

## Model for Quantitative Analysis of Dissolved Haematite Relative to the Initial Solution pH during Leaching of Iron Oxide Ore in Oxalic Acid

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### Abstract

Model for quantitative analysis of dissolved haematite (relative to the initial solution pH) during leaching of iron oxide ore in oxalic acid solution has been derived. The model;

$$\%Fe_2O_3 = \left( \frac{N}{N_c} \left( \frac{1}{\gamma} \right) \right)$$

was found to calculate the concentration of dissolved haematite being dependent on the values of the initial leaching solution pH measured during the leaching process. The respective positive and negative deviation of the model-predicted values of %Fe<sub>2</sub>O<sub>3</sub> (dissolved) from the corresponding experimental values was found to be less than 11% which is quite within the acceptable range of deviation limit of experimental results. The values of the assumed coefficients of dilution (N) and dissolution of haematite (N<sub>c</sub>) in oxalic acid solution were calculated to be 197.7503 and 700.0618 respectively. [Researcher. 2009;1(4):7-14]. (ISSN: 1553-9865).

**Keywords:** Model, Dissolved Haematite, Solution pH, Oxalic Acid, Iron Oxide Ore.

### 1. Introduction

Past reports [1,2] have shown that at a temperature as low as 25°C, the presence of Fe<sup>2+</sup> significantly enhances the leaching of iron extraction from silica sand. Ferrous oxalate is quickly oxidized by air during dissolution, giving room for an induction period of a few hours unless a strong acidic environment (<pH 1) or an inert atmosphere is maintained. It has been found [3] that maintaining the high level of ferrous oxalate in the leach liquor using an inert gas enhance the reaction kinetics. It is believed that during this process, removal of phosphorus from the iron compound and subsequent dissolution of the phosphorus oxide formed were effected.

It has been reported [4] 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<sub>2</sub>C<sub>2</sub>O<sub>4</sub>, whereas HC<sub>2</sub>O<sub>4</sub> is the most predominant species at pH 2.5 – 3.0.

Studies [5,6] have shown that the final pH of leaching solution depend on the leaching time, initial pH for the leaching solution and the leaching temperature.

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 [7]. These models are:

$$\%Fe_2O_3 = K (\gamma/\mu) \quad (1)$$

$$Q = K_c \mu \quad (2)$$

Where

%Fe<sub>2</sub>O<sub>3</sub> = Concentration of dissolved haematite in oxalic acid solution.

γ = Final pH of the leaching solution at time t at which %Fe<sub>2</sub>O<sub>3</sub> was obtained.

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

K = Constant of proportionality associated with haematite dissolution

K<sub>c</sub> = Constant of proportionality associated with heat absorption

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

Nwoye [7] found that optimization of the weight input of iron oxide ore could be achieved using the model; (%Fe<sub>2</sub>O<sub>3</sub> = K (γ/μ) ) by comparing the concentrations of dissolved haematite at different weights input of the iron oxide ore, with the view to identifying the optimum weight input of iron oxide ore that

gives the maximum dissolution of  $\text{Fe}_2\text{O}_3$ . The model also indicates that the concentration of haematite dissolved during the leaching process is directly proportional to the final pH of the leaching solution and inversely proportional to the weight input of the iron oxide ore.

It was also found [7] that values of  $Q$  obtained from both the experiment and model ( $Q = K_C \mu$ ) agree to the fact that leaching of iron oxide ore using oxalic acid solution is an endothermic process, hence the absorbed positive heat energy by the leaching solution. The quantity of heat energy absorbed by the oxalic acid solution during the leaching process (as calculated from the model;  $Q = K_C \mu$ ) was found to be directly proportional to the weight input of the iron oxide ore. These results were obtained at initial pH 6.9, average grain size of  $150\mu\text{m}$  and leaching temperature of  $30^\circ\text{C}$ . The constants of proportionality  $K$  and  $K_C$  associated with the respective derived models were evaluated to be 0.0683 and 66.88 respectively.

