

# Multi-Factorial Analysis of Particulate Iron Ore Desulphurization during Beneficiation with Powdered Potassium Chlorate

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**Abstract** – Particulate iron ore desulphurization was carried out using powdered potassium chlorate which acted as an oxidant on the sulphur present in the ore. The process analysis and mechanism of the desulphurization process involving oxygen gas interaction with sulphur through molecular combination within the Gas Evolution Temperature Range (GETR); 375-502°C as observed in previous works were confirmed. It was observed that sulphur transformed into vapour within this temperature range facilitated easy reaction with oxygen gas produced from the decomposition of  $KClO_3$ . Sulphur present in the iron ore was successfully reduced to 0.007 % using 12g of  $KClO_3$  at a treatment temperature of 800°C. A model was derived and used as a tool for quantitative evaluation of removed sulphur concentration based on initial sulphur content, treatment temperature and mass-input of  $KClO_3$ . The derived model is expressed as;

$$S_R = 3 \times 10^{-4} \alpha^3 - 7.45 \times 10^{-3} \alpha^2 + 0.0613 \alpha + 0.0001 \gamma + \beta^2 - 0.1987$$

The validity of the three-factorial model was found to be rooted on the expression  $5.0327S_R + 1 = 1.5098 \times 10^{-3} \alpha^3 - 37.4937 \times 10^{-3} \alpha^2 + 0.3085 \alpha + 5.0327 \times 10^{-4} \gamma + 5.0327 \beta^2$  where both sides of the expression are correspondingly approximately equal. Statistical analysis of the derived model-predicted, regression model-predicted and experimental sulphur removed concentrations for each value of treatment temperature and mass-inputs of  $KClO_3$  considered shows a standard errors of 0.0025,  $3.01 \times 10^{-5}$  & 0.0057% and 0.0082, 0.0108 & 0.0105% respectively. Furthermore, removed sulphur concentration per unit treatment temperature as obtained from derived model-predicted, regression model-predicted and experimental results are  $1.51 \times 10^{-4}$ ,  $1.965 \times 10^{-4}$  and  $1.55 \times 10^{-4}$  %/°C respectively. Similarly, removed sulphur concentration per unit mass-input of  $KClO_3$  as obtained from derived model-predicted, regression model-predicted and experimental results are  $7.55 \times 10^{-3}$ ,  $9.825 \times 10^{-3}$  and  $7.75 \times 10^{-3}$  %/g. Deviation analysis indicates that the maximum deviation of the model-predicted removed sulphur concentration from the corresponding experimental results is less than 19.6%.

**Keywords** – Iron Ore, Gas Evolution Temperature Range (GETR), Powdered Potassium Chlorate, Sulphur.

## I. INTRODUCTION

Failure of steel put in service in very hot enclosure or environment has been attributed to presence of a

membrane of high concentration of sulphur as iron sulphide in the steel crystals (Chapman,1972). Under this condition, the material becomes embrittled abruptly fails due to hot shortness. It has been reported (Edneral,1979) that during heating of ingots before rolling or forging, the inter-granular sulphur-rich layers within the metal microstructure soften resulting to the destruction of the bonds between the grains and invariably results to crack formation during plastic working. This defect is also called hot or red shortness.

The need for very high quality defect free engineering structures has necessitated various researches aimed at reducing the sulphur content of the iron oxide ore to the generally admissible level since the admissible limit of sulphur content of pig iron for the production of ordinary low carbon steel is 0.030 percent (Kosmider and Danckert, 1973).

Kosmider and Danckert (1973) has reported iron extraction from iron ore and concentrates by pyrometallurgical processes based upon the application of heat and reducing gases. The report stated that at temperatures of 700° -1,100°C, iron oxides such as hematite ( $Fe_2O_3$ ) and magnetite ( $Fe_3O_4$ ), the principal iron-bearing minerals, are readily reduced to metallic iron. It is strongly believed that within this period, a reasonable quantity of the sulphur present in the ore is removed.

Currently, it is widely accepted to desulphurize pig iron outside of or during the blast furnace operation by way of filling a ladle with the pig iron and adding to it as a single charge or in a series of smaller incremental charges, soda in granulated or powder form (Kosmider and Danckert, 1973). Application of lime in various desulphurization methods has been as a mix (lime/magnesium mix) or a lone addition. The researchers observed that usage of "fluidized" lime and magnesium not only decreases explosion risks associated with usage of calcium carbide but reduces the cost of the treatment compared to the process of using calcium carbide. This technique also has less environmental impact. The researchers also explored the potentiality of using another technique for desulphurizing pig iron which involves blow by pneumatic means lime or calcium carbide powder into the inactive pig iron in the ladle by means of an immersion lance. This

complements a discontinuous method; where the pig iron to be desulphurized must first be collected in the ladle in order to desulphurize the total ladle content. Such large quantities of pig iron can be desulphurized in most metallurgical plants, however, this method is obviously relatively expensive.

Kosmider and Danckert (1973) observed that the degree of desulphurization is dependent: (1) upon the grain size of the desulphurizer, (2) upon the holding time of the pig iron in the reactor, (3) upon the initial sulphur content, and (6) upon the desired final content of sulphur in the pig iron. (4) upon the immersion depth of the blowing lance, (4) upon the quantity of the desulphurizer (kg per ton of pig iron).

