



Model for Computational Analysis of the Concentration of Iron Upgraded during Dry Beneficiation of Iron Oxide Ore

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Abstract

Model for computational analysis of the concentration of iron upgraded during dry beneficiation of iron oxide ore (using powdered potassium chlorate as oxidant) has been derived. The model was found to predict the %Fe upgrades quite close to the corresponding %Fe values obtained from the actual beneficiation process. It was found that the model is dependent on the weight input of $KClO_3$ and the treatment temperature. The validity of the model was rooted on the mathematical relationship $(\%Fe/\alpha)N = \ln(T/\mu)$ where both sides of the expression correspondingly gives 4 (approximately). The positive or negative deviation of each of the model-predicted values of %Fe from those of the corresponding experimental values was found to be less than 16% which is quite within the range of acceptable deviation limit of experimental results, hence showing the usefulness of the model.

Keywords: Model, Computational Analysis, Upgraded Iron, Dry Beneficiation and Iron Oxide Ore.

1.0 Introduction

Agbaja has been located as Nigeria's largest known iron ore deposit estimated at 1250 metric tonnes. It consists of oolitic and pisolitic structures rich in iron oxides, in a matrix that is predominantly clay (Uwadiel, 1984). It was also found (Uwadiel, 1984) that the principal constituent of the ore is goethite, with minor hematite, maghemite, siderite, quartz, kaolinite pyrite and an average of 0.09% S.

Pehlke *et al.* (1975) reported that one of the most important factors influencing the desulphurization process during iron making is the state of oxidation of the bath.

Desulphurization of Agbaja iron oxide ore concentrate using solid potassium trioxochlorate (v) ($KClO_3$) as oxidant has been carried out (Nwoye, 2008). The concentrate was treated at a temperature range 500–800°C. 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°C) 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°C) 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, 2009a). Concentrates were treated at a temperature range 500–800°C. Results of the process analysis indicate that oxygen required for the desulphurization process was produced following decomposition of $KClO_3$ within a temperature range 375–502°C. 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°C respectively)

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are the ideal conditions for the best desulphurization efficiency.

Previous study (Nwoye, 2008) indicates that Agbaja oolitic iron ore, which has not been responsive to so many upgrading processes, has been upgraded to 73.4% Fe assay (starting from as-received concentrate assaying 56.2% Fe) by pyrometallurgical-oxidation method. Main parameters investigated were the effects of treatment temperature and oxidant (KClO_3) on the upgrading process. It was established that 800°C is the optimum temperature for the upgrading step considering the range of temperature used (500-800°C). 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°C respectively) during the process are vital conditions for improving on the grade of the ore concentrate.

Following an intensive study (Uwadiel, 1990) on selective oil agglomeration of Agbaja iron ore, the crude ore of Fe content (45.6%), was concentrated by oil agglomeration technique to 90% Fe recovery and 65% Fe assay. The researcher stated that the ore require grinding to minus 5 μm to effect adequate liberation. These results were obtained at optimum pH 9. It was found following studies (Uwadiel and Whewell 1988) on the effect of temperature on magnetizing reduction of Agbaja iron ore 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°C.

Kulkarni and Somasundaran (1980) found that oleate can be used to enhance concentrate Fe recovery. 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 particles and negatively charged oleic acid droplet.

Model for predictive analysis of the concentration of sulphur removed by molecular-oxygen-induced desulphurization of Agbaja (Nigeria) iron oxide ore

has been derived (Nwoye,2009b). The model is expressed as;

$$\%S = (\text{Log}T - \text{Log} \alpha - \text{Log}k_n) / \mu \text{Log} \gamma \quad \dots 1$$

where

%S is the concentration of sulphur removed during the pyrometallurgical-oxidation process.

$k_n = 9.75$ (Decomposition coefficient of KClO_3 at the treatment temperature of 600°C) determined in the experiment (Nwoye, 2009b).