Nwoye [8] derived a model for predicting the time for dissolution of pre-quantified concentration of phosphorus during leaching of iron oxide ore in oxalic acid solution as:

$$\tau = \text{Log} \left( \frac{\left( \frac{P^{1/4}}{1.8} \right)}{\text{Log}T} \right) \quad (3)$$

Where

$T$  = Leaching temperature ( $^\circ\text{C}$ ) in the experiment [9], taken as specified leaching temperature ( $^\circ\text{C}$ ) aiding the expected dissolution of phosphorus .

$N=1.8$ (Dissolution coefficient of phosphorus in oxalic acid solution during leaching of iron oxide ore) determined in the experiment [9].

$P$  = Concentration of dissolved phosphorus (mg/Kg) in the experiment [9], taken as pre-quantified concentration of phosphorus expected to dissolve after a leaching time  $t$  (mg/Kg) in the model.

$\tau$  = Leaching time (sec.) in the experiment [9], taken as time for dissolution of the pre-quantified concentration of phosphorus (hrs) in the model.

The model was found to depend on a range of specified leaching temperatures ( $45\text{-}70^\circ\text{C}$ ) for its validity. It was found [9] that the time for dissolution of any given concentration of phosphorus decreases with increase in the leaching temperature (up to  $70^\circ\text{C}$ ), at initial pH 5.5 and average grain size of  $150\mu\text{m}$ .

Nwoye et al. [10] also formulated a model for predicting the concentration of phosphorus removed during leaching of iron oxide ore in oxalic acid solution. It was found to predict the removed phosphorus concentration, with utmost dependence on the final pH of the leaching solution and weight input of the iron oxide ore. The model indicates that the concentration of phosphorus removed is inversely proportional to the product of the weight input of the iron oxide ore and the final pH of the leaching solution. Process conditions considered during the formulation of the model [10] include: leaching temperature of  $25^\circ\text{C}$ , initial solution pH 5.5 and average ore grain size;  $150\mu\text{m}$ ).

Biological processes for phosphorus removal have also been evaluated based on the use of several types of fungi, some being oxalic acid producing. Anyakwo and Obot [11] recently presented their results of a study on the use of *Aspergillus niger* and their cultural filtrates for removing phosphorus from Agbaja (Nigeria) iron oxide ore. The results of this work [11] show that phosphorus removal efficiencies at the end of the 49 days of the leaching process are 81, 63 and 68% for 5, 100 and 250 mesh grain sizes respectively.

An attempt has been made in the past [12] to leach Itakpe iron oxide ore using oxalic acid solution in order to determine the maximum concentration of phosphorus that is removable. Results of chemical analysis of the ore indicate that the percentage of phosphorus in the ore is about 1.18%, which from all indication is quite high and likely to affect adversely the mechanical properties of the steel involved; hence the need for dephosphorization. It was reported [12] that phosphorus can be removed from iron oxide ore through a process associated with hydrometallurgy. Phosphorus was removed at a temperature of  $25^\circ\text{C}$  and initial solution pH 2.5, leading to the dissolution of the phosphorus oxide formed. This involved using acid leaching process to remove phosphorus from the iron oxide ore in readiness for steel making process.

Nwoye [13] derived a model for evaluating the final pH of the leaching solution during leaching of iron oxide ore in oxalic acid solution. The model evaluates the pH value as the sum of two parts, involving the % concentrations of Fe and  $\text{Fe}_2\text{O}_3$  dissolved. The model can be expressed as;

$$\gamma = 0.5 \left( \frac{K_1}{\% \text{Fe}} + \frac{K_2}{\% \text{Fe}_2\text{O}_3} \right) \quad (4)$$

Where

$K_1$  and  $K_2$  = dissolution constants of Fe and  $Fe_2O_3$  respectively.

$\gamma$  = final pH of leaching solution (after time t).

It was also found that the model [13] could predict the concentration of Fe or  $Fe_2O_3$  dissolved in the oxalic acid solution at a particular final solution pH by taking Fe or  $Fe_2O_3$  as the subject formular. The prevailing process conditions under which the model works include: leaching time of 30mins., constant leaching temperature of 30°C, average ore grain size; 150 $\mu$ m and 0.1M oxalic acid.

