

Response Evaluation of Iron Extraction to the Oxidative Action of Added Powdered Potassium Chlorate Relative to As-Beneficiated Iron Content

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ABSTRACT

Response evaluation of iron extraction to the oxidative action of added powdered potassium chlorate was carried out relative to the as-beneficiated iron content. A model was derived, validated and used as a tool for the evaluation. The model is expressed as;

$$\zeta = -0.0008 \ln \theta - 0.00001\gamma + 0.0039$$

The validity of the two-factorial model was found to be rooted on the expression $\zeta - 0.0039 = -0.0008 \ln \theta - 0.00001\gamma$ where both sides of the expression are correspondingly approximately equal. Statistical analysis of the extracted iron concentration as obtained from experiment and derived model for each value of the mass-input of KClO_3 shows standard errors of 5.19×10^{-5} and 8.45×10^{-6} % respectively. Furthermore, extracted iron concentration per unit mass-input of KClO_3 as obtained from experiment and derived model-predicted results were 7×10^{-5} and 6.25×10^{-5} % g^{-1} respectively.

Keywords: Evaluation, Extracted Iron, Potassium Chlorate Addition, Iron Ore

I. INTRODUCTION

Hydrometallurgical treatment of ores for metal extraction purposes has been widely recognized and accepted to be significantly environmental friendly. Intensive research and development are unavoidably necessary to review this potentiality and also explore ways of improving on the extraction techniques for enhanced results. There should also be increased research interests in exploring optimum methods of achieving balance between high yield and clean atmosphere.

Evaluation of the prospect and effectiveness of dissolving iron (from iron compounds) in organic acids such as acetic, oxalic formic, citric and ascorbic acids has shown that oxalic acid is most effective and promising because of its acid strength, good complexing

characteristics and high reducing power, compared to other organic acids [1]. Applicability of oxalic acid ensures precipitation of dissolved iron from the leach solution as ferrous oxalate, which can be re-processed to form pure haematite by calcinations [2].

Empirical analysis of some results generated from these extraction processes has been carried using various derived models as analytical tools [3-8]. These models have significantly shown the functional dependence of extracted iron on the leaching solution temperature and pH [3, 8], leaching solution temperature [4]. Some have shown that iron extraction through acid leaching depends greatly on mass-input of ore and solution pH [5, 7] as well as on solution temperature and mass-input of ore [6].

The aim of this work is to evaluate the response of iron extraction to the oxidative action of added powdered potassium chlorate relative to the iron as-beneficiated content. A model will be derived, validated and used for the evaluation.

II. METHODS AND MATERIAL

Agbaja (Nigeria) iron ore concentrate used for this work was obtained from Nigeria Metallurgical Development Centre (NMDC) Jos. This concentrate was dried in air (under atmospheric condition) and used in the as-received condition with particle size; 150µm. A weighed quantity of the dried iron ore concentrate was mixed with 9g of powdered KClO₃ (obtained from Fisher Scientific Company Fair Lawn, New Jerry, USA). These mixtures were provided on five different iron crucibles. The mixtures were heated to a temperature of 400⁰C in a Gallenkamp Hot pot electric furnace at NMDC Laboratory for 600 secs. and thereafter were emptied on white steel pans for observation. The experiment was repeated using varying mass-inputs of KClO₃ i.e 9.5, 10, 13, 15g and constant mass-inputs of iron ore. Weighed quantities of the sample mixtures for each experiment set were taken (after heating) for chemical analysis (to determine the extracted Fe concentration) using wet analysis method. The average of the extracted Fe concentration determined in each experiment set was taken as the precise result [9].

Model Formulation

Experimental data [9] obtained from the highlighted research work were used for the model derivation. Computational analysis of these data shown in Table 1, gave rise to Table 3 which indicate that;

$$\zeta - K = -N \ln \vartheta - S_e \gamma \quad (1)$$

Introducing the values of K, N and S_e into equation (2)

$$\zeta - 0.0039 = -0.0008 \ln \vartheta - 0.00001\gamma \quad (2)$$

$$\zeta = -0.0008 \ln \vartheta - 0.00001\gamma + 0.0039 \quad (3)$$

Where

(ζ) = Conc. of extracted iron (%)

(γ) = As- beneficiated Fe content of the iron ore (%)

(ϑ) = Mass-input of KClO₃ (g)

K = 0.0039, N = 0.0008, S_e = 0.00001; K, N and S_e are equalizing constant (determined using C-NIKBRAN [10])