The mechanism and process analysis of desulphurizing Agbaja iron ore concentrate using powdered potassium trioxochlorate (v) ( $KClO_3$ ) as oxidant has been carried out (Nwoye, 2009). Results of the study show in clear terms that the oxygen required for the desulphurization process was produced from the decomposition of  $KClO_3$  within a temperature range 375-502°C. The researcher 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 on 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) are the ideal conditions for the best desulphurization efficiency.

Several models (Nwoye et al., 2009a, 2009b, 2009c; Nwoye, 2010) have been derived for analysis of the removed sulphur concentration during desulphurization of iron oxide ore using powdered potassium chlorate ( $KClO_3$ ) as oxidant. Some of these models show significant dependence of sulphur removal on the treatment temperature (Nwoye et al., 2009a). The validity of the model;

$$\%S = 0.1011(\text{Log}T)^{-1} \quad (1)$$

was strongly rooted in the expression  $[(T)^{\gamma\%S}] = \alpha/k_n$  where both sides of the relationship are correspondingly almost equal. Similar derivation (Nwoye, 2010) predicted the concentration of removed sulphur based on the treatment temperature. The model is expressed as ;

$$\%S = 0.0745 (\text{Log}T)^{-1} \quad (2)$$

In both cases the temperatures are in degree celsius. Furthermore, Nwoye et al. (2009a), carried out an empirical analysis of sulphur removal based on the mass-input of  $KClO_3$ . Based on the model derived for analysis, the researchers found sulphur removal to be inversely proportional to the logarithm of the mass-input of the  $KClO_3$  used as oxidant. In the model [5 expressed as;

$$\%S = 0.0415 (\text{Log} \gamma)^{-1} \quad (3)$$

The validity of the model was rooted on the core expression  $k_n[(\gamma)^{\mu\%S}] = T/\alpha$  where both sides of the

expression are correspondingly almost equal. A very similar model (Nwoye et al., 2009c), expressed as;

$$\%S = 0.0357 (\text{Log} \alpha)^{-1} \quad (4)$$

shows that the concentration of removed sulphur is also inversely proportional to the logarithm of the mass-input of the  $KClO_3$  used as oxidant. The model also gives a single series factor predictive analysis of sulphur removal based on the quantity of potassium chlorate added during the process.

The aim of this work is to evaluate the prospect of reducing the sulphur content of Agbaja iron ore below 0.02wt% using powdered potassium chlorate as an oxidant, and then attempt a quantitative evaluation of sulphur removal based on initial sulphur content, treatment temperature and  $KClO_3$  mass-input. The essence of this work is stemmed on the difficulty in achieving reduction in the iron ore sulphur content below 0.020% in the blast furnace. A feat also considered to be very expensive.

## II. MATERIALS AND METHODS

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; 150 $\mu$ m. A weighed quantity of the dried iron ore concentrate was mixed with different proportions of powdered  $KClO_3$  (obtained from Fisher Scientific Company Fair Lawn, New Jersey, USA) as weighed with a triple beam balance at NMDC laboratory. Iron crucibles were filled with the sample mixtures of 5g of  $KClO_3$  and 50g of ore concentrate. These samples in the crucibles were then heated to a temperature of 500°C in a Gallenkamp Hot pot electric furnace at NMDC Laboratory for 5 minutes and thereafter were emptied on white steel pans for observation. The experiment was repeated using varied combination of mass-input of  $KClO_3$  i.e 7, 10, 11, 12 and treatment temperature i.e 500, 600, 700, 750 and 800°C, while the mass-input of the ore is kept constant. Weighed quantities of the sample mixtures for each experiment set were taken (after being heated) for chemical analysis (to determine percentage sulphur removal) using wet analysis method. The average of the sulphur removed concentration determined in each experiment set was taken as the precise result.

It is important to state that treatment temperature range was chosen to prevent the melting of the ore during the process.

## III. MODEL FORMULATION

Experimental data obtained from the highlighted research work were used for the model derivation. Computational analysis of these data shown in Table 2, gave rise to Table 3 which indicate that;

$$K_e S_R + 1 \approx N\alpha^3 - N_e \alpha^2 + S\alpha + S_e \gamma + K \beta^2 \quad (5)$$

Introducing the values of K,  $K_e$ , N,  $N_e$ , S, and  $S_e$  into equation (5)

$$5.0327 S_R + 1 = 1.5098 \times 10^{-3} \alpha^3 - 37.4937 \times 10^{-3} \alpha^2 + 0.3085 \alpha + 5.0327 \times 10^{-4} \gamma + 5.0327 \beta^2 \quad (6)$$

$$5.0327 S_R = 1.5098 \times 10^{-3} \alpha^3 - 37.4937 \times 10^{-3} \alpha^2 + 0.3085 \alpha + 5.0327 \times 10^{-4} \gamma + 5.0327 \beta^2 - 1 \quad (7)$$

$$S_R = \left( \frac{1.5098 \times 10^{-3} \alpha^3 - 37.4937 \times 10^{-3} \alpha^2 + 0.3085 \alpha + 5.0327 \times 10^{-4} \gamma + 5.0327 \beta^2 - 1}{5.0327} \right) \quad (8)$$

$$S_R = 3 \times 10^{-4} \alpha^3 - 7.45 \times 10^{-3} \alpha^2 + 0.0613 \alpha + 0.0001 \gamma + \beta^2 - 0.1987 \quad (9)$$

