

Predictability of Sulphur Removal Efficiency during Processing of Iron Ore Designated for Production of Orthopedics Devices

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Abstract Predictability of sulphur removal efficiency of iron ore (designated for production of orthopedic devices) has carried out based treatment temperature and mass-input of $KClO_3$ used as oxidizing agent. Results generated from experiment, derived model and regression model show that sulphur removal efficiencies increases with increase in both treatment temperature and mass-input of $KClO_3$ up to $800^\circ C$ and 12g of $KClO_3$ respectively. A two-factorial empirical model was derived, validated and used for the predictive analysis. The validity of the derived model expressed as: $\mathcal{J} = 1.5 \times 10^{-11} \varpi^{4.3318} + 5.6655 \vartheta - 25.237$ was rooted in the model core expression $\mathcal{J} + 25.237 = 1.5 \times 10^{-11} \varpi^{4.3318} + 5.6655 \vartheta$, where \mathcal{J} , ϖ and ϑ are the sulphur removal efficiency, treatment temperature and mass-input of $KClO_3$ respectively. Both sides of the core expression are correspondingly approximately equal. This research presents the possibility of limiting the Processed Iron Ore Remnant Sulphur (PIORS) through strategized input of ϖ and ϑ during processing of iron ore designated for orthopedic devices. This was geared towards enhancing the durability and biocompatibility of medical devices made of steel since PIORS is deleterious to the mechanical properties and functional performance of the steel-made medical devices. Sulphur removal efficiency per unit rise in treatment temperature & per unit mass-input of $KClO_3$ as well as standard error incurred in predicting the sulphur removal efficiency for each value of the treatment temperature & mass-input of $KClO_3$ as obtained from experimental, derived model and regression model predicted results were 0.2422, 0.2659 and 0.2493 % / $^\circ C$ & 11.0109, 12.0865 and 11.3315 % /g as well as 6.5587, 6.3878 and 3.3787×10^{-5} & 3.2057, 2.6827 and 3.5936% respectively. The correlations between sulphur removal efficiency and treatment temperature & per unit mass-input of $KClO_3$ as obtained from experiment, derived model and regression model indicated were all > 0.98 . Deviation analysis revealed that the maximum deviation of model-predicted sulphur removal efficiency from the experimental results is 12.33%. This invariably translated into over 87% operational confidence for the derived model as well as over 0.87 dependency coefficients of sulphur removal efficiency on treatment temperature and $KClO_3$ addition.

Keywords: prediction, sulphur removal efficiency, iron ore processing, orthopedics devices production

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1. Introduction

Research [1] has identified metals as biomaterials due to their immense strength and toughness. Results of the research revealed that the widely used implant metals such stainless steel, titanium and cobalt alloys are generally biocompatible and some have adverse effect on the human health due to ions released and impurities (not properly removed during processing) from these metals. The research also reported that the major problem with metals is the generation of fine wear particles in service that can lead to inflammation and implant loosening.

The researcher concluded that biocompatibility should prevail in the biometal-biomedical device interaction within the body system, since biometals and associated biomedical devices are used in some parts of the human body.

Report [2] revealing medical practices, has shown that placing a prosthetic device into the body, goes with two considerations which include: functional performance & biocompatibility as well as nature of the physiological environment.

Functional performance considers the effect of the physiological environment on the biometal/device [2]. This implies that the biometal must satisfy its design

requirements with respect to the environment where it serves with time. The various functions to which biometal is put includes: control of blood and fluid flow; eg artificial heart, electrical stimuli; eg pacemaker, light transmission; eg implanted lenses and sound transmission; eg cochlear implant. It is expected that biometals must not degrade in their various properties within the environment of the body and must not cause any adverse reactions within the host body. This is in line with the requirement and expectation for biocompatibility [2].

