Model for Quantitative Analysis of Iron Upgraded during Solid-State Concentration of Iron Oxide Ore using Powdered Potassium Chlorate

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Abstract: Model for quantitative analysis of the concentration of iron upgraded during solid-state concentration of iron oxide ore (using powdered potassium chlorate as oxidant) has been derived. The model ; $\%Fe = 6.4\,[(6.3969 - \ln\mu)^{1.6667}]$ was found to be dependent on the mass-input of $KClO_3$ within a range: 7-12g. The validity of the model is rooted in the expression $(\%Fe/C_n)^{\alpha} = \ln(T/\mu)$ where both sides of the expression are correspondingly approximately equal to 4. The maximum deviation of the model-predicted values of upgraded iron from those of the corresponding experimental values was found to be less than 26% which is quite within the range of acceptable deviation limit of experimental results. The correlation and iron upgrade per unit mass of oxidant added as obtained from experiment and derived model were evaluated as 1.0000 & 0.9958 and 2.12%/g & 2.78%/g respectively. [Academia Arena, 2010;2(5):8-11] (ISSN 1553-992X).

Keywords: Model, Upgraded Iron, Concentration, Iron Oxide Ore.

1. Introduction

It has been found that Agbaja iron oxides are so finely disseminated within gangue material that their dissociation requires grinding the ore to about $\leq 5\mu m$ (Uwadiele, 1984). The ore was found to contain 45.6%Fe and principally goethite, with minor hematite, maghemite, siderite, kaolinite and guartz (Uwadiele, 1984).

Nwoye (2008a) carried out desulphurization of Agbaja iron oxide ore concentrate using solid potassium trioxochlorate (V) $(KClO_3)$ as oxidant. The concentrate was treated at a temperature range $500 - 800^0C$. The results of the investigation revealed that simultaneous increase in both the percentage of the oxidant added (up to 15g per 50g of ore) and treatment temperature (maximum 800^0C) used give the ideal conditions for increased desulphurization efficiency. This translates into high desulphurization efficiency when both oxidant concentration (up to 15g per 50g of ore) and treatment temperature (maximum 800^0C) are high.

The mechanism and process analysis of desulphurization of Agbaja iron ore concentrate using powdered potassium trioxochlorate (v) $(KClO_3)$ as oxidant has been reported (Nwoye, 2009). Concentrates were treated at a temperature range $500 - 800^0C$. Results of the process analysis indicate that oxygen required for the desulphurization process was produced following decomposition of $KClO_3$ within a temperature range $375\text{-}502^oC$. It was observed that this temperature range is the Gas Evolution Temperature Range (GETR) for sulphur present in Agbaja iron ore. Sulphur vapour and oxygen gas produced at this temperature range were believed to have reacted to form and liberate SO_2. The process analysis suggests that the mechanism of the desulphurization process involves gaseous state interaction between oxygen and sulphur through molecular combination. The results for the extent of desulphurization reveal that simultaneous increase in both the percentage of the oxidant added and treatment temperature used (up to 15g $KClO_3$ per 50g of ore and maximum of 800^0C respectively) are the ideal conditions for the best desulphurization efficiency.

An intensive and selective oil agglomeration of Agbaja iron ore has been carried out (Uwadiele 1990). The researcher, starting from the crude ore Fe content (45.6%), concentrated the ore by oil agglomeration technique to 90% Fe recovery and 65% Fe assay. He stated that the ore require grinding to minus 5μm to effect adequate liberation. These results were obtained at optimum pH 9. Successful studies on the effect of temperature on magnetizing reduction of Agbaja iron ore have been carried out (Uwadiele and Whewell, 1988). The results of the investigation showed that the fine-grained oolitic Agbaja iron ore, which is not responsive to conventional processing techniques, can be upgraded by the magnetizing reduction method with an Fe recovery of 87.3% and Fe assay of 60% at 600^0C.