Where

$S_R$  = Conc. of removed sulphur (%)

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

$(\beta)$  = Initial sulphur content of the ore (%)

$N = 1.5098 \times 10^{-3}$ ; Equalizing constant (determined using C-NIKBRAN (Nwoye, 2008))

$(\alpha)$  = Mass-input of  $\text{KClO}_3$  (g)

$N_e = 37.4937 \times 10^{-3}$ ; Equalizing constant (determined using C-NIKBRAN(Nwoye, 2008))

$S = 0.3085$ ; Equalizing constant (determined using C-NIKBRAN (Nwoye, 2008))

$S_e = 5.0327 \times 10^{-4}$ ; Equalizing constant (determined using C-NIKBRAN(Nwoye, 2008))

$K = 5.0327$ ; Equalizing constant (determined using C-NIKBRAN (Nwoye, 2008))

$K_e = 5.0327$ ; Equalizing constant (determined using C-NIKBRAN (Nwoye, 2008))

#### IV. 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  $\text{KClO}_3$  (due to air in the furnace). Mass of iron oxide ore: (50g), treatment time: 300 secs., treatment temperature range: 500-800 $^{\circ}\text{C}$ , ore grain size; 150 $\mu\text{m}$ , and mass of  $\text{KClO}_3$ ; (7-12g) were also used.

The boundary conditions are: furnace oxygen atmosphere due to decomposition of  $\text{KClO}_3$  (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.

#### V. RESULTS AND DISCUSSIONS

The result of the chemical analysis carried out on the beneficiated iron ore concentrate is presented in Table 1. The table shows that the percentage of sulphur present in the as-beneficiated ore is 0.09%.

Table 1: Result of chemical analysis of iron ore used

Element/Compound	Fe	S	$\text{SiO}_2$	$\text{Al}_2\text{O}_3$
Unit (%)	56.2	0.09	15.91	5.82

Oxygen gas from the decomposition of  $\text{KClO}_3$  attacked the ore in a gas-solid reaction in line with previous work (Nwoye, 2009), hence removing (through oxidation) the

sulphur present in the ore in the form of  $\text{SO}_2$  Equations (10) and (11) show this.

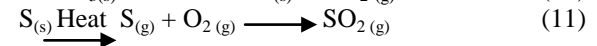
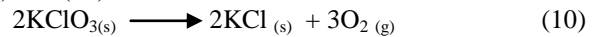


Table 2 shows that at constant treatment temperature, the concentration of removed sulphur increases with increase in the mass-input of  $\text{KClO}_3$ . On the other hand, at constant mass-input of  $\text{KClO}_3$  the removed sulphur concentration increases with increase in the treatment temperature.

Table 2: variation of removed sulphur concentration with treatment temperature and mass-input of  $\text{KClO}_3$ .

Temp. $^{\circ}\text{C}$	Mass of $\text{KClO}_3$ (g)	$S_R$ (%)
500	7	0.022
600	7	0.031
600	10	0.040
700	11	0.053
750	12	0.064
800	12	0.083

Table 3: Variation of  $5.0327 S_R + 1$  and  $1.5098 \times 10^{-3} \alpha^3 - 37.4937 \times 10^{-3} \alpha^2 + 0.3085 \alpha + 5.0327 \times 10^{-4} \gamma + 5.0327 \beta^2$

$5.0327 S_R + 1$	$1.5098 \times 10^{-3} \alpha^3 - 37.4937 \times 10^{-3} \alpha^2 + 0.3085 \alpha + 5.0327 \times 10^{-4} \gamma + 5.0327 \beta^2$
1.1107	1.1326
1.1560	1.1830
1.2013	1.1882
1.2667	1.2594
1.3221	1.3301
1.4177	1.3552

#### VI. MODEL VALIDATION

The validity of the model is strongly rooted in equation (6) (core model equation) where both sides of the equation are correspondingly approximately equal. Table 3 also agrees with equation (6) following the values of  $5.0327 S_R + 1$  and  $1.5098 \times 10^{-3} \alpha^3 - 37.4937 \times 10^{-3} \alpha^2 + 0.3085 \alpha + 5.0327 \times 10^{-4} \gamma + 5.0327 \beta^2$  evaluated from the experimental results in Table 2.

Furthermore, the derived model was validated by comparing the removed sulphur 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.