Further studies [2] on the physiological environment on which biometals and associated biodevices can operate indicate aqueous solution made up of 0.9M NaCl, containing organic acids, proteins, enzymes, biological macromolecules, electrolytes and dissolved oxygen, nitrogen compounds, and soluble carbonate. Results from the research [2] shows that $\text{pH} \approx 7.4$ is normal for physiological extracellular fluid. The research also shows that cells (eg. inflammatory cells and fibrotic cells) secrete several complex compounds that may significantly affect an implanted biomaterial. Furthermore, applications of these biometals/devices have been reported [2] to be also dependent on mechanical environment: static, dynamic, stress, strain and friction which degrades the metal through corrosion, dissolution and leaching. Medical practice has shown that the resultant degradation, affects the materials adversely in terms of strength, fracture toughness and wear resistance [2].

The raw material for steel production is iron oxide ore. Steel is chiefly made up of over 95% Fe and carbon less than 1% [3]. Increasing addition of Cr into the Fe and C matrix and structure re-designs the steel to stainless steel [4]. Addition of nickel to the stainless steel microstructure causes the austenite structure to be maintained at room temperature hence producing austenitic stainless steel [4]. The research [4] identified 316 stainless steel as useful in producing early hip implants due to its good strength, ability to work harden and pitting corrosion resistance. Stainless steel usage in biomedical engineering is restricted to short term use according to ISO standards (for devices such as screws, plates, fittings and wires for orthopaedics) due to potential long term release of Ni^{2+} , Cr^{3+} , and Cr^{6+} into the body [4].

The mechanical properties of stainless steel includes: ultimate tensile strength (UTS); 190-690Mpa and elongation; 12- 40% [3]. The mechanical properties of iron and steel products are deleteriously affected by sulphur. Any sulphur content of the pig iron (from which steel is made), in excess of an admissible limit (0.01%), has to be reduced outside or during the blast furnace operations. This will improve the quality and purity of the produced steel designated for the manufacture of medical devices.

Studies [5] on desulphurization has shown that failure of steel put in service in very hot environment is due to presence of a membrane of high concentration of sulphur as iron sulphide in steel crystals.

Empirical models [6,7,8,9,10] have been derived for predicting the concentration of sulphur removed during desulphurization of iron oxide ore using powdered potassium chlorate (KClO_3) as oxidant. These models show the dependency of sulphur removal on the mass-input of KClO_3 (used as oxidizing agent) and treatment temperature [7]. The validity of the models which show

dependency of sulphur removal on treatment temperature are rooted on the expression $[(\text{T})^{\gamma\%S}] = \alpha/k_n$ where both sides of the relationship are correspondingly almost equal. On the other hand, those which show dependency of sulphur removal on mass-input of KClO_3 are rooted on the expression $k_n[(\gamma)^{\mu\%S}] = \text{T}/\alpha$.

Research [11] has been carried out to study the limit of desulphurization of iron ore, as function of the initial sulphur content of the ore and removed sulphur concentration. Investigation on the process analysis and mechanism of the desulphurization process revealed that oxygen gas from the decomposition of KClO_3 interacted with sulphur through molecular combination within the Gas Evolution Temperature Range (GETR); 375-502°C. Sulphur transformation into vapour within this temperature range was observed to facilitate easy reaction with oxygen gas to form SO_2 . A limit of desulphurization; 92.22% was experimentally achieved following successful reduction of the initial ore sulphur content from 0.09 to 0.007 % using 12g of KClO_3 at a treatment temperature of 800°C.

A model expressed as;

$$D_L = 0.1954\alpha^2 + 0.3111\alpha + 1.3333 \times 10^{-4} \gamma^2 - 0.1075\gamma + 33.3333\beta + 24.6708 \quad (1)$$

was derived and used as a tool for empirical analysis of limit of desulphurization based on treatment temperature, mass-input of KClO_3 , sulphur loss-sulphur initial ratio.