Table 1: Variation of iron extracted concentration with mass-input of KClO₃ [9]

(ζ)	(ϑ)	(γ)
0.00174	9	45.9
0.00166	9.5	45.9
0.00157	10	45.9
0.00138	13	45.9
0.00132	15	45.9

Boundary and Initial Condition

Consider iron ore (in a furnace) mixed with potassium chlorate (oxidant). The furnace atmosphere is not contaminated i.e (free of unwanted gases and dusts). Initially, atmospheric levels of oxygen are assumed just before the decomposition of KClO₃ (due to air in the furnace). Mass of iron oxide ore: (50g), treatment time: 600 secs., treatment temperature range: 400⁰C, ore grain size; 150µm and range of KClO₃ mass-input: 9-15g.

The boundary conditions are: furnace oxygen atmosphere due to decomposition of KClO₃ (since the furnace was air-tight closed) at the top and bottom of the ore particles interacting with the gas phase. At the bottom of the particles, a zero gradient for the gas scalar are assumed and also for the gas phase at the top of the particles. The reduced iron is stationary. The sides of the particles are taken to be symmetries.

III. RESULTS AND DISCUSSION

The result of the chemical analysis carried out on the beneficiated iron ore concentrate is presented in Table 2. The table shows that the percentage of total Fe in the as-beneficiated ore is 45.9%.

Table 2: Result of chemical analysis of iron ore used [9]

Element/Compound	Fe _T	P	SiO ₂	Al ₂ O ₃
Unit (%)	78.6	0.9	5.3	11.3

Model Validation

The validity of the model is strongly rooted in equation (2) (core model equation) where both sides of the equation are correspondingly approximately equal. Table 3 also agrees with equation (2) following the values of $\zeta - 0.0039$ and $-0.0008 \ln \vartheta - 0.00001 \gamma$ evaluated from the experimental results in Table 1.

Table 3: Variation of $\zeta - 0.0039$ with $-0.0008 \ln \vartheta - 0.00001 \gamma$

$\zeta - 0.0039$	$-0.0008 \ln \vartheta - 0.00001 \gamma$
-0.00216	-0.00222
-0.00224	-0.00226
-0.00233	-0.00230
-0.00252	-0.00251
-0.00258	-0.00263

Furthermore, the derived model was validated by comparing the extracted iron concentration predicted by the model and that obtained from the experiment. This was done using various evaluative techniques such as computational, statistical, graphical and deviational analysis.

Computational Analysis

Computational analysis of the experimental and model-predicted extracted iron concentration was carried out to ascertain the degree of validity of the derived model. This was done by comparing extracted iron per unit leaching time as well as extracted iron per unit mass-input of KClO_3 evaluated from model-predicted results with those from actual experimental results

Extracted iron concentration per unit mass-input of KClO_3 ζ_m (%/g) was calculated from the equation;

$$\zeta_m = \zeta / m \quad (4)$$

Therefore, a plot of the extracted iron concentration against mass-input of KClO_3 as in Fig. 1 using experimental results in Table 1, gives a slope, S at points (12, 0.00166) and (15, 0.00132) following their substitution into the mathematical expression;

$$\zeta_m = \Delta \zeta / \Delta m \quad (5)$$

Equation (5) is detailed as

$$\zeta_m = \zeta_2 - \zeta_1 / m_2 - m_1 \quad (6)$$

Where

$\Delta \zeta$ = Change in extracted iron concentrations of ζ_2, ζ_1 at two mass-input values m_2, m_1 . Considering the points (9.5, 0.00166) and (13, 0.00138) for (m_1, ζ_1) and (m_2, ζ_2) respectively, and substituting them into equation (6), gives the slope as $-7 \times 10^{-5} \% \text{ g}^{-1}$ which is the extracted iron concentration per unit mass-input of KClO_3 during the actual extraction process [11].