Attempt has been made to enhance concentrate Fe recovery (Kulkarni and Somasundaran 1980). The researchers stated that concentrate Fe recovery decreases progressively below pH 8. In this pH region, oleate used is present as dispersion of oleic acid, and its adsorption on the surface of the iron oxides is similar to

the process of hetero-coagulation involving positively charged iron oxide particle and negatively charged oleic acid droplet. Main parameters investigated were the effects of treatment temperature and oxidant ($KClO_3$) on the upgrading process. It was established that 800^0C is the optimum temperature for the upgrading step considering the range of temperature used ($500-800^0C$). It was observed from results of the investigation that both oxidant and temperature increase (up to 12g per 50g of iron ore and maximum of 800^0C respectively) during the process are vital conditions for improving on the grade of the ore concentrate.

Nwoye et al (2009) derived a model for computational analysis of the concentration of iron upgraded during dry beneficiation of iron oxide ore. The model;
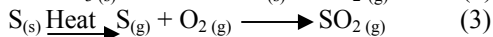
$$\%Fe = 2.25[(\ln(T/\mu))^{2.58}] \qquad (1)$$

shows that the concentration of upgraded iron is dependent on the treatment temperature T, used when the mass of iron oxide ore μ, added is constant.

The aim of this work is to derive a model for quantitative analysis of iron upgraded during solid-state concentration of Agbaja (Nigerian) iron oxide ore (using powdered potassium chlorate as oxidant).

2. Model

The solid phase (ore) is assumed to be stationary, contains some unreduced iron remaining in the ore. It was found (Nwoye,2008b) that oxygen gas from the decomposition of $KClO_3$ attacked the ore in a gas-solid reaction, hence removing (through oxidation) the sulphur present in the ore in the form of SO_2 .Equations (2) and (3) show this.

$$2KClO_{3\,(s)} \longrightarrow 2KCl_{\,(s)} + 3O_{2\,(g)} \qquad (2)$$
$$S_{(s)} \underset{Heat}{\longrightarrow} S_{(g)} + O_{2\,(g)} \longrightarrow SO_{2\,(g)} \qquad (3)$$

Nwoye, (2008) posited that when sulphur inherent in the iron ore is removed in this stance; the concentration of iron present in the ore is upgraded since sulphur is an impurity element.

2.1 Model Formulation

Experimental data obtained from research work (Nwoye, 2006) carried out at SynchroWell Research Laboratory, Enugu were used for this work.

Results of the experiment as presented in report (Nwoye, 2006) and used for the model formulation are as shown in Table 1. Computational analysis of the experimental data (Nwoye, 2006) shown in Table 1, gave rise to Table 2 which indicate that;

$$(\%Fe/C_n)^{\alpha} = \ln(T/\mu) \quad \text{(approximately)} \qquad (4)$$

Introducing the values of α and C_n into equation (4);

$$(\%Fe/6.4)^{0.6} = \ln(T/\mu) \qquad (5)$$

Since the inverse of 1.6667 = 0.6

$$(\%Fe/6.4)^{1/1.6667} = \ln(T/\mu) \qquad (6)$$

Multiplying the indices of both sides by 1.6667;

$$\%Fe/6.4 = (\ln(T/\mu))^{1.6667} \qquad (7)$$

$$\%Fe/6.4 = [(\ln T - \ln\mu)^{1.6667}] \qquad (8)$$

Introducing the value of T into equation (8)

$$\%Fe = 6.4 [(6.3969 - \ln\mu)^{1.6667}] \qquad (9)$$

Where

%Fe = Percentage iron upgrade during the concentration process

(α) = 0.6 (Decomposition coefficient of $KClO_3$ during the concentration process) determined in the experiment (Nwoye, 2006)

(μ) = Weight of $KClO_3$ added as oxidant during the concentration process (g).

(C_n) = 6.4 (Oxidation coefficient of $KClO_3$ relative to its weight-input during the beneficiation process) determined in the experiment (Nwoye, 2006).

N_e = 1.6667 (Assumed iron enhancement index)

T = Treatment temperature (^0C)

Table1:Variation of upgraded concentration of iron with weight-input of $KClO_3$ (Nwoye,2006)

%Fe	(μ)	M (g)
61.64	7	50
63.78	8	50
65.88	9	50
68.00	10	50
70.16	11	50
72.24	12	50

3. 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 $KClO_3$ (due to air in the furnace).Weight, M of iron oxide ore; (50g), and treatment time; 360secs. were used. Treatment temperature; 600^oC, ore grain size; 150µm, and weight-range of $KClO_3$ (oxidant); (7-12g) were also used. These and other process conditions are as stated in the experimental technique (Nwoye, 2006).