Nwoye [14] has reported that the heat absorbed by oxalic acid solution during leaching of iron oxide ore can be predicted using the model he derived which works under the process condition; initial pH 6.9, average ore grain size; 150 $\mu$ m and leaching temperature; 30°C. The model [14] can be stated as

$$Q = K_N \left( \frac{\gamma}{\%Fe_2O_3} \right) \quad (5)$$

Where

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

$\gamma$  = Final pH of the leaching solution (at time t).

$\%Fe_2O_3$  = Concentration of haematite dissolved in oxalic acid solution during the leaching process.

$K_N$  = 4.57 (Haematite dissolution constant in oxalic acid solution) determined in the experiment [14].

Nwoye [14] carried out further work on the model using the same process conditions and observed that on re-arranging the model as;

$$\%Fe_2O_3 = K_N \left( \frac{\gamma}{Q} \right) \quad (6)$$

the concentrations of haematite predicted deviated very insignificantly from the corresponding experimental values. In this case, the value of Q was calculated by considering the specific heat capacity of oxalic acid. Values of heat absorbed by the oxalic acid solution during the leaching of iron oxide ore as predicted by the model [14] agree with the experimental values that the leaching process is endothermic. This is because all the predicted values of the heat absorbed by the oxalic acid solution were positive. The model shows that the quantity of heat absorbed by oxalic acid solution during the leaching process is directly proportional to the final pH of the solution and inversely proportional to the concentration of haematite dissolved.

Model for evaluation of the concentration of dissolved phosphorus (relative to the final pH of the leaching solution) during leaching of iron oxide ore in oxalic acid solution has been derived [15]. It was observed that the validity of the model is rooted in the relationship  $\ln P = N/\alpha$  where both sides of the expression are approximately equal to 4. The model;  $P = e^{(12.25/\alpha)}$  is dependent on the value of the final pH of the leaching solution which varies with leaching time. In all, the positive or negative deviation of the model-predicted phosphorus concentration from its corresponding value obtained from the experiment was found to be less than 22%.

Temperature measured at the reaction sites gives an idea of whether the reaction is speeding up or stopping especially when it is measured consistently.

It has been reported [16] that the temperature of a reaction system plays the major role in controlling the rate of the reaction.

Past report [17] has shown that measurement of the temperature of a reaction system consistently shows whether the reaction involved is endothermic or exothermic.

Nwoye [18] derived a model for the computational analysis of the solution temperature during leaching of iron oxide ore in hydrochloric acid solution. The model is expressed as:

$$T = e^{(8.9055/\gamma)} \quad (7)$$

Where

T = Solution temperature during leaching of iron oxide ore using hydrochloric acid. (°C)

N = 8.9055 (pH coefficient for hydrochloric acid solution during leaching of iron

oxide ore) determined in the experiment [18].

$\gamma$  = Final pH of the leaching solution at the time t when the solution temperature is evaluated.

The model is dependent on the value of the final pH of the leaching solution which was found to also depend on the concentration of iron dissolved in the acid. The prevailed process conditions on which the validity of the model depended on include: initial pH 2.5, leaching time; 30 minutes, leaching temperature; 25°C, average ore grain size; 150 $\mu$ m and hydrochloric acid concentration at 0.1mol/litre.

Nwoye et al [19] derived a model for predicting the concentration of dissolved iron during leaching of iron oxide ore in sulphuric acid solution. The model is stated as;

$$\%Fe = 0.35(\alpha/T)^3 \quad (8)$$

Where

T = Solution temperature at the time t, when the concentration of dissolved iron is evaluated. ( $^{\circ}$ C)

0.35= (pH coefficient for iron dissolution in sulphuric acid solution during the leaching process) determined in the experiment [19].

$\alpha$  = Final pH of the leaching solution at the time t, when the concentration of dissolved iron is evaluated.