**VII. COMPUTATIONAL ANALYSIS**

A comparative computational analysis of the experimental and model-predicted removed sulphur concentration were carried out to ascertain the degree of validity of the derived model. This was done by comparing sulphur removal per unit rise in treatment temperature and sulphur removal per unit mass-input of  $KClO_3$  evaluated from model-predicted results with those from actual experimental results

Removed sulphur concentration per unit mass-input of  $KClO_3$   $S_C^M$  (%/g) was calculated from the equation;

$$S_C^M = S_C / M \tag{12}$$

Therefore, a plot of the concentration of sulphur removed against mass-input of  $KClO_3$  as in Fig. 1 using experimental results in Table 2, gives a slope, S at points (7, 0.022) and (11, 0.053) following their substitution into the mathematical expression;

$$S_C^M = \Delta S_C / \Delta M \tag{13}$$

Equation (13) is detailed as

$$S_C^M = S_C2 - S_C1 / M2 - M1 \tag{14}$$

Where

$\Delta S_R$  = Change in removed sulphur concentrations of  $S_{C2}, S_{C1}$  at two mass-input values of  $KClO_3$   $M_2, M_1$ . Considering the points (7, 0.022) and (11, 0.053) for  $(M_1, S_{C1})$  and  $(M_2, S_{C2})$  respectively, and substituting them into equation (14), gives the slope as  $7.75 \times 10^{-3}$  %/g which is the removed sulphur concentration per mass-input of  $KClO_3$  during the actual desulphurization process.

A plot of the concentration of sulphur removed against mass-input of  $KClO_3$  (as in Fig. 2) using derived model-predicted results gives a slope:  $7.55 \times 10^{-3}$  %/g on substituting the points (7, 0.0263) and (11, 0.0565) for  $(M_1, S_{C1})$  and  $(M_2, S_{C2})$  respectively into equation (14). This is the model-predicted removed sulphur concentration per mass-input of  $KClO_3$ .

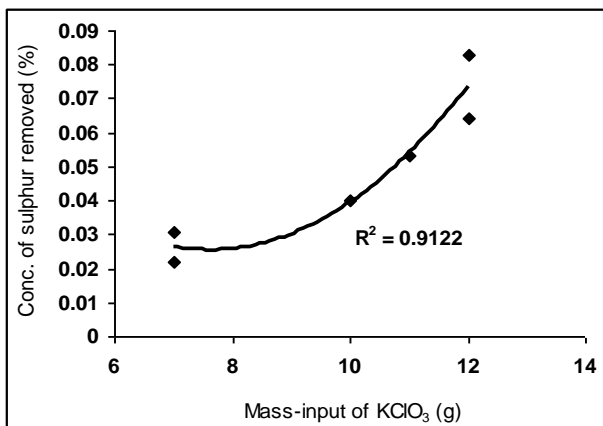


Fig.1. Coefficient of determination between concentration of removed sulphur and mass-input of  $KClO_3$  as obtained from the experiment

Similarly, a plot of the concentration of sulphur removed against mass-input of  $KClO_3$  (as in Fig. 3) using regression model-predicted results gives a slope:  $9.825 \times 10^{-3}$  %/g on substituting the points (7, 0.0177) and (11, 0.057) for  $(M_1, S_{C1})$  and  $(M_2, S_{C2})$  respectively into equation (14). This is the regression model-predicted removed sulphur concentration per mass-input of  $KClO_3$ .

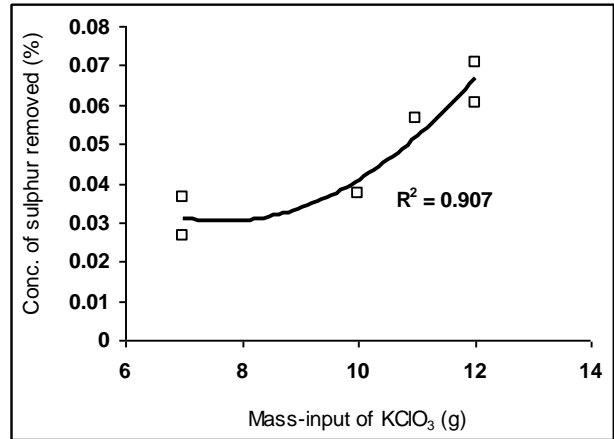


Fig.2. Coefficient of determination between concentration of removed sulphur and mass-input of  $KClO_3$  as obtained from derived model

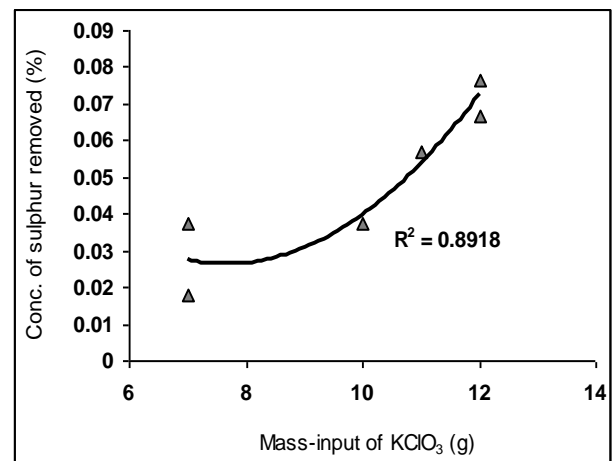


Fig.3. Coefficient of determination between concentration of removed sulphur and mass-input of  $KClO_3$  as obtained from regression model