The boundary conditions are: furnace oxygen atmosphere due to decomposition of $KClO_3$ (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.

4. Model Validation

The formulated model was validated by direct analysis and comparison of %Fe values predicted by

the model and those obtained from the experiment for equality or near equality.

Analysis and comparison between these %Fe values reveal deviations of model-predicted %Fe values from those of the experiment. This is attributed to the fact that the surface properties of the ore and the physiochemical interactions between the ore and the oxidant (under the influence of the treatment temperature) which were found to have played vital roles during the oxidation-beneficiation process (Nwoye, 2006) were not considered during the model formulation. This necessitated the introduction of correction factor, to bring the model-predicted %Fe values to those of the experimental %Fe values (Table 3).

Deviation (Dv) (%) of model-predicted %Fe values from experimental %Fe values is given by

$$Dv = \left(\frac{Dp - DE}{DE} \right) \times 100 \qquad (10)$$

Where   Dp = Predicted %Fe values from model
DE = Experimental %Fe values

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

$$Cf = -Dv \qquad (11)$$

Therefore

$$Cf = -\left(\frac{Dp - DE}{DE} \right) \times 100 \qquad (12)$$

Introduction of the corresponding values of Cf from equation (12) into the model gives exactly the corresponding experimental %Fe values. (Nwoye, 2006)

5. Results and Discussion

The derived model is equation (9). A comparison of the values of %Fe from the experiment and those from the model shows very minimum positive and negative deviations less than 26% which is quite within the acceptable range of deviation limit of experimental results hence depicting the reliability and validity of the model. This is shown in Table 3. Table 2 also agrees with equation (4) following the values $(\%Fe/C_n)^\alpha$ and $\ln(T/\mu)$ evaluated from Table 1 as a result of corresponding computational analysis. The validity of the model is rooted in equation (4) where both sides of the equation are correspondingly approximately equal to 4.

Table 2: Variation of $(\%Fe/C_n)^\alpha$ with $\ln(T/\mu)$

$(\%Fe/C_n)^\alpha$	$\ln(T/\mu)$
3.8923	4.4510
3.9729	4.3175
4.0508	4.1997
4.1285	4.0943
4.2067	3.9990
4.2811	3.9120

It is believed that since 1.6667 is the index of the expression $\ln(T/\mu)$, it follows from the model formulation that it affects the two main input process parameters responsible for the upgrading of the iron oxide ore. This way, it contributes to the upgrading of the iron. Therefore, the constant 1.6667 is assumed to be the Iron Enhancement Index (N_e). This agrees with the fact that the upgrade in Fe as reported in Table 1 was as a result of the influence of weight-input of oxidant ($KClO_3$) on the iron oxide ore at the treatment temperature during the concentration process.

Also, mathematically, since the constant 1.6667 affects the treatment temperature and weight-input of $KClO_3$ as in equations (7) and (8), it follows that the constant invariably contributes to the predicted value of the upgraded iron.

Table 3: Comparison between %Fe upgrade as predicted by model and as obtained from experiment (Nwoye , 2006).

$\%Fe_{exp}$	$\%Fe_M$	Dv (%)	Cf (%)
61.64	77.0840	+25.06	-25.06
63.78	73.2692	+14.88	-14.88
65.88	69.9677	+6.20	-6.20
68.00	67.0656	-1.37	+1.37
70.16	64.4841	-8.09	+8.09
72.24	62.1629	-13.95	+13.95

An ideal comparison of the concentrations of upgraded iron per unit mass of the oxidant added as obtained from experiment and as predicted by the model for the purpose of testing the validity of the model is achieved by considering the R^2 values. The values of the correlation coefficient, R calculated from the equation;

$$R = \sqrt{R^2} \qquad (13)$$

using the r-squared values (coefficient of determination) from Figures 1 and 2 show very close correlation (0.9958) and (1.0000) between model-predicted and experimentally obtained concentrations of upgraded iron respectively.
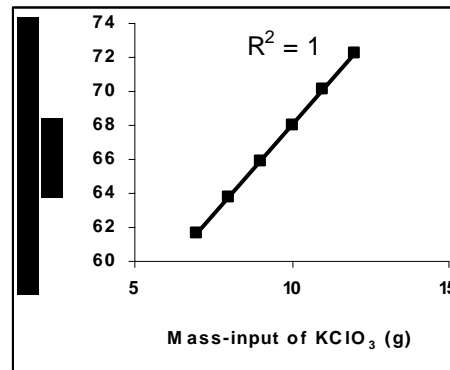

