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Model for computational analysis of dissolved haematite and heat absorbed by oxalic acid solution during leaching of iron oxide ore

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Abstract

Models for computational analysis of the concentration of dissolved haematite and heat absorbed by oxalic acid solution during leaching of iron oxide ore have been derived. It was found that optimization of the weight input of iron oxide ore can be achieve by comparing the concentrations of dissolved haematite at different weights of iron oxide used, with the view to identifying the optimum weight of iron oxide ore that gives the maximum dissolution of Fe_2O_3.The values of Q obtained from both experiment and model agree that the leaching of iron oxide ore using oxalic acid solution is an endothermic process and hence heat energy is absorbed by the leaching solution and of positive values. The respective deviations of the model-predicted values of $\%Fe_2O_3$ and Q from those of the corresponding experimental values is less than 39% which is quite within the acceptable range of deviation limit of experimental results. The constants of proportionality K and K_C associated with the derived models; $\%Fe_2O_3 = K(\gamma/\mu)$ and $Q = K_C \mu$ were evaluated to be 0.0683 and 66.88 respectively.

Keywords: Model; Dissolved haematite; Heat absorbed; Iron oxide ore; Oxalic acid; Leaching

1. Introduction

It has been agreed by researchers (Panias et al., 1996) that the optimum pH for dissolving iron oxide is pH 2.5–3.0. The solution pH governs the distribution of various oxalate ions in the leach system. Below pH 1.5, oxalic acid exists mainly as $H_2C_2O_4$, whereas HC_2O_4 is the most predominant species at pH 2.5 – 3.0.

The presence of Fe^{2+} was found to significantly enhance the leaching of iron extraction from silica sand at a temperature even as low as 25°C (Taxiarchour, et al., 1997). Ferrous oxalate however is oxidized quickly by air during the dissolution and in general an induction period of a few hours was observed unless a strong acidic environment (<pH 1) or an inert atmosphere is maintained. Maintaining the high level of ferrous oxalate in the leach liquor using an inert gas, was found to enhance the reaction kinetics.

Final pH of leaching solution has been found to depend on the leaching time, initial pH for the leaching solution and the leaching temperature (Pinches, 1975; Nwoye, 2008).

The aim of this work is to derive models for computational analysis of the concentration of dissolved haematite and heat absorbed by oxalic acid solution during leaching of Itakpe iron oxide ore.

2. Model

The solid phase (ore) is assumed to be stationary, contains the un-leached iron remaining in the ore. Hydrogen ions from the oxalic acid attack the ore within the liquid phase in the presence of oxygen.

2.1. Model formulation

Experimental data obtained from studies carried out were used for this work. Results of the experiments carried out as presented in Nwoye and Job, 2005 and shown in Table 1 indicate that;

$$\%Fe_2O_3 \propto \left(\frac{\gamma}{\mu}\right) \tag{1}$$

Introducing a constant of proportionality K into equation (1)

$$\%Fe_2O_3 = K\left(\frac{\gamma}{\mu}\right) \tag{2}$$

Also results of experiments presented in Nwoye and Job, 2005 and shown in Table 2 indicate that;

$$Q \alpha \mu \quad (3)$$

Introducing constant of proportionality K_C into equation (3)

$$Q = K_C \mu \quad (4)$$

Equations (2) and (4) are the derived models.

where

$\%Fe_2O_3$ = Concentration of dissolved haematite in oxalic acid solution.

γ = Final pH of the leaching solution at time t at which $\%Fe_2O_3$ was obtained.

μ = Weight of iron oxide added into the oxalic acid leaching solution (g)

K = Constant of proportionality associated with haematite dissolution

K_C = Constant of proportionality associated with heat absorption

Q = Quantity of heat absorbed by oxalic acid solution during the leaching process (J)

The values of K and K_C from equations (2) and (4) were calculated using the samples A (from Table 1) and B (from Table 2) respectively. These samples were chosen at random since all samples from each table were subjected to the same experimental process conditions. Both values were obtained by substituting the values of γ/μ and $\%Fe_2O_3$ for sample A into equation (2) and also Q and μ for sample B into equation (4) respectively.

