

THE MIXING OF PSEUDO-PLASTIC YIELD STRESS SLURRIES : MASS TRANSFER

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ABSTRACT

The experimental system selected for the study consists of a 10L agitated vessel containing a slurry made up of chromic acid solution and a solid mixture of copper, ball clay and silica particles. The rate of dissolution of copper particles in the chromic acid suspension was studied under both Newtonian and non-Newtonian flow conditions. A UV-visible spectrophotometer was used to track the changes in concentration of potassium dichromate in the slurry. The results showed that the mass transfer rate is a function of solids concentration, particle size, temperature, slurry viscosity and agitation rate.

INTRODUCTION

Mixing of slurries are extensively used in the chemical and mineral processing industries (Nagata, 1975; Harnby et al, 1985). Although considerable research has been performed on Newtonian flow behaviour (Harriott, 1962; Nienow, 1975; Yamazaki et al, 1989), the more complex field of non-Newtonian flow (Couche, 1961), which occurs frequently in industrial processes, has only received scant mention in the literature.

The efficient mixing of pseudo-plastic yield stress slurries is of particular importance to the gold mining industry as gold extraction consists of primarily a chemical reaction occurring in a complex environment (Avraamides, 1982; Shaw and McDonough, 1982). Proper operation and control of the conditions which enhance gold leaching will lead to higher yields. Research on mixing of non-Newtonian fluids should provide a better understanding of the processes occurring within the system and the findings should be beneficial to the gold processing industry.

Owing to the toxicity of sodium cyanide solutions used in the leaching of gold and the high value of the latter, a more practical and suitable system is required. The dissolution of copper in aqueous potassium dichromate-sulphuric acid solutions was studied by Gregory and Riddiford (1960). Their study demonstrated that the rate of reaction was entirely diffusion-controlled, provided that the acidity is maintained sufficiently high. This system was used for modelling the gold/cyanide process.

This present study has concentrated on the effect of the rheological properties of the slurry on the mass transfer rate in an agitated vessel.

ANALYTICAL TECHNIQUE

Mass Transfer Coefficient

The dissolution of copper particles in sulphuric acid in the presence of potassium dichromate can be represented by the following reaction



The reaction is assumed to be pseudo first-order with respect to dichromate (Gregory and Riddiford, 1960; Madden and Nelson, 1964) as excess copper was used. The rate of disappearance of dichromate ions is given by equation (2)

$$-V \frac{dC}{dt} = k A C \quad (2)$$

where V is the volume of solution, C is the concentration of dichromate at time t , A is the total surface area of copper particles at time t , i.e. $A = A(t)$, and k is the mass transfer rate coefficient.

Integration of equation (2) leads to

$$V \ln \left(\frac{C_0}{C} \right) = k \int_0^t A(t) dt \quad (3)$$

where C_0 is the initial concentration of dichromate. Thus if concentration-time data, and $A(t)$ and V are known, the mass transfer coefficient k may be evaluated from equation (3).

Spectrophotometry

The Beer-Lambert law (Vogel et al, 1989) can be stated in equation (4)

$$A_b = \log \left(\frac{I_0}{I} \right) = \epsilon l C \quad (4)$$

where A_b is the absorbance, I_0 is the intensity of the incident beam of the monochromatic radiation, I is that of the emergent radiation which has traversed a specimen of thickness l and concentration C , ϵ is the molar absorption coefficient.

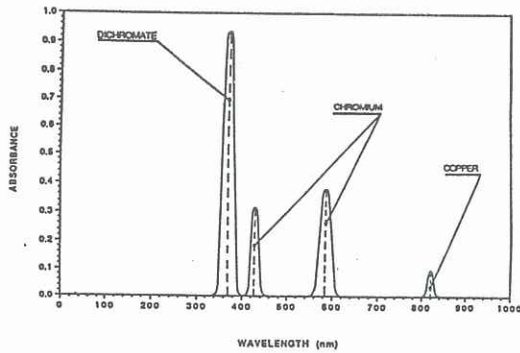


Figure 1: Analytical wavelength of ions.

If the value of ϵ and the thickness l are known, the Beer-Lambert law may be written as

$$C \propto A_b \quad (5)$$

Hence, plotting A_b as ordinate, against concentration as abscissa, a straight line will result and it serves as the calibration line for determining unknown concentrations of solutions.