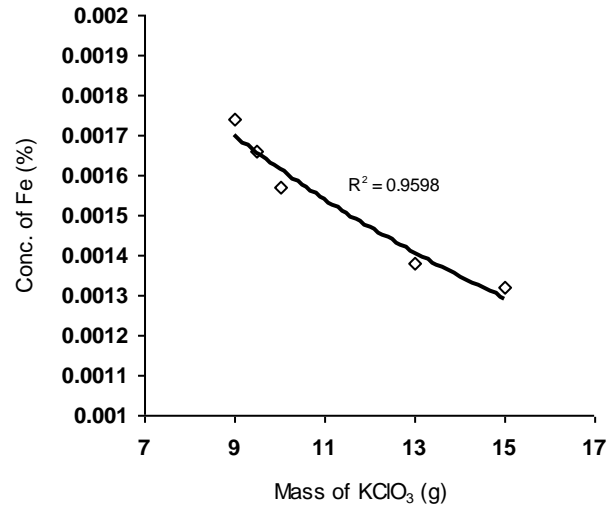


Figure 1: Coefficient of determination between extracted iron concentration and mass-input of KClO_3 as obtained from experiment [9]

A plot of the concentration of extracted iron against mass-input of KClO_3 (as in Fig. 2) using derived model-predicted results gives a slope: $-6.25 \times 10^{-5} \% \text{ g}^{-1}$ on substituting the points (9.5, 0.00164) and (13, 0.00139) for (m_1, ζ_1) and (m_2, ζ_2) respectively into equation (6). This is the model-predicted extracted iron concentration per unit mass-input of KClO_3 .

A comparison of this set of values for extracted Fe concentration (per unit mass-input of KClO_3) also shows proximate agreement and a high degree of validity of the derived model.

It is very pertinent to state that the actual extracted Fe concentration per unit mass-input of KClO_3 (as obtained from experiment and derived model) was just the magnitude of the signed value. The associated sign preceding these values signifies that the associated slope tilted to negative plane. Based on the foregoing, extracted Fe concentration per unit mass-input of KClO_3 as obtained from experiment and derived model were $7 \times 10^{-5} \% \text{ g}^{-1}$ and $6.25 \times 10^{-5} \% \text{ g}^{-1}$ respectively.

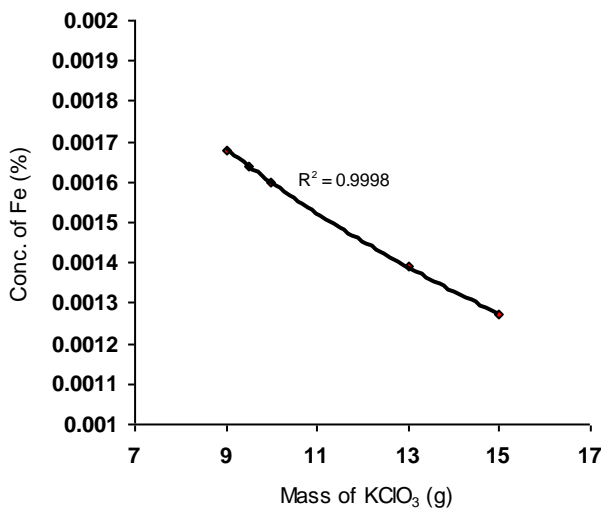


Figure 2: Coefficient of determination between extracted iron concentration and mass-input of KClO₃ as obtained from derived model

Statistical Analysis

The standard errors (STEYX) in predicting the extracted iron concentration (using results from experiment [9] and derived model) for each value of the mass-input of KClO₃ are 5.19×10^{-5} and 8.45×10^{-6} respectively. The standard error was evaluated using Microsoft Excel version 2003.

Also the correlations between extracted iron concentration and mass-input of KClO₃ as obtained from experiment and derived model considering the coefficient of determination R^2 from Figs. 1 and 2 was calculated using the equation;

$$R = \sqrt{R^2} \quad (7)$$

The evaluations show correlations 0.9797 and 0.9999 respectively. These evaluated results indicate that the derived model predictions are significantly reliable and hence valid considering its proximate agreement with results from actual experiment [9].

Graphical Analysis

Comparative graphical analysis of Fig. 3 shows very close alignment of the curves from model-predicted extracted iron concentration (MoD) and that of the experiment (ExD). The degree of alignment of these curves is indicative of the proximate agreement between both experimental and model-predicted extracted iron concentration.