Removed sulphur concentration per unit rise in treatment temperature of  $KClO_3$   $S_C^T$  (%/ $^{\circ}C$ ) was calculated from the equation;

$$S_C^T = S_C / T \tag{15}$$

Therefore, a plot of the concentration of sulphur removed against treatment temperature as in Fig. 4 using experimental results in Table 2, gives a slope, S at points (500, 0.022) and (700, 0.053) following their substitution into the mathematical expression;

$$S_C^T = \Delta S_C / \Delta T \tag{15}$$

Equation (15) is detailed as

$$S_C^T = S_C2 - S_C1 / T2 - T1 \tag{16}$$

Where

$\Delta S_R$  = Change in removed sulphur concentrations of  $S_{C2}, S_{C1}$  at two treatment temperature values  $T_2, T_1$ . Considering the points (500, 0.022) and (700, 0.053) for  $(T_1, S_{C1})$  and  $(T_2, S_{C2})$  respectively, and substituting them into equation (16), gives the slope as  $1.55 \times 10^{-4}$  %/ $^{\circ}C$  which is the sulphur removal per unit rise in treatment temperature during the actual desulphurization process.

Furthermore, a plot of the concentration of sulphur removed against treatment temperature (as in Fig. 5) using derived model-predicted results gives a slope:  $1.51 \times 10^{-4} \%/^{\circ}\text{C}$  on substituting the points (500, 0.0263) and (700, 0.0565) for  $(T_1, S_{C1})$  and  $(T_2, S_{C2})$  respectively into equation (16). This is the model-predicted removed sulphur per unit rise in treatment temperature.

Also a plot of the concentration of sulphur removed against treatment temperature (as in Fig. 6) using regression model-predicted results gives a slope:  $1.965 \times 10^{-4} \%/^{\circ}\text{C}$  on substituting the points (500, 0.0177) and (700, 0.057) for  $(T_1, S_{C1})$  and  $(T_2, S_{C2})$  respectively into equation (16). This is the regression model-predicted sulphur removal per unit rise in treatment temperature.

A comparison of these two sets of values for removed sulphur concentration (per unit mass-input of  $\text{KClO}_3$  and per unit treatment temperature) also shows proximate agreement and a high degree of validity of the derived model.

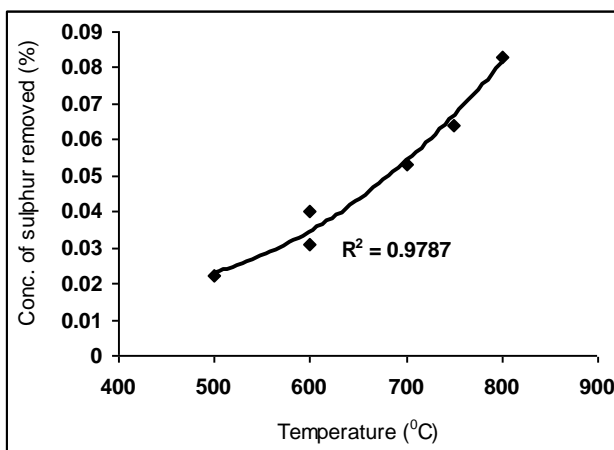


Fig.4. Coefficient of determination between concentration of removed sulphur and treatment temperature as obtained from the experiment

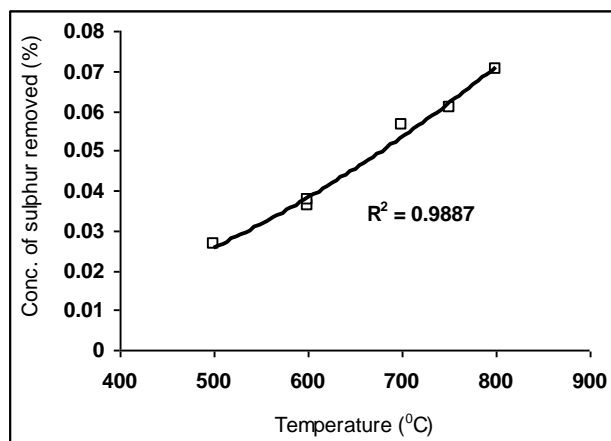


Fig.5. Coefficient of determination between concentration of removed sulphur and treatment temperature as obtained from derived model

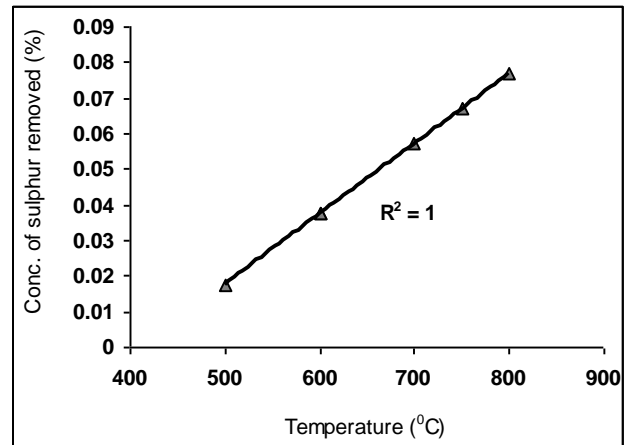


Fig.6. Coefficient of determination between concentration of removed sulphur and treatment temperature as obtained from regression model

## VII. STATISTICAL ANALYSIS

The standard error (STEYX) in predicting the removed sulphur concentration (using results from derived model, regression model and experiment) for each value of the treatment temperature and mass-input of  $\text{KClO}_3$  are 0.0025,  $3.01 \times 10^{-5}$  & 0.0057 % and 0.0082, 0.0108 & 0.0105 % respectively. The standard error was evaluated using Microsoft Excel version 2003.

