"Research Note"

DEVELOPING AN EXPERIMENTAL MODEL TO ESTIMATE THE DISPERSION NUMBER FOR A PILOT FLOTATION COLUMN IN SARCHESHMEH COPPER COMPLEX[*]

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Abstract– Two empirical models are presented in order to determine the dispersion number and mean residence time for the pilot scale column cell in the Sarcheshmeh copper complex. To check the accuracy of these models a series of continuous flotation tests were also performed. Mixing condition and residence time distribution were also evaluated in the column. Continuous kinetic tests and examination of the model accuracy were also performed at three different residence times. Empirical equations developed for the prediction of the dispersion number cannot be generalized to every situation, but using this model one can develop an empirical relationship to be applied for the pilot scale column in Sarcheshmeh, the result of which is in good correlation with those obtained from RTD tests. By comparing the recovery from a mixing condition and that obtained from continuous kinetic tests, the accuracy of the empirical equation was shown.

Keywords– Column flotation, dispersion number, residence time, Sarcheshmeh copper complex

1. INTRODUCTION

Recovery in the collection zone for continuous column flotation systems is a function of mean residence time, rate constant and mixing condition. It can be calculated using the following equations [1]:

$$1 - R = \frac{4A \exp(\frac{1}{2N_d})}{(1+A)^2 \exp(\frac{A}{2N_d}) - (1-A)^2 \exp(\frac{-A}{2N_d})} \tag{1}$$

$$A = (1 + 4k_{fc}\tau N_d)^{0.5} \tag{2}$$

Rate constant (k_{fc}) usually is measured using batch scale data. Mean residence time (τ) and dispersion number (N_d) can be determined by applying a tracer and following the path [2]. However in practice, empirical equations are being used to calculate (N_d). These equations can be obtained using particle size analysis. For example, using the Bakingham theory one can present an empirical model to calculate the dispersion number [3]. In this theory, it is discussed that, if there are n value and m dimensions, values can be arranged in the form of m-n dimensionless parameters. These dimensionless parameters are as follows [4]:

$$\Pi_1 = \varepsilon_g \qquad \Pi_2 = \frac{D_c}{H_c} \qquad \Pi_3 = \frac{J_l}{J_g} \qquad \Pi_4 = N_d$$

where J_g is the superficial gas velocity, J_l is the superficial liquid velocity, and H_c is the collection zone height. Therefore there is a function of the above values from which N_d can be evaluated. This function is as follows [4]:

$$F(\Pi_1, \Pi_2, \Pi_3, \Pi_4) = F\left(\varepsilon_g, \frac{D_c}{H_c}, \frac{J_l}{J_g}, N_d\right) = 0 \Rightarrow N_d = f\left(\varepsilon_g, \frac{D_c}{H_c}, \frac{J_l}{J_g}\right)$$

Also to calculate mean residence time the following equation can be applied [1]:

$$\tau = \frac{V_c}{Q_F} \tag{3}$$

V_C and Q_F are the collection zone volume and volumetric flow of the pulp [1].

2. PILOT SCALE COLUMN

In the Sarcheshmeh copper complex the pilot scale column is equipped with automatic control for measurement and for adjusting the froth depth. Manometers and flowmeters are used to determine gas holdup and flow rate. The cell is 4.7 meters in height and 26 centimeters in diameter. Two internal spargers act as bubble generators.

3. TEST WORK

In order to determine the mixing condition in the collection zone, several retention time distribution (RTD) measurements were performed using a 2 phase system (water and gas). A sodium chloride solution was injected and conductivity in underflow was measured at regular intervals. In order to analyze the results, a computer software called Rtdwen, which was developed at Sarcheshmeh, was used [5]. Input data is NaCl concentration at any time, which can be replaced by conductivity. The software then calculates mean residence time and standard deviation based on Weller and n-mixer models. The dispersion number is calculated using the following relationship [1]:

$$\sigma_r^2 = \frac{\sigma^2}{\tau^2} = 2N_d - 2N_d^2\left[1 - \exp(\frac{-1}{N_d})\right] \tag{4}$$

In which σ^2 and τ are standard deviation and mean residence time, respectively. Kinetic tests were performed in a continuous system and the recovery calculated using the following relationship [1]:

$$R_{fc} = \frac{c(f-t)}{f(c-t)} X100 \tag{5}$$

After adjusting the feed rate to stabilize the column, 3 samples were taken from feed, tail and concentrate for chemical analysis. Mean residence time was calculated using Eq. (3). Therefore, in each test, recoveries of molybdenum, copper and iron were obtained from the adjusted residence time. Eight series of tests were performed to evaluate the mixing condition and residence time distribution in the column. Operating conditions are shown in Table 1.

Table 1. Operating conditions for RTD tests

Test	Cm/s J_g	Cm/s J_B	Lpm Q_F	Cm/s J_l	(%) ε_g	(m) H_c
RTD1	0.63	0.15	18	0.565	2.8	3.7
RTD2	0.94	0.15	21	0.659	4	4
RTD3	0.94	0.15	24	0.753	4	4.3
RTD4	0.63	0.15	24	0.753	2.8	4.3
RTD5	0.63	0.15	21	0.659	2.8	4
RTD6	0.78	0.15	18	0.565	3.2	3.7
RTD7	0.94	0.15	18	0.565	4	3.7
RTD8	0.78	0.15	21	0.659	3.2	4

4. RESULTS AND DISCUSSIONS

Results and prediction models 3 and 4 are shown in Table 2.