In this study, there are three ions of interest in the solution, namely, dichromate, chromic(III) and cupric(II). The variation of absorbance with wavelength of incident light of the three ions was determined using a UV-visible spectrophotometer. The wavelengths for maximum absorbance by each of the ions are shown in figure 1. The analytical wavelengths obtained are: 370 nm for dichromate, 585 nm for chromium and 820 nm for copper (Cu^{2+}).

For verifying that none of the other ions interfered with the measurement of any one of them, mixtures of varying concentrations of the three species were made up ranging from 100% dichromate (0.0005 mol/L) to 100% chromium (0.005 mol/L) to 100% copper (0.01 mol/L). The absorbance of each of these solutions was measured at the analytical wavelength of 370 nm corresponding to the dichromate peak.

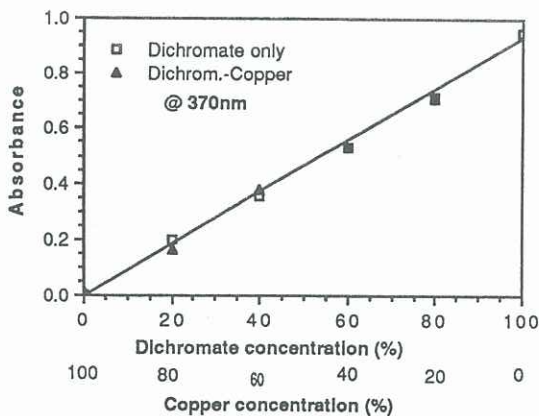


Figure 2: Effect of copper on dichromate absorbance.

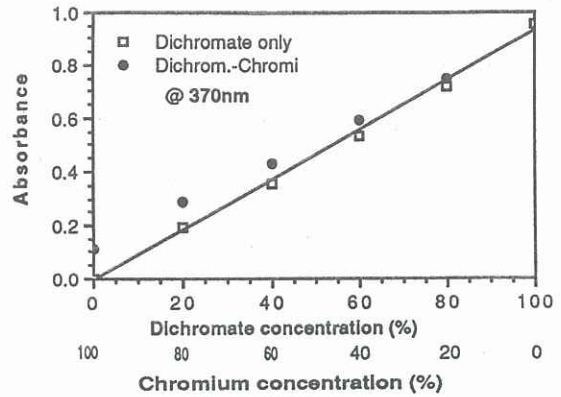


Figure 3: Effect of chromium on dichromate absorbance.

Figure 2 shows the effect of dissolved copper ion on the absorbance of dichromate ion. The results showed that copper ions did not interfere with the absorbance of dichromate. Figure 3 gives the effect of chromium ions on the absorbance of dichromate ion. The figure shows that for chromium ions greater than 40% chromium (0.002 mol/L), slightly higher absorbances resulted. However, in this study the maximum concentration of chromium in the solution is only 0.001 mol/L. Thus it can be assumed that neither copper nor chromium has any significant interference on the absorbance of dichromate at 370 nm.

The mixing system included the addition of ball clay and silica to the slurry. It was thus necessary to determine if the presence of these solids affected the absorbance of any of the ions in the solutions. It was also considered possible that the ball clay and silica could separately absorb the ions from the solution, thus changing the ionic concentration. This effect was investigated by using mixtures of ball clay and silica of different concentrations suspended in solutions containing the same three standard solutions, copper sulphate, chromium sulphate and potassium dichromate. After mixing the prepared slurries, samples were centrifuged to provide a clear supernatant fluid for spectrophotometric measurements. Figure 4 shows the results obtained in the presence of mixtures of ball clay and silica. It can be concluded that the presence of such inerts did not affect the absorbance by the various ions in solution.

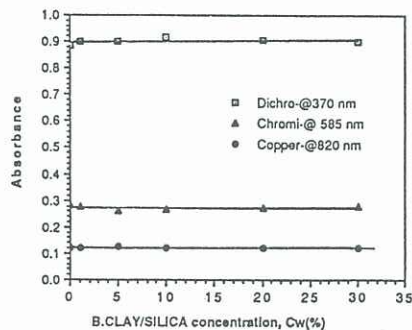


Figure 4: Effect of inert solids on absorbance of various ions.