$\mu = 2.1739$ (Oxidation coefficient of KClO_3 relative to the treatment temperature (600°C)) determined in the experiment (Nwoye, 2009b).

α is the weight of iron oxide ore added (g)

T is the treatment temperature used for the process (°C)

γ is the weight of KClO_3 added (g)

$D_e = 0.0415$ (Assumed Desulphurization Enhancement Factor)

On substituting these parameters into the model, equation (1) reduces to;

$$\%S = 0.0415 / \text{Log} \gamma \quad \dots 2$$

The model was found to predict the concentration of sulphur removed, very close to the corresponding %S values obtained from the actual experimental process. It was found that the model is dependent on the values of the weight input of the oxidant (KClO_3) during the desulphurization process. The validity of the model was rooted in the expression $k_n [(\gamma)^{\mu\%S}] = T/\alpha$ where both sides of the expression were correspondingly almost equal.

Nwoye *et al.* (2009) derived a model for predicting the concentration of iron upgraded during pyrobeneficiation of iron oxide ore (pelletized with powdered potassium chlorate). The model-predicted %Fe upgrades were found to agree a direct relationship between %Fe values and weight-input of KClO_3 as exhibited by %Fe upgrades obtained from the experiment. The model;

$$\%Fe = 7.1367\gamma \quad \dots 3$$

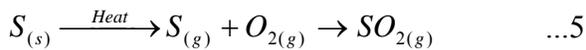
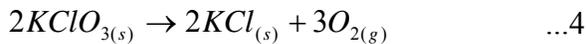
indicates that iron upgrade is dependent on the weight input of KClO_3 . The validity of the model was rooted in the expression $(\%Fe/\gamma)^a = (T/\beta)^N$ where both sides of the expression are correspondingly almost equal. The positive or negative deviation of each of the model - predicted

values of %Fe from those of the corresponding experimental values was found to be less than 19% which is quite within the range of acceptable deviation limit of experimental results.

The aim of this work is to derive a model for computational analysis of the concentration of iron upgraded during dry beneficiation of Agbaja (Nigerian) iron oxide ore (using powdered potassium chlorate as oxidant).

2.0 Model

The solid phase (ore) is assumed to be stationary, contains some unreduced iron remaining in the ore. It was found (Nwoye, 2008) 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 (4) and (5) show this.



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;

$$(\%Fe/\alpha)^N = \ln(T/\mu) \quad (\text{approximately}) \quad \dots 6$$

Introducing the values of N and α into equation (6);

$$(\%Fe/2.25)^{0.3876} = \ln(T/\mu) \quad \dots 7$$

Since the inverse of $2.58 = 0.3876$

$$(\%Fe/2.25)^{1/2.58} = \ln(T/\mu) \quad \dots 8$$

Multiplying the indices of both sides by 2.58;

$$\%Fe/2.25 = (\ln(T/\mu))^{2.58} \quad \dots 9$$

$$\%Fe = 2.25[(\ln(T/\mu))^{2.58}] \quad \dots 10$$

And so

$$\%Fe = \alpha[(\ln(T/\mu))^{N_e}] \quad \dots 11$$

where

%Fe is the upgraded concentration of iron during the beneficiation process determined experimentally by Nwoye, 2006.

$N = 0.3876$ (Decomposition coefficient of $KClO_3$ during the beneficiation process) determined experimentally by Nwoye, 2006.

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

$\alpha = 2.25$ (Oxidation coefficient of $KClO_3$ relative to its weight-input during the beneficiation process) determined experimentally by Nwoye, 2006.

$N_e = 2.58$ (Assumed iron enhancement index)

T = Treatment temperature ($^{\circ}C$)

Equation (10) or (11) is the derived model.

Table 1: Variation of upgraded concentration of iron with treatment temperature

%Fe _{exp}	T ($^{\circ}C$)	M (g)
68.00	500	50
68.36	550	50
68.80	600	50
68.92	650	50
69.00	700	50
69.07	750	50
69.10	800	50

M is the weight -input of iron oxide ore.