Figure 1: Variation of mass-input of $KClO_3$ on the concentration of iron upgraded as obtained from experiment (Nwoye, 2006)
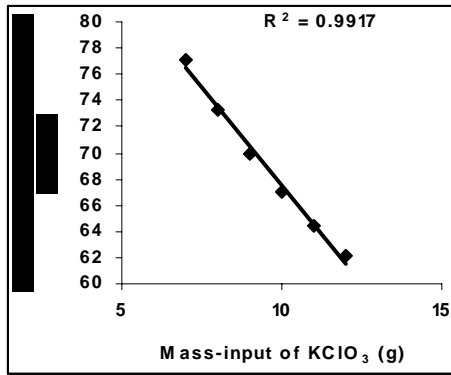
Figure 2:Variation of mass-input of $KClO_3$ on the concentration of iron upgraded as derived by model .

This suggests that the model predicts very accurate and reliable concentration of upgraded iron with respect to the actual experiment results.

5.1 Iron upgrade per mass of oxidant ($KClO_3$)
Iron upgrade per unit mass of oxidant added resulting from oxidation of the iron ore at a temperature of 600^0C. Iron upgrade per unit mass of oxidant added was determined following comparison of the iron upgrade per unit mass of oxidant added as obtained by calculations involving experimental results, and model-predicted results obtained directly from the model.

Iron upgrade per unit mass of the oxidant added during the oxidation process, I_e (% /g) was calculated from the equation;

$$I_e = I/m \qquad (14)$$

Therefore, a plot of the concentrations of upgraded iron I against mass of $KClO_3$ added m, as in Figure 1 using experimental results in Table 1, gives a slope, S at points (7, 63.78) and (12, 72.24) following their substitution into the mathematical expression;

$$S = \Delta I/\Delta m \qquad (15)$$

Eqn. (15) is detailed as

$$S = I_2 - I_1/ m_2 - m_1 \qquad (16)$$

Where

ΔI = Change in the concentrations of upgraded iron I_2, I_1 at two oxidant mass-input values m_2, m_1. Considering the (8, 63.78) and (12, 72.24) for (I_1, m_1) and (I_2, m_2) respectively, and substituting them into eqn. (16), gives the slope as 2.12 %/g which is the concentration of upgraded iron per unit mass oxidant added during the actual experimental oxidation process. Also similar plot (as in Figure 2) using model-predicted results gives a slope. Considering points (8, 73.2692) and (12, 62.1629) for (I_1, m_1) and (I_2, m_2) respectively and substituting them into eqn. (16) gives the value of slope, S as -2.78 %/g. This is the model-predicted concentration of upgraded iron. It is important to state that the model-predicted value is of magnitude 2.78% and not 2.78%.The

negative sign before 2.78% only indicates negative slope which resulted from non-consideration of the surface properties of the ore and the physiochemical interactions between the ore and the oxidant (which actually played vital role during the experiment (Nwoye,2006)) during the model formulation. A comparison of these two concentrations of upgraded iron per unit mass of oxidant added shows proximate agreement. This indicates a very high degree of validity for the model as a reliable tool for predicting the concentration of upgraded iron per unit mass of oxidant added during oxidation of Agbaja iron oxide ore at an oxidant mass-input range :7-12g..

6. Conclusion
The model computes the percentage upgrade in iron during concentration of Agbaja iron oxide ore (using powdered potassium chlorate). The deviation of the model-predicted %Fe values from the corresponding experiment %Fe values is less than 26% which is quite within the acceptable range of deviation limit of experimental results. The validity of the model is rooted in the expression $(\%Fe/C_n)^\alpha = \ln(T/\mu)$ where both sides of the expression are correspondingly approximately equal to 4.

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

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