Deviational analysis indicates that the derived model gives best-fit process analysis with a deviation range of just 0.65-8.82%, from experimental results and invariably an operational confidence level range 91.18-99.35%. The deviation range corresponds to limit of desulphurization range: 31.4019-86.6128%, treatment temperature range: 600-800°C, KClO_3 mass-input range: 7-12g and range of sulphur loss-sulphur initial ratio: 0.3444-0.5556. Hence, the derived model can exclusive, be significantly and viably operational within these process conditions.

This research is aimed at treating iron ore with powdered potassium chlorate (under the influence of temperature) with the view to predicting sulphur removal efficiency (based on the input variables) during preparation of iron ore for making steel designated for production of orthopedic devices. The essence of this work is stemmed on the need to drastically reduce the sulphur content of iron ore below even the admissible limit so as to maintain high quality, purity and biocompatibility level for the steel when used for producing orthopedic devices. This process is expected to be carried out outside and before the blast furnace operation of iron and steel making.

2. 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 μm . 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 $500^\circ C$ 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, 9, 10.5, 12 and treatment temperature i.e 600, 700, 750 and $800^\circ C$, 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.

Sulphur removal efficiency \mathcal{J} was calculated from the expression [11]

$$\mathcal{J} = \frac{S_o - S_F}{S_o} \times 100 \quad (2)$$

Where

\mathcal{J} is the sulphur removal efficiency (%), S_F is the sulphur content of the ore after treatment and S_o is the initial sulphur content of the ore (before treatment).

2.1. 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, indicate that;

$$\mathcal{J} + S = N \mathcal{r}^{\mathcal{h}} + K \mathcal{\vartheta} \quad (3)$$

Substituting the values of S , N , \mathcal{h} and K into equation (3) reduces it to;

$$\mathcal{J} + 25.237 = 1.5 \times 10^{-11} \mathcal{r}^{4.3318} + 5.6655 \mathcal{\vartheta} \quad (4)$$

$$\mathcal{J} = 1.5 \times 10^{-11} \mathcal{r}^{4.3318} + 5.6655 \mathcal{\vartheta} - 25.237 \quad (5)$$

Where

$S = 25.237$, $N = 1.5 \times 10^{-11}$, $\mathcal{h} = 4.3318$ and $K = 5.6655$ are equalizing constants (Determined using C-NIKBRAN [12])

(\mathcal{J}) = Sulphur removal efficiency (%)

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

$(\mathcal{\vartheta})$ = Mass input of $KClO_3$ (g)

2.2. Boundary and Initial Condition

Consider iron ore (in a furnace) mixed with potassium chlorate (oxidizing agent). 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). Mass of iron oxide ore: (50g), treatment time: 300 secs., treatment temperature range: $500-800^\circ C$, ore grain size; $150\mu m$, and mass of $KClO_3$; (5-12g) were also used.

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.

3. 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	SiO ₂	Al ₂ O ₃
Unit (%)	56.2	0.09	15.91	5.82

It is strongly believed that oxygen gas from the decomposition of $KClO_3$ attacked the ore in a gas-solid reaction in line with previous work [6], hence removing (through oxidation) the sulphur present in the ore as S in the form of SO_2 . Equations (6) and (7) show this.

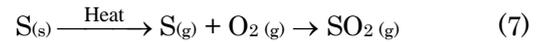
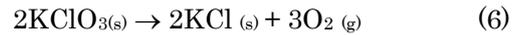


Table 2. Variation of sulphur removal efficiency with treatment temperature and mass-input of $KClO_3$

Temp.($^\circ C$)	Mass of $KClO_3$ (g)	\mathcal{J} (%)
500	5	11.11
600	7	34.44
700	9	51.11
750	10.5	71.67
800	12	92.22

It is very important to state in clear terms that the treatment temperature remained constant during investigation of the effect of mass-input of $KClO_3$ on the removal of sulphur. On the other hand, the mass-input of $KClO_3$ remained constant during investigation of the effect of treatment temperature on the sulphur removal. Table 2 was constituted by just picking at random (from the whole expanse of experimentally generated results) different sets of values of treatment temperature and mass-input of $KClO_3$ corresponding to the same sulphur removal efficiency. The essence of this was to achieve a predictive analysis of the sulphur removal efficiency for any random and corresponding combination of the input process parameters: treatment temperature and mass-input of $KClO_3$ (within the boundary conditions) during desulphurization of the iron ore. This quickly gives a metallurgist an idea of the treatment temperature - mass-input of $KClO_3$ combination that will likely remove sulphur most.

