0.73	18.34	85.7	38.0	85.2
	Oxide rough conc	6.61	2.65	0.80	1.85	6.6	23.0	5.0	13.22	0.76	12.46	92.3	61.0	91.8
	Final tails	81.44	0.25	0.11	0.14	8.2	39.0	4.7	2.66	0.23	2.43	100.0	100.0	100.0
	Head (calc)	100.00	2.66	0.23	2.43	100.0	100.0	100.0	-	-	-	-	-	-
25	Cu rougher conc 1	4.82	30.17	0.69	29.48	53.7	14.4	57.4	30.17	0.69	29.48	53.7	14.4	53.7
	2	2.90	24.48	0.90	23.58	26.2	11.3	27.6	28.03	0.77	27.26	79.9	25.6	79.9
	3	2.13	6.92	0.70	6.22	5.4	6.4	5.3	23.47	0.75	22.72	85.3	32.1	85.3
	4	2.53	3.15	0.59	2.56	2.9	6.4	2.6	19.32	0.72	18.60	88.3	38.5	88.2
	Oxide rough conc	6.49	1.90	0.82	1.08	4.6	23.0	2.8	13.33	0.75	12.58	92.8	61.5	92.8
	Final tails	81.13	0.24	0.11	0.13	7.2	38.5	4.3	2.71	0.23	2.48	100.0	100.0	100.0
	Head (calc)	100.00	2.71	0.23	2.48	10.0	100.0	100.0	-	-	-	-	-	-
35	Cu rougher conc 1	5.21	30.92	0.69	30.23	57.8	15.5	61.6	30.92	0.69	30.23	57.8	15.5	57.8
	2	3.37	21.47	0.87	20.60	25.9	12.6	27.1	27.21	0.76	26.45	83.7	28.1	83.7
	3	2.65	5.01	0.63	4.33	4.8	7.2	4.5	21.97	0.73	21.24	88.4	35.3	88.5
	4	3.59	1.50	0.57	0.93	1.9	8.8	1.3	17.01	0.69	16.32	90.4	44.1	90.4
	Oxide rough conc	7.71	1.17	0.58	0.59	3.2	19.2	1.8	11.59	0.65	10.94	93.6	63.3	93.6
	Final tails	77.47	0.11	0.11	0.12	6.4	36.7	3.6	2.79	0.23	2.56	100.0	100.0	100.0
	Head (calc)	100.00	2.79	0.23	2.56	100.0	100.0	100.0	-	-	-	-	-	-
	Head (assay)		2.71	0.26	2.45	-	-	-	-	-	-	-	-	-

Table II

Konkola laboratory flotation test work results (thickener U/F)

% Solids	Fraction	Wt %	Grade %			Recovery			Cum Grade					Cum Recov
			TCu	ASCu	AlCu	TCu	ASCu	AlCu	TCu	ASCu	AlCu	TCu	ASCu	AlCu
35	Cu rougher conc 1	5.44	27.33	0.70	26.63	53.9	16.5	57.3	27.33	0.70	26.63	53.9	16.5	57.3
	2	3.12	23.21	0.91	22.30	26.2	12.3	27.5	25.83	0.78	25.05	80.1	28.8	84.8
	3	2.25	5.06	0.70	4.36	4.1	6.8	3.9	21.51	0.76	20.75	84.2	35.7	88.6
	4	3.39	1.73	0.46	1.27	2.1	6.8	1.7	16.78	0.69	16.09	86.3	42.4	90.3
	Oxide rough conc	7.27	1.08	0.53	0.55	2.8	16.7	1.6	11.47	0.64	10.83	89.2	59.1	91.9
	Final tails	78.53	0.38	0.12	0.26	10.8	40.9	8.1	2.76	0.23	2.53	100.0	100.0	100.0
	Head (calc)	100.00	2.76	0.23	2.53	100.0	100.0	100.0	-	-	-	-	-	-
	Head (assay)	-	2.65	0.27	2.38	-	-	-	-	-	-	-	-	