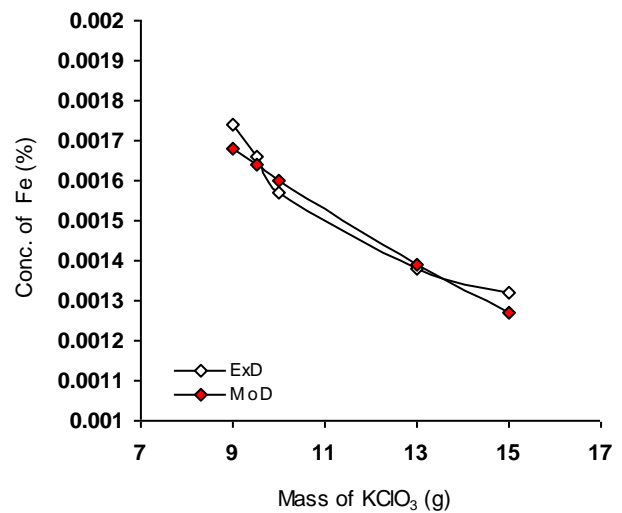


Figure 3 : Comparison of the extracted iron concentrations (relative to mass-input of KClO₃) as obtained from experiment [9] and derived model

Deviational Analysis

Analysis of extracted Fe concentrations from the experiment and derived model revealed deviations on the part of the model-predicted values relative to values obtained from the experiment. This is attributed to the fact that the surface properties of the iron ore and the physiochemical interactions between the ore and the oxidant (KClO₃) which were found to have played vital roles during the process were not considered during the model formulation. This necessitated the introduction of correction factor, to bring the model-predicted extracted Fe concentration to those of the corresponding experimental values.

Deviation (Dn) of model-predicted extracted Fe concentration from that of the experiment is given by

$$Dn = \left(\frac{Pv - Ev}{Ev} \right) \times 100 \quad (8)$$

Where

Pv = Extracted iron concentration as predicted by derived model

Ev = Extracted iron concentration as obtained from experiment [9]

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

$$Cr = -Dn \quad (9)$$

Therefore

$$Cr = - \left(\frac{Pv - Ev}{Ev} \right) \times 100 \quad (10)$$

Introduction of the corresponding values of Cr from equation (10) into the derived model gives exactly the extracted iron concentration as obtained from experiment.

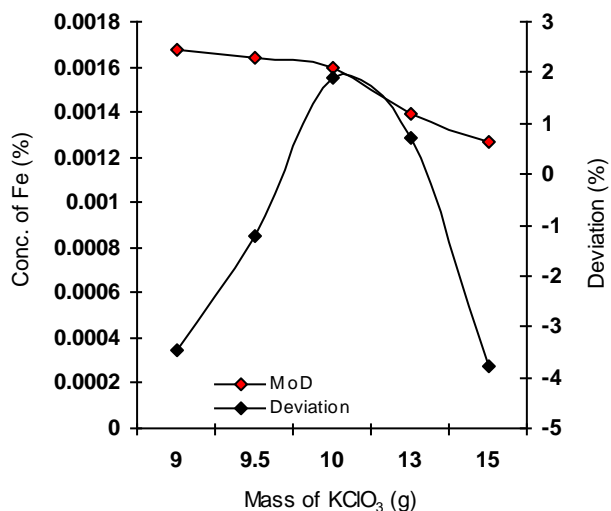


Figure 4: Variation of model-predicted extracted iron concentration with associated deviation from experimental results (relative to mass-input of KClO₃)

Fig. 4 show that the maximum deviation of the model-predicted extracted iron concentration from the corresponding experimental values is less than 4%. The figure shows that the least and highest magnitudes of deviation of the model-predicted extracted iron concentration (from the corresponding experimental values) are + 0.72 and - 3.79 % which corresponds to extracted iron concentrations: 0.00139 and 0.00127 %, as well as mass-input of KClO₃: 13 and 15 g respectively.

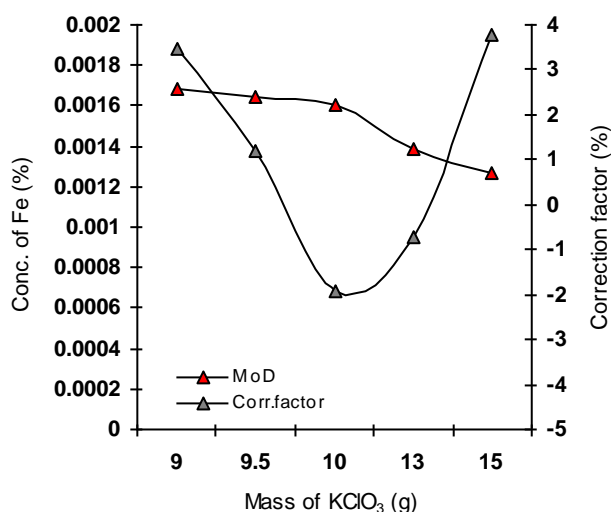


Figure 5 : Variation of model-predicted extracted iron concentration with associated correction factor from experimental results (relative to mass-input of KClO₃)

Comparative analysis of Figs. 4 and 5 indicate that the orientation of the curve in Fig. 5 is opposite that of the deviation of model-predicted extracted iron concentration (Fig. 4). This is because correction factor is the negative of the deviation as shown in equations (9) and (10).