Even though Table 2 is randomly constituted, it still shows that the efficiency of sulphur removal increases with increase in the treatment temperature and mass-input of $KClO_3$ up to $800^\circ C$ and 12g of $KClO_3$ respectively.

3.1. Model Validation

The validity of the model is strongly rooted in equation (4) (core model expression) where both sides of the

equation are correspondingly approximately equal, following the values of $\delta_2 + 25.237$ and $1.5 \times 10^{-11} \gamma^{4.3318} + 5.6655 \theta$ evaluated from the experimental results in Table 2.

Furthermore, the derived model was validated by comparing the sulphur removal efficiencies 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.

3.2. Computational Analysis

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

Sulphur removal efficiency per unit mass-input of $KClO_3$ S_e^M (%/g) and treatment temperature S_e^T (%/°C) was calculated from the equation;

$$S_e^M = \Delta \delta / \Delta \theta \tag{8}$$

Equation (8) is detailed as

$$S_e^M = \delta_2 - \delta_1 / \theta_2 - \theta_1 \tag{9}$$

Where

$\Delta \delta$ = Change in sulphur removal efficiencies δ_2, δ_1 at two $KClO_3$ mass-input values θ_2, θ_1 . Considering the points (5, 11.11) & (10.5, 71.67), (5, 10.4609) & (10.5, 76.9364) and (5, 10.1835) & (10.5, 72.5067) as shown in Figure 8, then designating them as (δ_1, θ_1) & (δ_2, θ_2) for experimental, derived model and regression model predicted results respectively, and also substituting them into equation (9), gives the slopes: 11.0109, 12.0865 and 11.3315 %g⁻¹ as their respective sulphur removal efficiencies per unit mass-input of $KClO_3$.

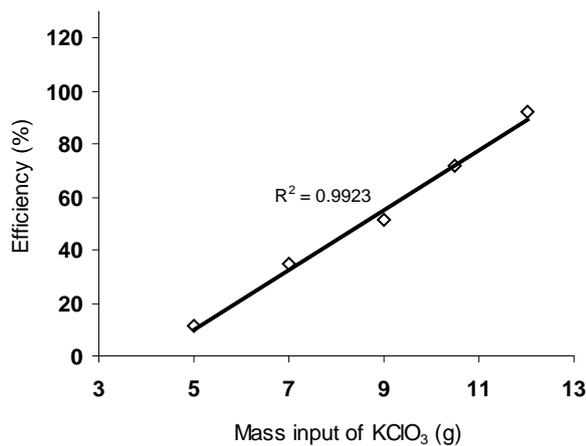


Figure 1. Coefficient of determination between sulphur removal efficiency and mass-input of $KClO_3$ as obtained from the experiment

Similarly, considering the points (500, 11.11) & (750, 71.67), (500, 10.4609) & (750, 76.9364) and (500, 10.1835) & (750, 72.5067) as shown in Figure 8 and Table 1, then designating them as (δ_1, γ_1) & (δ_2, γ_2) for experimental, derived model and regression model predicted results respectively, and also substituting them

into equation (9) (as $S_e^T = \delta_2 - \delta_1 / \gamma_2 - \gamma_1$) gives the slopes: 0.2422, 0.2659 and 0.2493 %/°C as their respective sulphur removal efficiencies per unit rise in treatment temperature.