The model (formulated at conditions; leaching temperature of 25 $^{\circ}$ C, initial solution pH 5.0 and average grain size; 150 $\mu$ m) is dependent of the final pH and temperature of the leaching solution. The model shows that the concentration of iron dissolved during the leaching process is directly proportional to the third power of the ratio of final leaching and temperature.

The aim of this work is to derive a model for quantitative analysis of dissolved haematite relative to the initial solution pH during leaching of Itakpe (Nigeria) iron oxide ore in oxalic acid solution.

## 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 research work [20] carried out at SynchroWell Research Laboratory, Enugu were used for this work.

Results of the experiment as presented in report [20] and used for the model formulation are as shown in Table 1.

Computational analysis of the experimental data [20] shown in Table 1, gave rise to Table 2 which indicate that;

$$\gamma \propto \left( \frac{1}{D} \right) \quad (9)$$

$$D \propto \%Fe_2O_3 \quad (10)$$

$$D = 1000\%Fe \quad (11)$$

Introducing constants of proportionality into equations (9) and (10)

$$\gamma = \left( \frac{N}{D} \right) \quad (12)$$

Similarly equation (10) becomes

$$D = N_c (\%Fe_2O_3) \quad (13)$$

Table 1 indicates that D is constant for the concentrations of dissolved iron and haematite Therefore, equating equations (11) and (13);

$$1000\%Fe = N_c (\%Fe_2O_3) \quad (14)$$

$$\left( \frac{\%Fe}{\%Fe_2O_3} \right) = \left( \frac{N_c}{1000} \right) \quad (15)$$

Substituting equation (11) into (12);

$$\gamma = \left( \frac{N}{1000\%Fe} \right) \quad (16)$$

From equation (16),

$$\%Fe = \left( \frac{N}{1000} \right) \times \left( \frac{1}{\gamma} \right) \quad (17)$$

Substituting equation (17) into (15);

$$\left( \frac{N}{1000\gamma\%Fe_2O_3} \right) = \left( \frac{N_c}{1000} \right) \quad (18)$$

Rearranging and evaluating equation (18) for  $\%Fe_2O_3$

$$\%Fe_2O_3 = \left( \frac{N}{N_c} \left( \frac{1}{\gamma} \right) \right) \quad (19)$$

Where  $\gamma$  = Initial pH of the leaching solution at time  $t = 0$ .

N= Constant of proportionality assumed as the coefficient of dilution for oxalic acid solution.

$N_c$ = Constant of proportionality assumed as the dissolution coefficient of haematite in oxalic acid solution.

D= Dilution factor

$\%Fe$  = Concentration of dissolved iron in oxalic acid during the leaching process.

$\%Fe_2O_3$  = Concentration of dissolved haematite in oxalic acid during the leaching process.

Equation (19) is the derived model.

The values of the constants N and  $N_c$  were calculated from equations (12) and (13) respectively (using Table 1) for each of the Samples (A-G) and average value of each constant taken since all samples were subjected to the same experimental process conditions (except initial solution pH). This was done by substituting the values of  $\gamma$ , D and D,  $\%Fe_2O_3$  obtained (after a leaching time of 180mins.) for Samples A-G into equations (12) and (13) respectively.

**Table 1: Variation of concentration of dissolved haematite with initial solution pH.[20]**

Sample Code	$\%Fe_2O_3$	$\%Fe$	D	$\gamma$
A	0.044	0.031	31.166	5.88
B	0.045	0.032	31.633	5.71
C	0.049	0.034	34.012	6.00
D	0.041	0.029	28.500	6.32
E	0.055	0.039	38.591	5.74
F	0.050	0.035	35.168	6.13
G	0.050	0.035	34.745	5.73

**Table 2: Values of assumed coefficients of dilution and dissolution of haematite in oxalic acid.**

Sample Code	N	N <sub>c</sub>
A	183.26	708.3182
B	180.62	702.9556
C	204.07	694.1224
D	180.12	695.1220
E	221.51	701.6545
F	215.58	703.3600
G	199.09	694.9000

