Model for Evaluating the Concentration of Iron Upgraded during Pyrobeneficiation of Iron Oxide Ore Pelletized with Powdered Potassium Chlorate

Chukwuka Ikechukwu Nwoye*[1], Stephen Obiji[1], Livinus Anyika[2], Uchenna Chukwuma Nwoye[3], Martins Obi[4], Atulegwu Patrick Uzoije[5], Stanley Udochukwu Ofoegbu[6]

[1]Department of Materials and Metallurgical Engineering, Federal University of Technology, Owerri Nigeria.

[2]Department of Industrial Chemistry, Federal University of Technology, Owerri, Nigeria.

[3]Data Processing, Modelling and Simulation Unit, Weatherford Nig. Ltd. Port-Harcourt Nigeria.

[4]Department of Industrial Mathematics, Federal University of Technology, Owerri, Nigeria.

[5]Department of Environmental Science, Federal University of Technology, Owerri, Nigeria.

[6]Department of Material Science, Aveiro University, Portugal.

chikeyn@yahoo.com

Abstract: Model for predicting the concentration of iron upgraded during pyrobeneficiation of iron oxide ore (pelletized with powdered potassium chlorate) has been derived. 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 = 7.1367γ indicates that iron upgrade is dependent on the weight input of $KClO_3$. The validity of the model was rooted in the expression $(\%Fe/\gamma)^\alpha = (T/\beta)^N$ 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. [New York Science Journal. 2009;2(4):17-23]. (ISSN: 1554-0200).

Keywords: Model, Evaluation, Upgraded Iron, Pyrobeneficiation, Iron Oxide Ore.

1. Introduction

Agbaja iron ore deposit is the largest known Nigerian iron ore deposit estimated at 1250 metric tonnes of ore reserve. It consists of oolitic and pisolitic structures rich in iron oxides, in a matrix that is predominantly clay. The principal constituent mineral is goethite, with minor hematite, maghemite, siderite, quartz, kaolinite pyrite and an average of 0.09%S [1].

It was discovered that one of the most important factors influencing the desulphurization process during iron making is the state of oxidation of the bath [2].

Nwoye [3] 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) (KCI0$_3$) as oxidant has been reported [4]. Concentrates were treated at a temperature range 500 – 800^{0}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^{0}C respectively) are the ideal conditions for the best desulphurization efficiency.

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 [5]. Main parameters investigated were the effects of treatment temperature and oxidant (KClO$_3$) on the upgrading process. It was established that 800^{0}C is the optimum temperature for the upgrading step considering the range of temperature used (500-800^{0}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^{0}C respectively) during the process are vital conditions for improving on the grade of the ore concentrate.
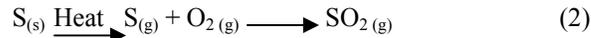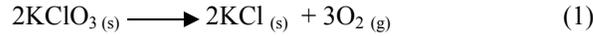
An intensive and selective oil agglomeration of Agbaja iron ore has been carried out [6]. The researcher, starting from the crude ore Fe content (45.6%), concentrated the ore by oil agglomeration technique to 90% Fe recovery and 65% Fe assay. He stated that the ore require grinding to minus 5μm to effect adequate liberation. These results were obtained at optimum pH 9. Successful studies [7] on the effect of temperature on magnetizing reduction of Agbaja iron ore have been carried out. 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^{0}C.

Attempt has been made to enhance concentrate Fe recovery [8]. 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.

The aim of this work is to derive a model for evaluating the concentration of iron upgraded during pyrobeneficiation of Agbaja (Nigeria) iron oxide ore with 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 [9] 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 (1) and (2) show this.

$$2KClO_{3\,(s)} \longrightarrow 2KCl_{(s)} + 3O_{2\,(g)} \qquad (1)$$

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

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

Results of the experiment as presented in report [10] and used for the model formulation are as shown in Table 1. Computational analysis of the experimental data [10] shown in Table 1, gave rise to Table 2 which indicate that;

$$(\%Fe/\gamma)^{\alpha} = (T/\beta)^{N} \quad \text{(approximately)} \qquad (3)$$