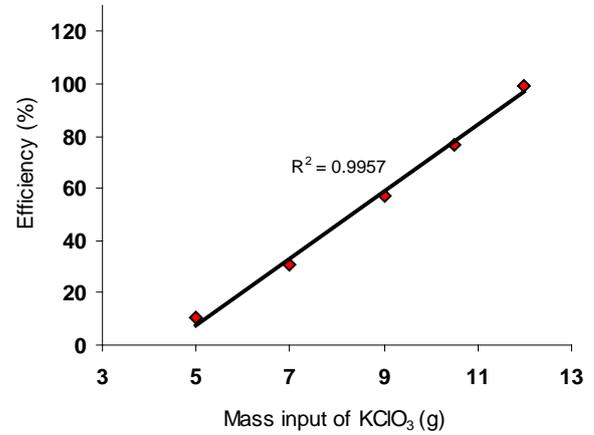


Figure 2. Coefficient of determination between sulphur removal efficiency and mass-input of $KClO_3$ as predicted by derived model

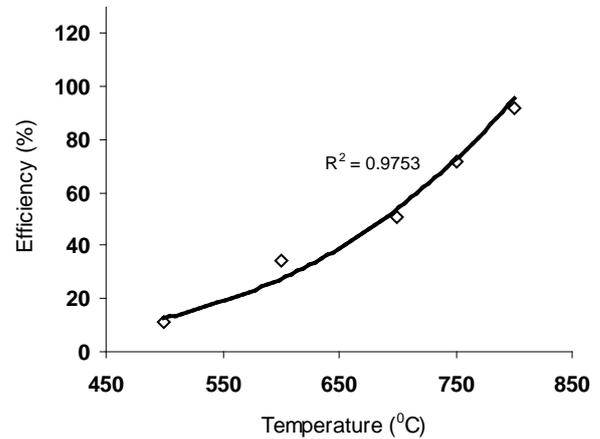


Figure 3. Coefficient of determination between sulphur removal efficiency and treatment temperature as obtained from experiment

A comparison of these two sets of values for sulphur removal efficiencies (per unit mass-input of $KClO_3$ and per unit rise in treatment temperature) also shows proximate agreement and a high degree of validity of the derived model.

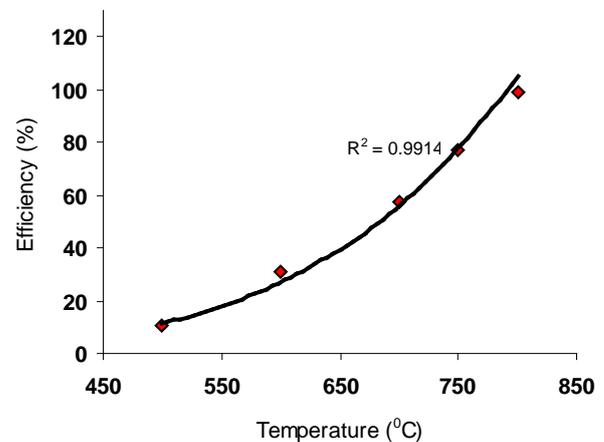


Figure 4. Coefficient of determination between sulphur removal efficiency and treatment temperature as predicted by derived model

3.3. Statistical Analysis

Standard Error (STEYX)

The standard errors incurred in predicting sulphur removal efficiency for each value of the mass-input of $KClO_3$ & treatment temperature considered as obtained from experiment and derived model were 3.2057 and 2.6827 & 6.5587 and 6.3878 % respectively. The standard error was evaluated using Microsoft Excel version 2003.

Correlation (CORREL)

The correlation coefficient between sulphur removal efficiency and mass-input of $KClO_3$ & treatment temperature were evaluated from the results of the derived model and experiment, considering the coefficient of determination R^2 from Figure 4-Figure 7. The evaluation was done using Microsoft Excel version 2003.

$$R = \sqrt{R^2} \tag{10}$$

The evaluated correlations are shown in Table 3 and Table 4. These evaluated results indicate that the derived model predictions are significantly reliable and hence valid considering its proximate agreement with results from actual experiment.