Table 1.
Variation of concentrations of dissolved haematite with final pH and weight input of iron oxide ore

Sample code	$\%Fe_2O_3$	μ	γ	$\frac{\gamma}{\mu}$
A	0.0800	6	7.03	1.1717
B	0.0520	10	6.90	0.6900
C	0.0220	22	6.90	0.3136
D	0.0160	26	6.90	0.2654
E	0.0126	30	6.92	0.2307
F	0.0112	34	6.91	0.2032
G	0.0110	38	6.91	0.1818

Table 2.
Variation of quantity of heat energy absorbed by oxalic acid solution with the weight-input of iron oxide ore.

Sample code	μ	Q
A	6	451.44
B	10	668.80
C	12	845.20
D	14	961.40
E	18	978.12
F	22	1228.92
G	24	1246.55
H	26	1258.18

3. Boundary and initial conditions.

Consider iron oxide ore in cylindrical flask 30cm high containing leaching solution of oxalic acid. The leaching solution is stationary i.e (non-flowing). The flask is assumed to be initially free of attached bacteria. Initially, atmospheric levels of oxygen are assumed. Varying weights of iron oxide ore; (6-38)g and (6-26)g were used for models associated with Fe_2O_3 and Q respectively. The final pH values of the leaching solutions were all taken after 30 minutes of starting the process for model associated with Fe_2O_3 dissolution while the initial pH of all samples were kept at 6.9 for model associated with Q. A constant leaching temperature of 30°C was used. Ore grain size; 150µm, volume of leaching solution; 0.1 litre and oxalic acid concentration; 0.1mol/Litre were used. These and other process conditions are as stated in the experimental techniques(Nwoye and Job, 1995).

The boundary conditions are: atmospheric levels of oxygen (since the cylinder was open at the top) at the top and bottom of the ore particles, a zero gradient for the liquid scalar are assumed and also for the gas phase at the top of the particles. The leaching solution is stationary. The sides of the particles are taken to be symmetries.

4. Model validation

The models formulated were validated by direct analysis and comparism of the Q and $\%Fe_2O_3$ values obtained from model and those from corresponding experimental values (Nwoye and Job, 2005) for equality or near equality. $\%Fe_2O_3$ and Q values from model were obtained by substituting the values of K, γ and μ for the other set of experimental data (B-G) into the model in equation (2) and also substituting the values of K_C and μ for experimental data set (A-H) except B into the model in equation (4) .

Analysis and comparism between these data reveal deviations of model data from experimental data. This is attributed to the non-consideration of the surface properties of the iron oxide ore and the physiochemical interactions between the ore and leaching solution which play vital roles during leaching.

These deviations necessitated the introduction of correction factor to bring the model Q and $\%Fe_2O_3$ values to exactly that of experimental Q and $\%Fe_2O_3$ values. Deviation (D_v) of model Q and $\%Fe_2O_3$ from experimental Q and $\%Fe_2O_3$ is given by

$$D_v = \frac{D_p - D_E}{D_E} \times 100 \quad (5)$$

where D_p = Predicted data from model

D_E = Experimental data (Nwoye and Job, 2005)

Correction factor (C_f) is the negative of the deviation ie.

$$C_f = -D_v \quad (6)$$

Therefore,

$$C_f = -100\left(\frac{Dp - DE}{DE}\right) \quad (7)$$

Based on the foregoing, addition of the values of C_f to the model data gives exactly the corresponding experimental values.

5. Results and Discussion

A comparism of the experimental Q and $\%Fe_2O_3$ values and those of the model show model values very much within the range of the experimental values. Results of this comparism are presented in Tables 3 and 4.

The dissolved haematite associated model computes the concentration of dissolved haematite when the final pH of the leaching solution and the weight of iron oxide ore added are known. Also Q associated model computes the heat absorbed by oxalic acid solution during the leaching process when the weight-input of iron oxide ore is known.