Average N = 197.7503 , Average N<sub>c</sub> = 700.0618

### 3. Boundary and Initial Condition

Consider iron 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. Constant weight 10g of iron oxide ore was used. The range of initial pH of leaching solution used; 5.71-6.32 and leaching time; 180 minutes were used. A constant leaching temperature of 25°C was used. Average ore grain size; 150µm, and oxalic acid concentration; 0.1mol/litre was used. These and other process conditions are as stated in the experimental technique [20]. 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 in the liquid and gas phases respectively. At the bottom of the 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 formulated model was validated by direct analysis and comparison of %Fe<sub>2</sub>O<sub>3</sub> values predicted by model and the corresponding experimental %Fe<sub>2</sub>O<sub>3</sub> values for equality or near equality. Analysis and comparison between these %Fe<sub>2</sub>O<sub>3</sub> values reveal deviations of model-predicted %Fe<sub>2</sub>O<sub>3</sub> values from the corresponding experimental values. This is believed to be due to the fact that the surface properties of the ore and the physiochemical interactions between the ore and leaching solution which were found to have played vital roles during the leaching process [20] were not considered during the model formulation. This necessitated the introduction of correction factor, to bring the model-predicted %Fe<sub>2</sub>O<sub>3</sub> values to those obtained from the experiment (Table 3).

Deviation (Dv) (%) of model-predicted %Fe<sub>2</sub>O<sub>3</sub> values from the corresponding experimental %Fe<sub>2</sub>O<sub>3</sub> values is given by

$$Dv = \left( \frac{Mv - Ev}{Ev} \right) \times 100 \quad (20)$$

Where Mv = Predicted %Fe<sub>2</sub>O<sub>3</sub> values from model  
Ev = %Fe<sub>2</sub>O<sub>3</sub> values obtained from experimental data

Correction factor (Cf) is the negative of the deviation i.e

$$Cf = -Dv \quad (21)$$

Therefore

$$Cf = -100 \left( \frac{Mv - Ev}{Ev} \right) \quad (22)$$

Introduction of the corresponding values of Cf from equation (22) into the model gives exactly the corresponding experimental %Fe<sub>2</sub>O<sub>3</sub> value [20].

### 5. Results and Discussion

The derived model is equation (19). A comparison of the values of %Fe<sub>2</sub>O<sub>3</sub> from the experiment and those from the model shows minimum deviation hence depicting the reliability and validity of the model. This is shown in Table 3. The respective deviations observed were less than 11% which is quite within the acceptable range of deviation of experimental results. The values of the assumed coefficients of dilution

(N) and dissolution of haematite ( $N_c$ ) in oxalic acid were evaluated to be 197.7503 and 700.0618 respectively.

**Table 3: Comparison between concentrations of dissolved iron as predicted by model and as obtained from experiment [20].**

$\%Fe_2O_{3exp}$	$\%Fe_2O_{3M}$	Dv (%)	Cf (%)
0.044	0.0480	+9.09	-9.09
0.045	0.0495	+10.00	-10.00
0.049	0.0471	-3.88	+3.88
0.041	0.0447	+9.02	-9.02
0.055	0.0492	-10.55	+10.55
0.050	0.0461	-7.80	+7.80
0.050	0.0493	-1.40	+1.40

Where

$\%Fe_2O_{3exp}$  =  $\%Fe_2O_3$  values from experiment [20]

$\%Fe_2O_{3M}$  =  $\%Fe_2O_3$  values predicted by model.

## 6. Conclusion

The model calculates the concentration of dissolved haematite relative to the initial solution pH during oxalic acid leaching of Itakpe (Nigeria) iron oxide ore. The respective deviations of the model-predicted  $\%Fe_2O_3$  values from the corresponding experimental  $\%Fe_2O_3$  values were less than 11% which is quite within the acceptable range of deviation limit of experimental results.

Further works should incorporate more process parameters into the model with the aim of reducing the deviations of the model-predicted  $\%Fe_2O_3$  values from those of the experiment.

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