Table 3. Comparison of the correlations evaluated from derived model predicted and ExD results based on mass-input of $KClO_3$

Analysis	Based on mass-input of $KClO_3$	
	ExD	D-Model
CORREL	0.9961	0.9978

Table 4. Comparison of the correlation evaluated from derived model-predicted ExD based on treatment temperature

Analysis	Based on treatment temperature	
	ExD	D-Model
CORREL	0.9876	0.9957

3.4. Graphical Analysis

Comparative graphical analysis of Figure 5 and Figure 6 shows very close alignment of the curves from model-predicted sulphur removal efficiency (MoD) and that of the experiment (ExD).

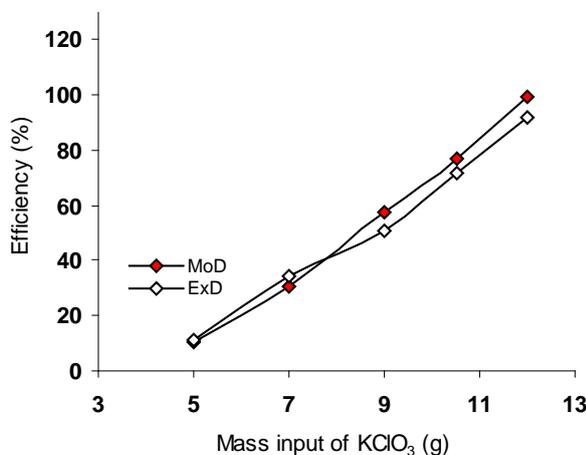


Figure 5. Comparison of sulphur removal efficiencies (relative to mass-input of $KClO_3$) as obtained from experiment and derived model

The degree of alignment of these curves is indicative of the proximate agreement between both experimental and model-predicted sulphur removal efficiency.

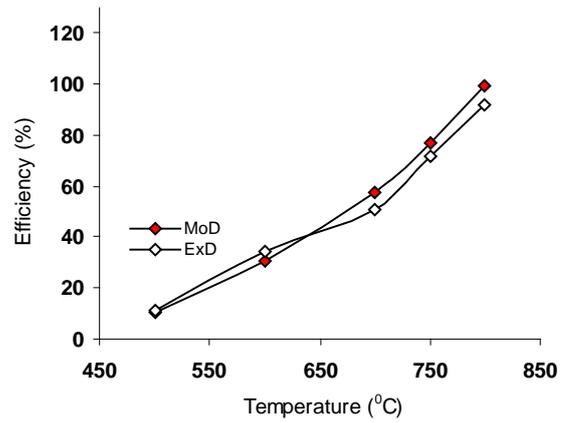


Figure 6. Comparison of sulphur removal efficiencies (relative to treatment temperature) as obtained from experiment and derived model

3.5. 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 (LSM)) in predicting the trend of the experimental results. Comparative analysis of Figure 7 and Figure 8 shows very close dimensions of covered area and alignment of curves which translated into significantly similar trend of data point's distribution for experimental (ExD), derived model-predicted (MoD) and regression model predicted (ReG) results of sulphur removal efficiencies.

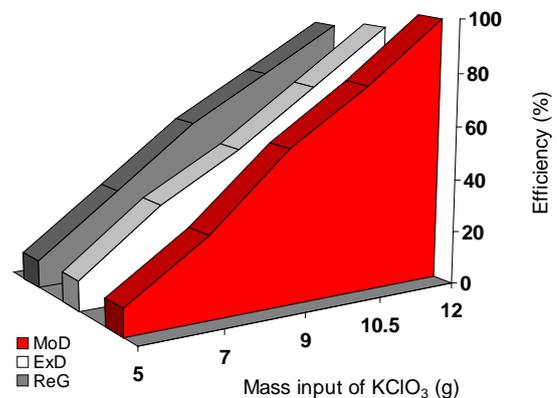


Figure 7. Comparison of sulphur removal efficiencies (relative to mass-input of $KClO_3$) as obtained from experiment, derived model and regression model