Furthermore, a tabular presentation of $\%Fe_2O_3$ dissolved and the weight input of iron oxide ore as shown in Table 3, shows that the model can be used also to optimize the weight input of iron oxide ore to be used for the leaching process. Here, the $\%Fe_2O_3$ dissolved for varied weights of iron oxide ore input are considered to know the weight that gives the maximum dissolution of Fe_2O_3. That weight becomes the optimum value. In Table 3, both the model and experimental $\%Fe_2O_3$ values are maximum at a weight input of 10g. This implies that when 10g of iron oxide ore and its associated final pH of leaching solution are substituted into the model equation (2), maximum dissolution of Fe_2O_3 is obtained.

The values of Q obtained from both the experiment (Nwoye and Job, 2005) and model show that the leaching of iron oxide ore using oxalic acid solution is an endothermic process and hence heat energy is absorbed by the leaching solution and of positive values (Table 4). The respective deviations of the model-predicted values of $\%Fe_2O_3$ and Q from those of the corresponding experimental values is less than 39% which is quite within the acceptable range of deviation limit of experimental results (Tables 3 and 4).

The values of Q, $\%Fe_2O_3$ and γ depend on the process parameters such as ore weight input, ore grain size, initial pH of leaching solution, leaching temperature, leaching time and ore mineralogy (Nwoye and Job, 2005). Therefore, K and K_C which depend on $\%Fe_2O_3$ and γ and Q respectively, are expected to depend on the process parameters highlighted. The values of K and K_C as evaluated from equations (2) and (4) are 0.0683 and 66.88 respectively.

Table 3
Comparism of percentage dissolved haematite as predicted by model and as obtained from experiment (Nwoye and Job, 2005)

Sample code	μ	$\%Fe_2O_{3M}$	$\%Fe_2O_{3exp}$	Dv (%)	C_f (%)
B	10	0.0471	0.0520	-9.42	+9.42
C	22	0.0214	0.0220	-2.73	+2.73
D	26	0.0181	0.0160	+13.13	-13.13
E	30	0.0158	0.0126	+25.40	-25.40
F	34	0.0139	0.0112	+24.11	-24.11
G	38	0.0124	0.0110	+12.73	-12.73

Table 4
Comparism of heat absorbed by oxalic acid solution as predicted by model and as obtained from experiment (Nwoye and Job, 2005)

Sample code	Q_M	Q_{exp}	Dv(%)	C_f(%)
A	451.44	401.28	-11.11	+11.11
C	845.20	802.56	-5.04	+5.04
D	961.40	936.32	-2.60	+2.60
E	978.12	1203.84	+23.08	-23.08
F	1228.92	1471.36	+19.73	-19.73
G	1246.55	1605.12	+28.76	-28.76
H	1258.18	1738.88	+38.21	-38.21

where $\%Fe_2O_{3M} = \%Fe_2O_3$ predicted from model
$\%Fe_2O_{3exp} = \%Fe_2O_3$ from experiment.
Q_{exp} = Heat absorbed by oxalic acid solution during the leaching process as obtained in the experiment (J)
Q_M = Heat absorbed by oxalic acid solution during the leaching process as predicted by the model. (J)

6. Conclusions

The model (equation (2)) computes the concentration of Fe_2O_3 dissolved relative to the weight of iron oxide ore (used for the leaching process) and final pH of the leaching solution. The other model (equation (4)) computes the heat absorbed by oxalic acid solution during the process.

Q values obtained from both the experiment (Nwoye and Job, 2005) and model show that the leaching of iron oxide ore using oxalic acid solution is an endothermic process and hence heat energy is absorbed by the leaching solution and of positive values.

The respective deviations of the model-predicted values of $\%Fe_2O_3$ and Q from those of the corresponding experimental values is less than 39% which is quite within the acceptable range of deviation limit of experimental results.

Optimization of weight input of iron oxide ore associated with the maximum dissolution of haematite during the leaching process was achieved using the model.

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