EXPERIMENTAL

A flat-bottomed 10L cylindrical tank of 240 mm diameter fitted with a water jacket was used as the experimental mixing tank. The tank has four baffles and the agitator used in this study was a 45° pitched three-blade turbine. A more detailed layout is illustrated in figure 5.

The system used for the study consisted of dissolution of copper particles in chromic acid in the mixing tank containing ball clay and silica as inert particles. The size distribution of particles was determined by a Malvern Mastersizer. The rheology of the slurry was measured in the modified viscometer developed by Overend et al (1984).

Samples were taken every two minutes after the addition of the copper to the slurry. The sample was then transferred into a tube and centrifuged immediately to stop the reaction by separating the solids from the solution.

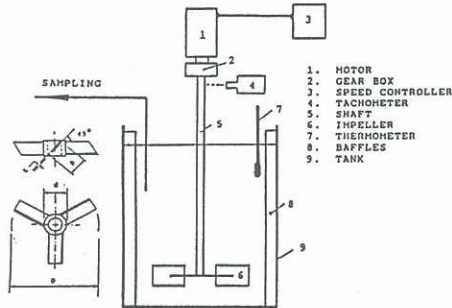


Figure 5: Experimental set-up.

RESULTS AND DISCUSSION

Effect Of Ball Clay And Silica

The rheograms in figure 6 show that a slurry with only silica resulted in Newtonian fluid behaviour as illustrated by the straight line plot. On the other hand, the slurries produced by ball clay or mixtures of ball clay and silica above 30% ball clay resulted in non-Newtonian behaviour. For slurries with higher percentages of ball clay, the viscosities were higher, resulting in lower mass transfer rates as shown in the plot of figure 7 where mass transfer coefficient is plotted against percentage clay in the solid mixture.

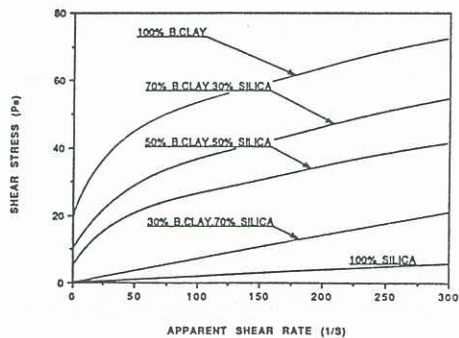


Figure 6: Rheograms, (solids concentration by mass, $C_w = 30\%$).

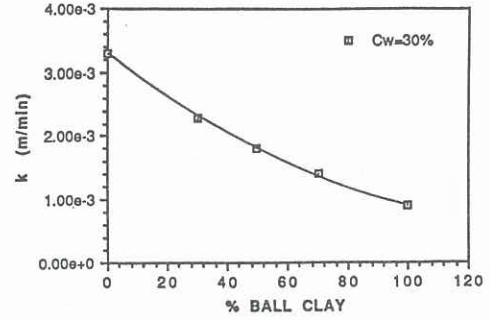


Figure 7: Effect of ball clay content in the slurry on the mass transfer coefficient.

Effect Of Solid Concentration

Figure 8 shows the effects of solids concentration of up to 50% solids on the mass transfer coefficients of the slurry system. Three solid mixtures, one is pure silica, another pure ball clay and a third consisting of 70% silica and 30% ball clay were used. The mass transfer coefficients were not significantly reduced when pure silica was used and the slurry was Newtonian. However, in the presence of 30% ball clay when the slurries were non-Newtonian, the mass transfer coefficients were significantly reduced as illustrated in figure 8.

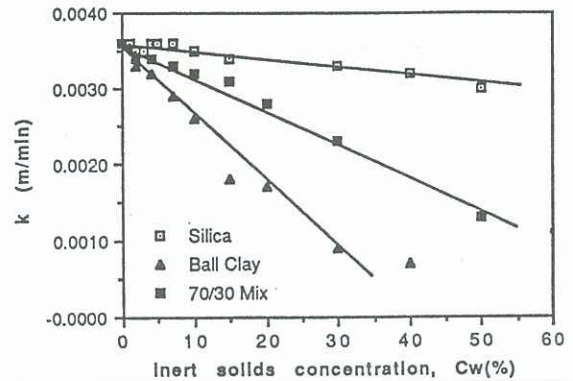


Figure 8: Effect of solids concentration on the mass transfer coefficient (Temperature = 19°C, $N = 480$ rpm).