Table 2. Results from test work and models

Test	τ (from test) (min)		σ^2 (from test) (min^2)		N_d (from test)		Model predication	
	Weller	N-mixer	Weller	N-mixer	Weller	N-mixer	N_d	(min) τ
RTD1	10.362	11.352	32.854	32.206	0.1297	0.10812	0.2250	10.085
RTD2	9.963	10.961	30.904	30.031	0.1317	0.10814	0.2507	9.345
RTD3	11.431	12.681	38.869	40.202	0.1264	0.10816	0.2184	8.79
RTD4	9.937	13.399	25.586	24.497	0.1117	0.0624	0.1678	8.79
RTD5	11.205	12.455	37.161	38.78	0.1257	0.10816	0.1926	9.345
RTD6	11.504	12.504	41.372	39.085	0.1322	0.10815	0.2606	10.085
RTD7	11.103	11.853	40.192	35.124	0.1372	0.10817	0.2928	10.085
RTD8	11.704	12.954	40.982	41.951	0.1271	0.10818	0.2231	9.345

As shown, values resulting from tests are in good correlation with those of applying models. However this is not true regarding N_d. This may be due to the experimental nature of the model used for N_d determination, which makes it unrealistic to generalize. If values for the Weller model are plotted against $\frac{V_c}{Q_F}$ (Fig. 1, diagram a, in which Y is τ Weller), a more realistic model for mean residence time can be obtained as follows:

$$\tau = 1.1467 \times \frac{V_c}{Q_F} \tag{6}$$

Using N_d, by applying Eq. (4) and also the results of RTD measurements, an empirical relationship can be developed for the evaluation of the dispersion number. For this purpose the N_d values for the testwork were plotted against $\frac{D}{H_c} \times \frac{J_g}{J_l} \times (1 - \varepsilon_g)$ (Fig. 1, diagram b), which resulted in the following equation:

$$N_d = 0.2252[\frac{D}{H_c} \times \frac{J_g}{J_l} \times (1 - \varepsilon_g)]^{0.2177} \tag{7}$$

Values calculated using Eqs. (6) and (7) are quite close to those from test works, and therefore using these models one can evaluate the dispersion number, as well as mean residence time for continuous kinetic tests within the limits of acceptable engineering accuracy. A multiplication factor in Eq. (7) is considered since the measured volume of the collection zone is less than the actual volume, which is due to the volume occupied by pipes and fittings.
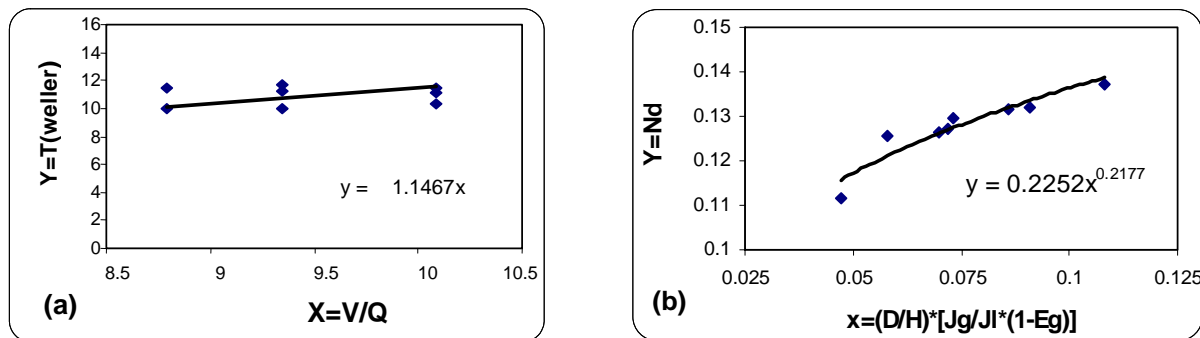
Fig. 1. Empirical data *vs*. Model, a) Mean residence time data   b) Dispersion number data

Validation of the Models: These tests were performed at three different residence times. Operating conditions, as well as residence time, were calculated using Eq. (3), and also predicted N_d, using Eq. (7), are brought in Table 3. The rate constant using batch kinetic tests equals 0.167/min. Recoveries from Eqs. (1) and (2) for different residence times were calculated and are presented in Table 4, together with the recovery from the tests.

Table 3. Operating conditions and models outcome for τ and N_d

Test	Lpm Q_g	Cm/s J_B	Lpm Q_F	Cm/s J_l	(%) ε_g	(m) H_c	τ (min)	N_d
c-s-1	30	0.94	24	0.75	4	4.3	10.080	0.1262
c-s-2	25	0.78	21	0.66	3.2	4	10.716	0.1270
c-s-3	20	0.63	18	0.56	2.8	3.7	11.564	0.1274

Table 4. Recoveries from experiments and models

Tests	R (%) Model	R (%) Test
c-s-1	76.6	77.8
c-s-2	78.3	79.2
c-s-3	80.4	81.5

5. CONCLUSIONS

1. Empirical equations developed for the prediction of the dispersion number can not be generalized to every situation. However using this model, one can develop an empirical relationship to be applied for the pilot scale column in Sarcheshmeh, the result of which is in good correlation with those obtained from RTD tests;
2. Precise volume of the cell has to be determined for application of Eq. (3);
3. Comparing the recovery from a mixing condition (model 1), and that obtained from continuous kinetic tests, the accuracy of the empirical equation can be proven.

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