Also the correlations between removed sulphur concentration and mass-input of  $\text{KClO}_3$  as well as removed sulphur concentration and treatment temperature as obtained from derived model, regression model and experiment considering the coefficient of determination  $R^2$  from Figs. 1-6 was calculated using the equation;

$$R = \sqrt{R^2} \quad (17)$$

and confirmed using Microsoft Excel version 2003 [8]. The evaluations show correlations 0.9524, 0.9444 and 0.9551 as well as 0.9943, 1.0000 and 0.9893 respectively. These evaluated results indicate that the derived model predictions are significantly reliable and hence valid considering its proximate agreement with results from regression model and actual experiment.

## VIII. GRAPHICAL ANALYSIS

Comparative graphical analysis of Figs. 7 and 8 shows very close alignment of the curves from model-predicted removed sulphur 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 sulphur removed concentration.

### Comparison of derived model with standard model

The validity of the derived model was further verified through application of the regression model (Least Square Method (ReG)) in predicting the trend of the experimental results. Comparative analysis of Figs. 9-11 shows very close alignment of curves and significantly similar trend of data point's distribution for experimental (ExD), derived

model-predicted (MoD) and regression model predicted (ReG) results of removed sulphur concentration.

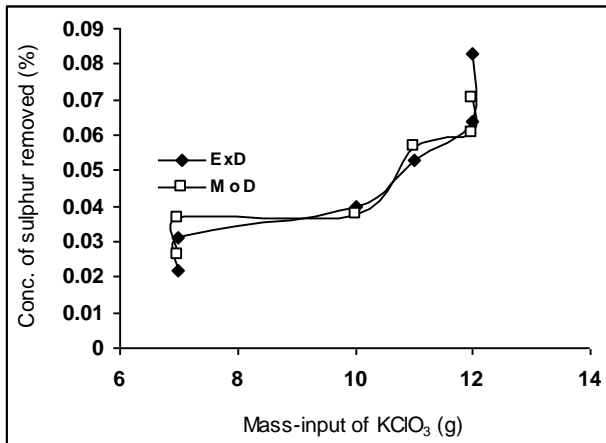


Fig.7. Comparison of the concentrations of removed sulphur (relative to mass-input of  $KClO_3$ ) as obtained from experiment and derived model

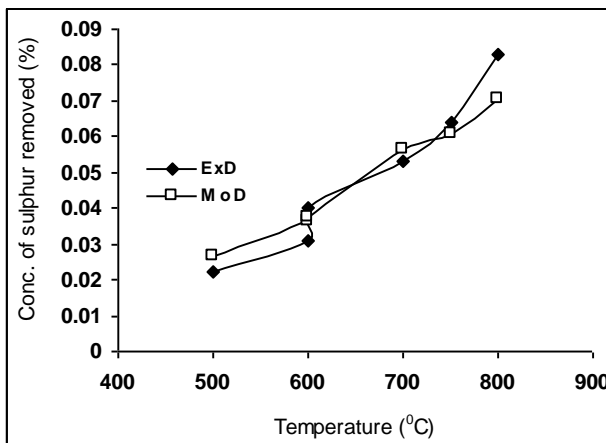


Fig.8. Comparison of the concentrations of removed sulphur (relative to treatment temperature) as obtained from experiment and derived model

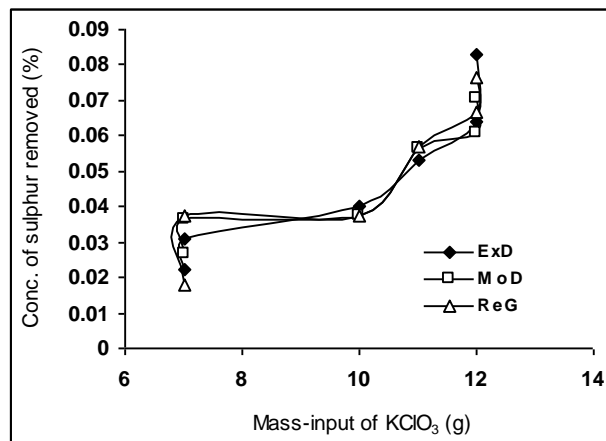


Fig.9. Comparison of the concentrations of removed sulphur (relative to mass-input of  $KClO_3$ ) as obtained from derived model, regression model and experiment