Effect Of Mixing Speed

Figure 9 shows the effect of impeller speeds on the mass transfer coefficient for various slurries containing 0%, 20%, 40% and 50% inert solids of % ball clay and % silica. As was expected, an increase of inert solids in the slurry resulted in lower mass transfer rates. At lower impeller speeds, the mass transfer coefficients increased significantly when the impeller speeds were increased indicating the importance of diffusion on mass transfer at these lower impeller speeds. However, at higher impeller speeds, when turbulence was established, the increase in mass transfer became more moderate as shown by the lower slopes of the plots in figure 9 at higher impeller speeds.

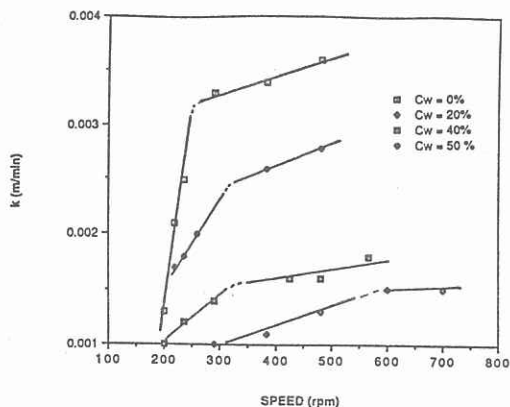


Figure 9: Effect of impeller speed on the mass transfer coefficient.

Effect Of Mean Inert Particle Size

The effect of mean inert particle size on the mass transfer coefficient is shown in figure 10. At inert solids concentration of 40% by mass, the effect of inert particle size was negligible. As the inert solids concentration was increased to 45% and 50%, coarser inert particles resulted in higher mass transfer rates. This further confirmed that mass transfer is diffusion controlled as finer particles produced higher viscosities.

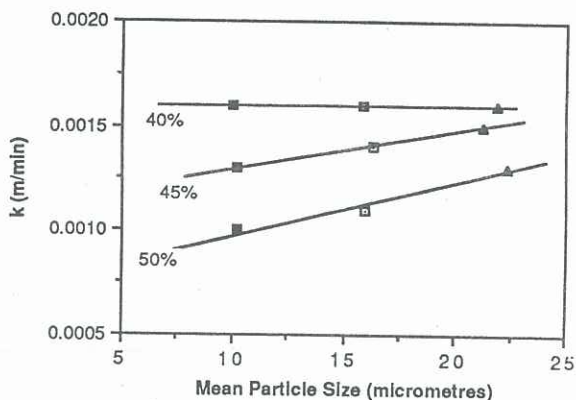


Figure 10: Effect of mean inert particle size on the mass transfer coefficient (Temp. = 19°C, N = 480 rpm).

Effect Of Temperature

The temperature dependence of the reaction is shown in figure 11. The exponential relationships between mass transfer coefficients and temperature agreed with that expected from Arrhenius law for rate processes. The three parallel lines produced for different solids concentrations indicated that the activation energy for the reaction are approximately equal and is independent of solids concentration. The activation energies obtained from the slope is 14.3 kJ/mol which agreed with the value noted by Gregory and Riddiford (1960).

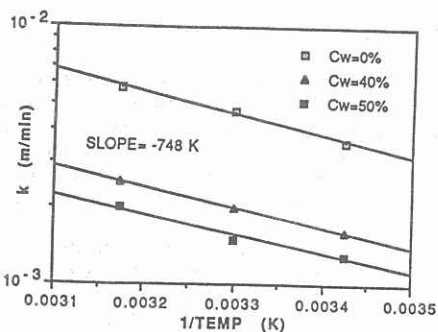


Figure 11: Effect of temperature on the mass transfer coefficient (N = 480 rpm).

CONCLUSIONS

- 1.- A spectrophotometric technique was developed as the analytical tool for the study of dissolution of copper particles in chromic acid solution.
- 2.- The mass transfer coefficients obtained in the study were found to be: (i) lower at higher solids concentration, (ii) higher at higher impeller speeds, (iii) lower for small mean inert particle sizes for solids concentrations greater than 40%, and (iv) lower as the slurry viscosity increases.
- 3.- The dissolution of copper is found to be diffusion controlled.
- 4.- The activation energy for copper dissolution in chromic acid is 14.3 kJ/mol.

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