It is believed that the correction factor takes care of the effects of surface properties of the iron ore and the physiochemical interactions between the ore and the oxidant (KClO₃) which were found to have played vital roles during the process were not considered during the model formulation. Figs 5 indicate that the least and highest magnitudes of correction factor to the model-predicted extracted iron concentrations are - 0.72 and + 3.79 % which corresponds to extracted iron concentrations: 0.00139 and 0.00127 %, as well as mass-input of KClO₃: 13 and 15 g respectively.

It is important to state that the deviation of model predicted results from that of the experiment is just the magnitude of the value. The associated sign preceding the value signifies that the deviation is a deficit (negative sign) or surplus (positive sign).

IV. CONCLUSION

Response evaluation of iron extraction to the oxidative action of added powdered potassium chlorate was carried out relative to the as-beneficiated iron content.. The validity of the two-factorial model was rooted on the expression $\zeta - 0.0039 = - 0.0008 \ln 9 - 0.00001\gamma$ where both sides of the expression are correspondingly approximately equal. Statistical analysis of the extracted iron concentration as obtained from experiment and derived model for each value of the mass-input of KClO₃ shows standard errors of 5.19×10^{-5} and 8.45×10^{-6} % respectively. Furthermore, extracted iron concentration per unit mass-input of KClO₃ as obtained from experiment and derived model-predicted results were 7×10^{-5} and 6.25×10^{-5} % g⁻¹ respectively.

V. REFERENCES

- [1] Ambikadevi, V. R., Lalithambika, M. (2000). Effects of Organic Acids on Ferric Iron Removal from Iron-Stained Kaolinite. Applied Clay Science, 16:133-145.
- [2] Taxiarchour, M., Pantias, D., Doumi, I., Paspaliaris, I., Kontopoulos, A. (1997). Removal of Iron from Silica Sand by Leaching with Oxalic Acid, Hydrometallurgy, 46: 215-227.

- [3] Nwoye, C. I., Amara, G. N., and Onyemaobi, O. O. (2008). Model for Evaluating Dissolved Iron during Leaching of Iron Oxide Ore in Sulphuric Acid Solution, *Inter. J. Nat. Appl. Sc.*, 4(2): 209-211.
- [4] Nwoye, C. I., Obasi, G. C., Mark, U., Inyama, S., Nwakwuo, C. C. (2009a). Model for Calculating the Concentration of Leached Iron Relative to the Final Solution Temperature during Sulphuric Acid Leaching of Iron Oxide Ore. *New York Science Journal*, 2(3):49-54.
- [5] Nwoye, C. I. and Ovri, J. E.O. (2010). Model for Calculating the Concentration of Dissolved Iron Relative to the weight-input of Iron Oxide Ore and Final Solution pH during Nitric acid leaching, *Journal of Engineering Science and Technology*, 5(2):151-164
- [6] Nwoye, C. I., Ofoegbu, S. U., Obi, M. C., Nwakwuo, C. C. (2009b). Model for Predictive Analysis of the Concentration of Dissolved Iron Relative to the Weight Input of Iron Oxide Ore and Leaching Temperature during Sulphuric Acid Leaching. *Nature and Science Journal*. 7(3):41-47.
- [7] Nwoye, C. I., Nwobodo, C. S., Nlebedim, C., Nwoye, U. C., Umana, R., and G. C. Obasi (2009c). Model for Predicting the Concentration of Iron Dissolved during Nitric Acid Leaching of Iron Oxide Ore in Oxalic Acid Solution, *New York Science Journal*, 2(6):1-12.
- [8] Nwoye, C. I., Mbuka, I. E. (2011). Model for Calculating the Concentration of Dissolved Iron Relative to the Final Solution pH and Temperature during Oxalic Acid Leaching of Iron Oxide Ore. *Journal of American Science*, 7(1):12-18.
- [9] Ameh, E. M. (2013). Dephosphorization of Agbaja Iron Ore By Sintering And Bioleaching Processes. Ph.D Thesis, Nnamdi Azikiwe University Awka, Anambra State, Nigeria.
- [10] Nwoye, C. I. (2008). C-NIKBRAN: Data Analytical Memory.