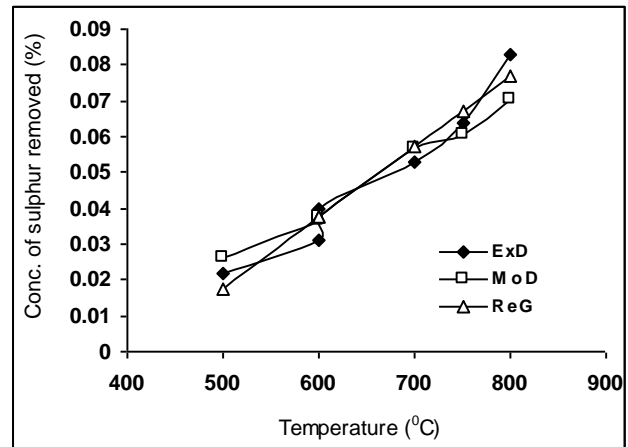


Fig.10. Comparison of the concentrations of removed sulphur (relative to treatment temperature) as obtained from derived model, regression model and experiment (DIRECT DATA SPREAD)

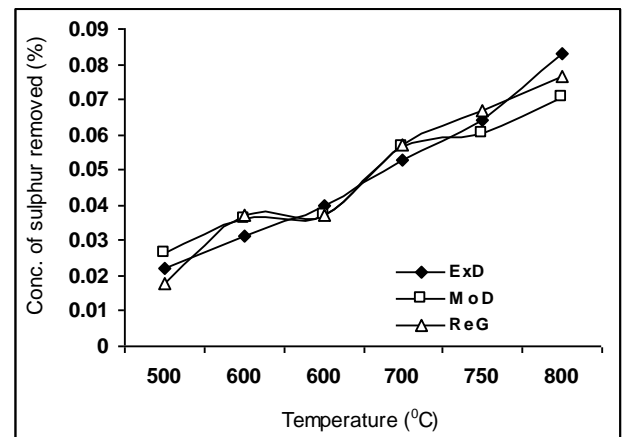


Fig.11. Comparison of the concentrations of removed sulphur (relative to treatment temperature) as obtained from derived model, regression model and experiment (LINE DATA SPREAD)

## IX. DEVIATIONAL ANALYSIS

Analysis of removed sulphur 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 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 removed sulphur concentration to those of the corresponding experimental values.

Deviation ( $D_n$ ) of model-predicted removed sulphur concentration from that of the experiment is given by

$$D_n = \left( \frac{P_s - E_s}{E_s} \right) \times 100 \quad (18)$$

Where

$P_s$  = Removed sulphur concentration as predicted by derived model

$E_s$  = Removed sulphur concentration as obtained from experiment

Correction factor ( $Cr$ ) is the negative of the deviation i.e  
 $Cr = -Dn$  (19)

Therefore

$$Cr = -\left(\frac{Ps - Es}{Es}\right) \times 100 \quad (20)$$

Introduction of the corresponding values of  $Cr$  from equation (20) into the derived model gives exactly the removed sulphur concentration as obtained from experiment.

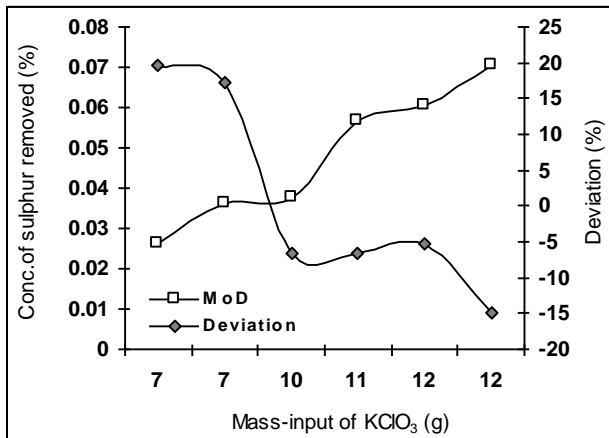


Fig. 12. Variation of model-predicted removed sulphur concentration with associated deviation from experimental results (relative to mass-input of  $KClO_3$ )

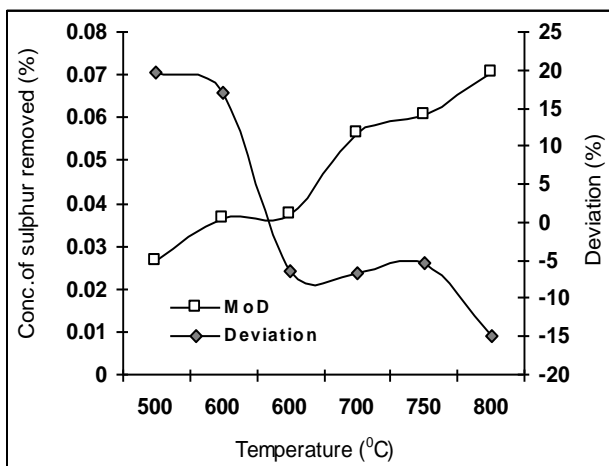


Fig. 13. Variation of model-predicted removed sulphur concentration with associated deviation from experimental results (relative to treatment temperature)

Figs. 12 and 13 show that the maximum deviation of the mode-predicted removed sulphur concentration from the corresponding experimental values is less than 19.6% and quite within the acceptable deviation limit of experimental results. These figures show that the least and highest magnitudes of deviation of the model-predicted removed sulphur concentration (from the corresponding experimental values) are -5.31 and + 19.55 % which

corresponds to removed sulphur concentrations: 0.0606 and 0.0263, treatment temperatures: 750 and 500°C, as well as ore mass-inputs: 12 and 7g respectively.