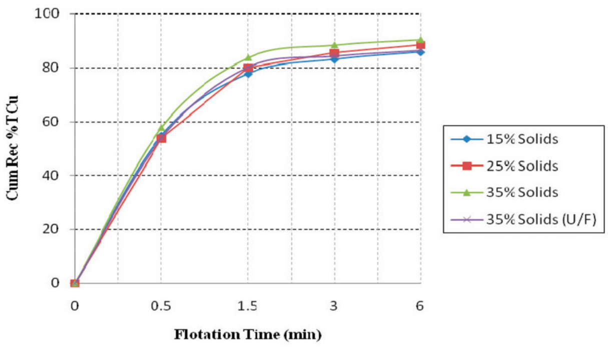

Figure 2—Recovery—time curves for Konkola flotation feed

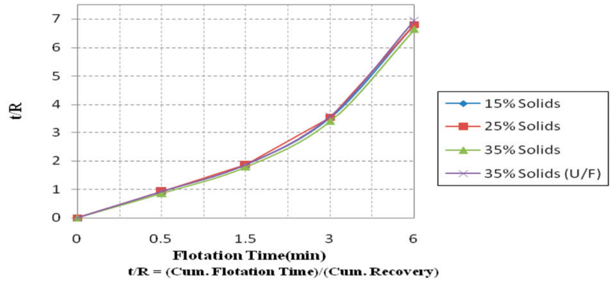

Figure 3—Test for second order flotation rate equations

Table III

Values of t/R and cumulative recovery %TCu

Flotation time (minutes)	Cumulative recoveries % TCu				t / R			
	15% Solids	25% Solids	35% Solids	35% Solids (TUF)	15% Solids	25% Solids	35% Solids	35% Solids (TUF)
0.5	54.8	53.7	57.8	53.9	0.91	0.93	0.86	0.93
1.5	77.7	79.9	83.7	80.1	1.93	1.88	1.79	1.87
3	83.0	85.3	88.4	84.2	3.61	3.52	3.39	3.56
6	85.7	88.3	90.4	86.3	7.00	6.80	6.64	6.95

* In the formula *t/R* recovery *R* has been divided by 100.

Table IV

Slopes, intercepts and correlation coefficients at various pulp densities

Test no.	% Solids	Slope (m)	Intercept (c)	Correlation coefficient (*r*)*
1	15	1.113	0.303	0.9999
2	25	1.075	0.327	0.9998
3	35	1.058	0.260	0.9997
4	35 (thickener underflow)	1.104	0.291	0.9996

* The closer *r* is to 1, the more linear is the relationship between *t/R* and *t*.

Rate equations

Linear regression analysis was applied on data presented in Table III to obtain slopes, intercepts of the curves shown in Figure 3. The slopes, intercepts and correlation coefficients are shown in Table IV.

With these values Equation [3] for each of the four pulp densities becomes :

- 15% solids: $t/R = 1.113t + 0.303$ [4]
- 25% solids: $t/R = 1.075t + 0.327$ [5]
- 35% solids: $t/R = 1.058t + 0.260$ [6]
- 35% (TUF): $t/R = 1.104t + 0.291$ [7]

These rate equations can be used to predict either flotation time in minutes or recovery. For example, taking Equation [4] at flotation feed density of 15% solids the time required to get a recovery of 85.7% TCu can be computed as follows:

$$\frac{t}{0.857} = 1.113t + 0.303$$

$$t = 0.954t + 0.260$$

$$0.046t = 0.260$$

$$t = 5.65 \text{ minutes}$$

However, 85.7% TCu is the recovery obtained after 6 minutes of sulphide flotation. The actual recovery calculated from the equation by putting in 6 minutes of flotation time is 85.9%. Therefore, there is a recovery loss of 0.2% during the flotation process. Similar calculations can be made for the remaining three tests.

Maximum sulphide recoveries

In Equation [3] the slope is given by $1/A$. Equating this to the slopes for the four tests, the maximum recovery, A, can be computed.