Taking logarithm of both sides of equation (3);

$$\text{Log}\,[(\%Fe/\gamma)^{\alpha}] = \text{Log}\,[(T/\beta)^{N}] \qquad (4)$$

$$\alpha \text{Log}(\%Fe/\gamma) = N\text{Log}(T/\beta) \qquad (5)$$

$$\alpha[\text{Log}(\%Fe/\gamma)] = N[\text{Log}T - \text{Log}\beta] \qquad (6)$$

$$\text{Log}(\%Fe/\gamma) = N/\alpha[\text{Log}T - \text{Log}\beta] \qquad (7)$$

Introducing the values of T, β, N and α into equation (7) reduces it to;

$$\text{Log}(\%Fe/\gamma) = 0.8535 \qquad (8)$$

$$(\%Fe/\gamma) = 10^{0.8535} \qquad (9)$$

$$(\%Fe/\gamma) = 7.1367 \qquad (10)$$

$$\%Fe/ = 7.1367\gamma \qquad (11)$$

Where

%Fe = Upgraded concentration of iron during the beneficiation process

N = 0.87 (Decomposition coefficient of $KClO_3$ during the beneficiation process) determined in the experiment [10].

(β) = Weight of iron oxide ore added during the beneficiation process (g)

(γ) = Weight of $KClO_3$ added during the beneficiation process (g).

T = Treatment temperature (^{0}C)

(α)= 1.10 (Oxidation coefficient of $KClO_3$ at the treatment temperature) determined in the experiment [10].

I_e =7.1367 (Assumed Iron Enhancement Factor)

Equation (11) is the derived model.

Table1:Variation of upgraded concentration of iron with weight-input of $KClO_3$.[10]

%Fe	(γ)	(β)
63.58	8	50
65.88	9	50
67.46	9.6	50
68.00	10	50
70.02	11	50
72.24	12	50

Table 2: Variation of $(\%Fe/\gamma)^{\alpha}$ with $(T/\beta)^{N}$

$(\%Fe/\gamma)^{\alpha}$	$(T/\beta)^{N}$
9.7781	8.6874
8.9323	8.6874
8.5399	8.6874
8.2368	8.6874
7.6597	8.6874
7.2037	8.6874

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 used; (50g), and treatment time; 360secs. were used. Treatment temperature; $600^{o}C$, ore grain size; 150μm, and weight of $KClO_3$; (8- 12g) were also used. These and other process conditions are as stated in the experimental technique [10].

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 [10] 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 the model-predicted %Fe values from experimental %Fe values is given by

$$Dv = \frac{Dp - DE}{DE} \times 100 \qquad (12)$$

Where Dp = Predicted %Fe values from model

   DE = Experimental %Fe values

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

$$Cf = -Dv \qquad (13)$$

Therefore

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

Introduction of the corresponding values of Cf from equation (14) into the model gives exactly the corresponding experimental %Fe values [10].

5. Results and Discussion

The derived model is equation (11). A comparison of the values of %Fe from the experiment and those from the model shows minimum positive and negative deviations less than 19% 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 (3) following the values $(\%Fe/\gamma)^{\alpha}$ and $(T/\beta)^N$ evaluated from Table 1 as a result of corresponding computational analysis. The validity of the model is rooted in equation (3) where both sides of the equation are correspondingly almost equal.

The model-predicted %Fe upgrades (as in equation (11)) were found to show a direct relationship with the weight-input of $KClO_3$ (agreeing with %Fe upgrades from the experiment as in Table 1) where 7.1367 acts as a multiplying constant of proportionality hence contributing to the iron upgrades mathematically. Based on the foregoing, the constant; 7.1367 is assumed to be the Iron Enhancement Factor I_e.

Table3: Comparison between %Fe upgrade as predicted by model and as obtained from experiment [10].

%Fe$_{exp}$	%Fe$_M$	Dv (%)	Cf (%)
63.58	57.0936	-10.20	+10.20
65.88	64.2303	-2.50	+2.50
67.46	68.5129	+1.57	-1.57
68.00	71.3670	+4.95	-4.95
70.02	78.5037	+12.12	-12.12
72.24	85.6404	+18.55	-18.55

Where

   %Fe$_{exp}$= %Fe upgrade from experiment [10]

   %Fe$_M$ = %Fe upgrade predicted by model

6. Conclusion

The model evaluates the upgraded iron concentration during pyrobeneficiation of Agbaja iron oxide ore pelletized with powdered potassium chlorate. The deviation of the model-predicted %Fe values from those of the experiment is less than 19% which is quite within the acceptable deviation limit of experimental results. The validity of the model is rooted in equation (3) where both sides of the equation are correspondingly almost equal.

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

Acknowledgement

Corresponding author:
Chukwuka Ikechukwu Nwoye
Department of Materials and Metallurgical Engineering, Federal University of Technology, Owerri

Nigeria.

chikeyn@yahoo.com

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2/5/2009