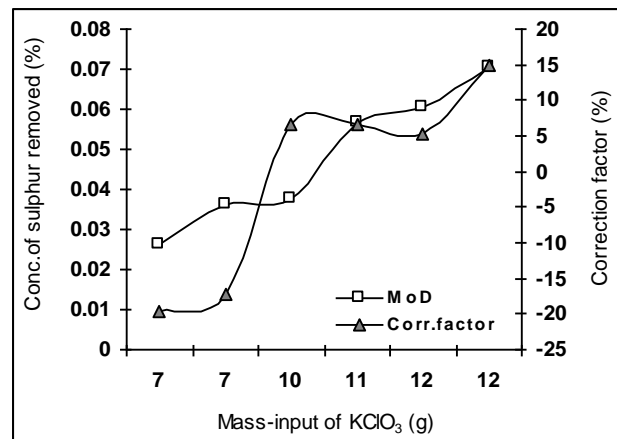


Fig. 14: Variation of model-predicted removed sulphur concentration with associated correction factor (relative to mass-input of  $KClO_3$ )

Comparative analysis of Figs. 12-15 indicates that the orientation of the curve in Figs. 14 and 15 is opposite that of the deviation of model-predicted removed sulphur concentration (Figs. 12 and 13). This is because correction factor is the negative of the deviation as shown in equations (19) and (20).

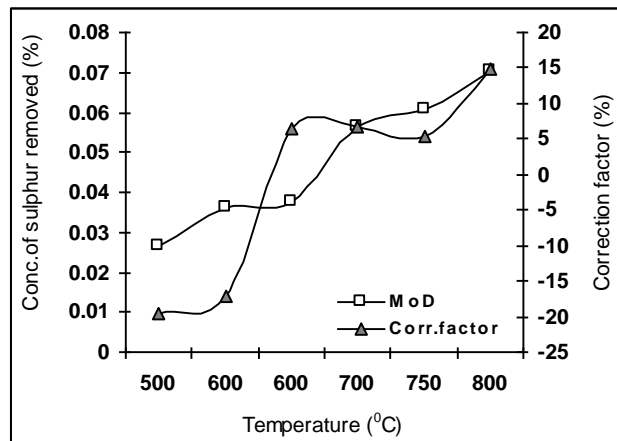


Fig. 15. Variation of model-predicted removed sulphur concentration with associated correction factor (relative to treatment temperature)

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 which were found to have played vital roles during the process were not considered during the model formulation. Figs. 14 and 15 indicate that the least and highest magnitudes of correction factor to the model-predicted removed sulphur concentration are +5.31 and -19.55 % which corresponds to removed sulphur concentrations: 0.0606 and 0.0263, treatment temperatures: 750 and 500°C, as well as ore mass-inputs: 12 and 7g 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).

## X. CONCLUSIONS

Particulate iron ore desulphurization was carried out using powdered potassium chlorate which acted as an oxidant on the sulphur present in the ore. The process analysis and mechanism of the desulphurization process involved oxygen gas interaction with sulphur through molecular combination within the Gas Evolution Temperature Range (GETR); 375-502°C. Sulphur transformed into vapour within this temperature range facilitated easy reaction with oxygen gas produced from the decomposition of  $\text{KClO}_3$ . Sulphur present in the iron ore was successfully reduced to 0.007 % using 12g of  $\text{KClO}_3$  at a treatment temperature of 800°C. A model was derived and used as a tool for quantitative evaluation of removed sulphur concentration based on initial sulphur content, treatment temperature and mass-input of  $\text{KClO}_3$ . The validity of the three-factorial model was found to be rooted on the expression  $5.0327S_R + 1 = 1.5098 \times 10^{-3} \alpha^3 - 37.4937 \times 10^{-3} \alpha^2 + 0.3085 \alpha + 5.0327 \times 10^{-4} \gamma + 5.0327 \beta^2$  where both sides of the expression are correspondingly approximately equal. Statistical analysis of the derived model-predicted, regression model-predicted and experimental sulphur removed concentrations for each value of treatment temperature and mass-inputs of  $\text{KClO}_3$  considered shows a standard errors of 0.0025,  $3.01 \times 10^{-5}$  & 0.0057% and 0.0082, 0.0108 & 0.0105% respectively. Furthermore, removed sulphur concentration per unit treatment temperature as obtained from derived model-predicted, regression model-predicted and experimental results are  $1.51 \times 10^{-4}$ ,  $1.965 \times 10^{-4}$  and  $1.55 \times 10^{-4} \text{ %/}^\circ\text{C}$  respectively. Similarly, removed sulphur concentration per unit mass-input of  $\text{KClO}_3$  as obtained from derived model-predicted, regression model-predicted and experimental results are  $7.55 \times 10^{-3}$ ,  $9.825 \times 10^{-3}$  and  $7.75 \times 10^{-3} \text{ %/g}$ . Deviation analysis indicates that the maximum deviation of the model-predicted removed sulphur concentration from the corresponding experimental results is less than 19.6%.

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