- 15% solids: $1/A = 1.113$
  $A = 0.898$
  $= 89.8\%$ TCu
- 25% solids: $1/A = 1.075$
  $A = 0.930$
  $= 93.0\%$ TCu
- 35% solids: $1/A = 1.058$
  $A = 0.945$
  $= 94.5\%$ TCu
- 35% solids
  (thickener underflow): $1/A = 1.104$
  $A = 0.906$
  $= 90.6\%$ TCu

Table V

TCu Recoveries obtained in the four tests

Test no.	Float feed % solids	Maximum theoretical recovery % TCu to sulphide rougher concentrate	Actual recovery % TCu to sulphide rougher concentrate	Actual overall (sulphide + oxide) recovery % TCu
1	15	89.8	85.7	92.3
2	25	93.0	88.3	92.8
3	35	94.5	90.4	93.6
4	35 (TUF)	90.6	86.3	89.2

Note that these recoveries, without altering the flotation conditions, can be obtained only after prolonged flotation times which may be too long for practical purposes.

To verify this, any one of the recoveries above can be put into respective equations to get flotation times of 272, 1 216 and 1 293 minutes for 15%, 25% and 35% solids in flotation feed respectively. In fact, in the case of thickener underflow the flotation time goes to infinity. This just goes to prove that recovery cannot be increased by merely keeping on increasing flotation time without altering the chemical environment in the flotation cell. For example, by adding a sulphidizer, an extra collector and frother at the end of sulphide rougher flotation stage the recoveries rise to 92.3, 92.8 and 93.6% TCu for feed pulp densities of 15, 25 and 35% solids respectively. The thickener underflow recovery also goes up to 89.2% TCu. These rises in recoveries were obtained by using an extra four minutes in the oxide flotation stage.

In this test work the actual recoveries of TCu to sulphide rougher concentrates were 85.7, 88.7, 90.4 and 86.3% for the four tests. These recoveries were less than the maximum ones calculated from Equations [4], [5] and [7] by 4.1%, 4.7%, 4.1% and 4.3%, respectively. This means that in the sulphide rougher flotation stage the flotation is only about 95% complete for each test. However, when flotation conditions are altered in the oxide flotation stage, the overall recoveries increased to 92.3, 92.8, 93.6 and 89.2% TCu for the four tests. This represents increments in recovery of 6.6, 4.5, 3.2 and 2.9% above those obtained in the sulphide flotation stage.

These increments in recovery showed that the test at 15% solids benefited the most from an oxide flotation stage whereas the thickener underflow benefited the least from an oxide flotation. This probably is evidence that the surface chemistry of the valuable minerals may have been altered in the pre-flotation thickener because of long residence time.

From these results it is evident that there is no clear-cut difference between the overall TCu recoveries at both low and high flotation pulp densities. This demonstrates that flotation at low pulp densities of Konkola ore is still possible as long as the oxide flotation stage is included in the process flowsheet. However, it is clear also that high flotation pulp densities improve the sulphide flotation in terms of flotation kinetics, grade and TCu recovery. The recoveries are summarized in Table V.

Rate constants

The rate constants, A^2K for the four tests are computed by taking reciprocals of the intercepts. The rate constants were determined as 3.30, 3.06, 3.85 and 3.44 for tests 1, 2, 3 and 4 respectively.

Conclusions

The rate equations developed for Konkola primary mill cyclone overflow at various flotation pulp densities are as follows:

- 15% solids: $t/R = 1.113t + 0.303$
- 25% solids: $t/R = 1.075t + 0.327$
- 35% solids: $t/R = 1.058t + 0.260$
  (Cyclone overflows)
- 35% solids: $t/R = 1.104t + 0.291$
  (Thickener underflow)

Metal recovery cannot be maximized only by increasing flotation time but also by changing the flotation environment in the cell.

Flotation pulp density affects sulphide rougher recoveries but not the overall recoveries (sulphide plus oxide float).

Preflotation thickening impairs Konkola ore flotation response, judging from the poor overall copper recoveries obtained from the thickener underflow sample.

Konkola ore flotation follows a second order flotation rate equation.

Reference

1. Arbiter, N. *Mining Engineer*, September 1951, pp. 791–796. ◆