(Source: Nwoye, 2006)

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

$(\%Fe/\alpha)^N$	$\ln(T/\mu)$
3.7478	3.5066
3.7555	3.6019
3.7648	3.6889
3.7674	3.7689
3.7691	3.8430
3.7705	3.9120
3.7712	3.9766

3.0 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 used; (50g), and treatment time; 360secs. were used. Treatment temperature range; 500-800°C, ore grain size; 150µm, and weight of $KClO_3$ (oxidant); 15g 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.

4.0 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:

$$Dv = \left(\frac{Dp - DE}{DE} \right) \times 100 \quad \dots 12$$

where

Dp is the predicted %Fe values from model

DE is the Experimental %Fe values

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

$$Cf = -Dv \quad \dots 13$$

$$Cf = - \left(\frac{Dp - DE}{DE} \right) \times 100 \quad \dots 14$$

Therefore, the introduction of the corresponding values of Cf from equation (14) into the model gives exactly the corresponding experimental %Fe values. as obtained by Nwoye, 2006.

5.0 Results and Discussion

The derived model is equation (10) or (11). Figure 1 shows that both values of the concentration of upgraded Fe from the experiment (Nwoye, 2006) shown in line Exp and the derived model (line MoD) in relation to the treatment temperature are generally quite close hence depicting the reliability and validity of the model.

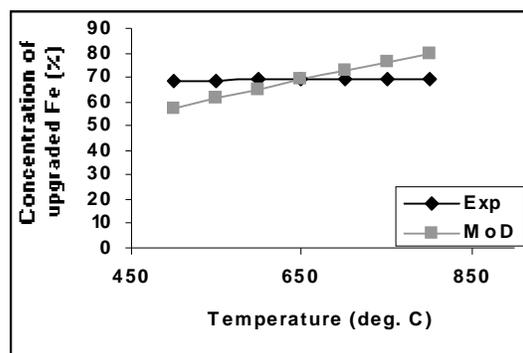


Figure 1: Comparison of the concentrations of Fe upgraded in relation to the treatment temperature as obtained from experiment (Nwoye, 2006) and derived model.

A comparison of the values of %Fe from the experiment and those from the model shows very minimum positive and negative deviations less than 16% which is quite within the acceptable 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 (6) following the values $(\%Fe/\alpha)^N$ and $\ln(T/\mu)$ evaluated from Table 1 as a result of corresponding computational analysis. The validity of the model is rooted in equation (6) where both sides of the equation are correspondingly approximately equal to 4

It is believed that since 2.58 is the index of the expression $\ln(T/\mu)$, it follows from the model formulation that it contributes to the upgrading of the iron. Therefore, the constant 2.58 is assumed to be the Iron Enhancement Index (N_e). This is because the upgrade in Fe as reported in Table 1 was as a result of the influence of the treatment temperature and weight-input of oxidant ($KClO_3$) on the iron oxide ore during the beneficiation process.

Also, mathematically, since the constant 2.58 affects the treatment temperature and weight-input of $KClO_3$ as in equation (10), it follows that the constant invariably contributes to the predicted value of the upgraded iron.

Table 3: Variation of deviation and correction factor with %Fe upgrade as predicted by model.

$\%Fe_M$	Dv (%)	Cf (%)
57.2782	-15.77	+15.77
61.3810	-10.21	+10.21
65.2794	-05.12	+05.12
68.9948	+ 0.11	- 0.11
72.5491	+05.14	-05.14
75.9577	+09.97	-09.97
79.2361	+14.67	-14.67

(where $\%Fe_M$ = %Fe upgrade predicted by model)

6.0 Conclusion

The model computes the upgraded iron concentration during dry beneficiation of Agbaja iron oxide ore (using powdered potassium chlorate). The deviation of the model-predicted %Fe values from those of the experiment is less than 16% which is quite within the acceptable deviation limit of experimental results. The validity of the model is

rooted in equation (6) where both sides of the equation 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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