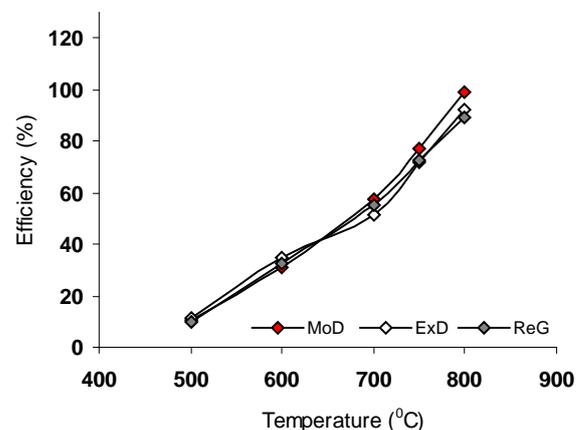


Figure 8. Comparison of sulphur removal efficiencies (relative to treatment temperature) as obtained from experiment, derived model and regression model

3.6. Deviation Analysis

The deviation D_v , of model-predicted sulphur removal efficiency from the corresponding experimental result was given by

$$D_v = \left(\frac{\delta_{MoD} - \delta_{ExD}}{\delta_{ExD}} \right) \times 100 \quad (11)$$

Where

δ_{ExD} and δ_{MoD} are sulphur removal efficiencies from experiment and derived model respectively.

Critical analysis of the sulphur removal efficiency obtained from experiment and derived model shows low 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 iron ore and the physico-chemical interactions between the iron ore and the oxidizing agent which played vital roles during the treatment process were not considered during the model formulation. This necessitated the introduction of correction factor, to bring the model-predicted sulphur removal efficiency to those of the corresponding experimental values.

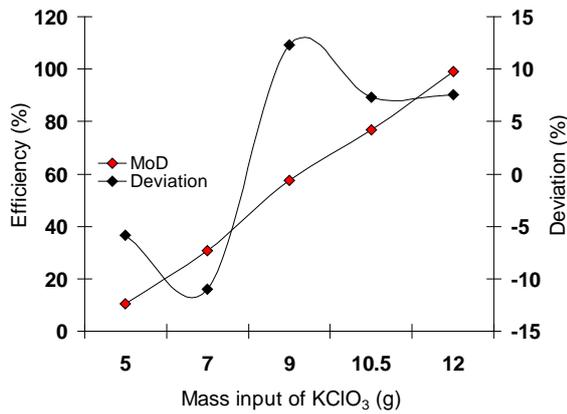


Figure 9. Variation of model-predicted sulphur removal efficiency (relative to mass-input of $KClO_3$) with associated deviation from experimental results

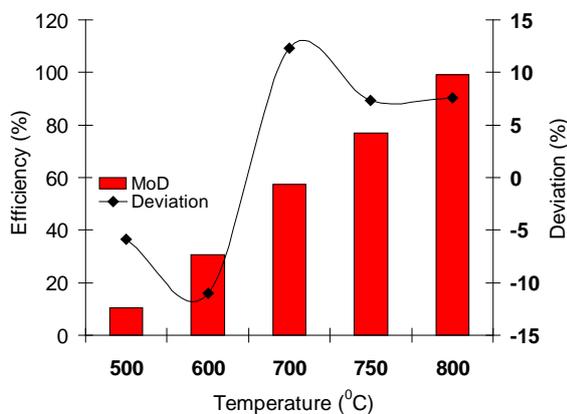


Figure 10. Variation of model-predicted sulphur removal efficiency (relative to treatment temperature) with associated deviation from experimental results

Deviational analysis from Figure 9 and Figure 10 indicates that the precise maximum deviation of model-predicted sulphur removal efficiency from the experimental results is 12.33%. This translates into over

87% operational confidence and response level for the derived model as well as over 0.87 dependency coefficient of sulphur removal efficiency on the collective operational contributions of treatment temperature and mass-input of $KClO_3$.

Critical analysis of Figure 9 and Figure 10 in relation to equation (11) shows that the least and highest magnitudes of deviation of the model-predicted sulphur removal efficiency (from the corresponding experimental values) are - 5.84 and + 12.33%. Figure 2, Figure 4, Figure 11 and Figure 12 indicate that these deviations correspond to sulphur removal efficiencies: 12.4609 and 59.4108 %; mass-input of $KClO_3$: 5 and 9 as well as treatment temperatures: 500°C and 700°C respectively.

Correction factor, Cf to the model-predicted results is given by

$$Cf = - \left(\frac{\delta_{MoD} - \delta_{ExD}}{\delta_{ExD}} \right) \times 100 \quad (12)$$

Critical analysis of Figure 9, Figure 10 and Table 5 indicates that the evaluated correction factors are negative of the deviation as shown in equations (11) and (12).

The correction factor took care of the negligence of operational contributions of the surface properties of the iron ore and the physico-chemical interactions between the iron ore and the oxidizing agent ($KClO_3$) which actually played vital role during the treatment process. The model predicted results deviated from those of the experiment because these contributions were not considered during the model formulation. Introduction of the corresponding values of Cf from equation (12) into the model gives exactly the corresponding experimental values of sulphur removal efficiency.

Table 5. Variation of correction factor (to model-predicted sulphur removal efficiency) with mass-input of $KClO_3$ and treatment temperature

(θ)	(γ)	Cf (%)
5	500	- 5.84
7	600	- 10.98
9	700	+12.33
10.5	750	+7.35
12	800	+7.57

Table 5 also shows that the least and highest correction factor (to the model-predicted sulphur removal efficiency) are + 5.84 and - 12.33 %. Since correction factor is the negative of deviation as shown in equations (11) and (12), Table 5, Figure 11 and Figure 12 indicate that these highlighted correction factors correspond to sulphur removal efficiencies: 12.4609 and 59.4108 %; mass-input of $KClO_3$: 5 and 9 as well as treatment temperatures: 500°C and 700°C respectively.

It is very pertinent 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).

4. Conclusions

Sulphur removal efficiency in iron ore (designated for production of orthopedic devices) has been predicted

based treatment temperature and mass-input of KClO_3 used as oxidizing agent. Results generated from experiment, derived model and regression model show that sulphur removal efficiencies increases with increase in both treatment temperature and mass-input of KClO_3 up to 800°C and 12g of KClO_3 respectively. The validity of the two-factorial empirical model derived, validated and used for the predictive analysis was rooted in the model core expression $\mathfrak{J} + 25.237 = 1.5 \times 10^{-11} \mathfrak{r}^{4.3318} + 5.6655 \mathfrak{g}$ where both sides of the expression are correspondingly approximately equal. The standard error incurred in predicting the sulphur removal efficiency for each value of the treatment temperature & mass-input of KClO_3 considered, as obtained from experiment, derived model and regression model were 6.5587, 6.3878 and 3.3787×10^{-5} & 3.2057, 2.6827 and 3.5936% respectively. Also, sulphur removal efficiency per unit rise in treatment temperature & per unit mass-input of KClO_3 as obtained from experimental, derived model and regression model predicted results were 0.2422, 0.2659 and 0.2493 % / $^\circ\text{C}$ & 11.0109, 12.0865 and 11.3315 % / g respectively. The correlations between sulphur removal efficiency and treatment temperature & per unit mass-input of KClO_3 as obtained from experiment, derived model and regression model indicated were all > 0.98 . Deviation analysis revealed that the maximum deviation of model-predicted sulphur removal efficiency from the experimental results is 12.33%. These invariably translated into over 87% operational confidence for the derived model as well as over 0.87 dependency coefficients of sulphur removal efficiency on treatment temperature and KClO_3 addition.

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