

## Model for Assessment of Sulphur Emission Polluting Laboratory Atmosphere during Thermo-Chemical Processing of Iron Ore Designated for Production of Spinal Rod

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A model has been derived for assessment of sulphur emission polluting laboratory atmosphere during thermo-chemical processing of iron ore designated for production of spinal rod. The iron oxide ore was processed using powdered potassium chlorate (KClO<sub>3</sub>) of mass range; 7-10g which simultaneously reduces the iron and oxidize the sulphur present in the iron oxide ore at a treatment temperature of 500<sup>0</sup>C. The model;

$$\%S = \left( \frac{0.0220}{\text{Log}\beta} \right)$$

indicates that the concentration of sulphur emission, is dependent on the values of the mass-input of the oxidant (KClO<sub>3</sub>) during the thermo-chemical processing. The validity of the model is believed to be rooted in the expression  $k_n[(\beta)^{\gamma\%S}] = T/\alpha$  where both sides of the expression are correspondingly approximately equal to 10. The maximum deviation of model-predicted concentration of sulphur emission from those of the corresponding experimental values was found to be less than 27% which is quite within the range of acceptable deviation limit of experimental results.

*Keywords: Model, Assessment, Sulphur Emission, Laboratory Atmosphere, Iron Ore.*

### 1. Introduction

Air pollution basically involves introduction into the atmosphere, of chemicals, particulate matter, or biological materials that cause harm or discomfort to humans or other living organisms, or damages the natural environment.

The atmosphere is a complex dynamic natural gaseous system that is essential to support life on planet Earth. Depletion of stratospheric ozone due to air pollution has long been recognized as a threat to human health as well as to the Earth's ecosystems.

Report [1] from the 2008 Blacksmith Institute World's Worst Polluted Places has shown that indoor air pollution and urban air quality are listed as two of the world's worst pollution problems.

An air pollutant is known as a substance in the air that can cause harm to humans and the environment. It has been shown [2] that these pollutants can be in the form of solid particles, liquid droplets, or gases. Furthermore, they may be natural or man-made.

It is widely accepted that pollutants can be classified as either primary or secondary. Primary pollutants are basically substances directly emitted from a process, such as ash from a volcanic eruption, the carbon monoxide gas from a motor vehicle exhaust or sulfur dioxide released from factories. Secondary pollutants are not emitted directly. Instead, they form in the air when primary pollutants react or interact. A typical secondary pollutant is ground level ozone — one of the many secondary pollutants that make up photochemical smog.

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Air pollution has since become an exceedingly unavoidable and inescapable part of urban living. The presence of pollutants in structures has been reported to lead to serious damage and cause adverse effects on human health [1, 2, 3].

Studies [1, 2, 3] have shown that modeling of urban air pollution is an important facet of pollution control and abatement. Models explain the occurrence, intensity, and movement of pollutants in order to predict pollutant levels at locations away from defined sources. The intrinsic, dynamic, random, and nonlinear nature of air pollution has made its prediction an inherently difficult problem. In this paper, however; a simple model for assessment evaluation of sulphur emission polluting laboratory atmosphere during thermo-chemical processing of iron ore designated for production of bone plate is proposed.

Several proposed and successfully derived model prediction schemes [4-7] have been applied to predict the resultant concentration of sulphur emission from iron oxide ore during laboratory reduction of the ore.

Biomaterials such as metals have been identified to play essential roles in assisting with the repair or replacement of bone tissue that has become diseased or damaged. For instance, metal pins, screws, plates, rods, and meshes are frequently required to replace the mechanical functions of injured bone during the time of bone healing and regeneration. A combination of high mechanical strength and fracture toughness has made metals more suitable for load-bearing applications compared with ceramics or polymeric materials. Currently approved and commonly used metallic biomaterials include stainless steels, titanium and cobalt-chromium-based alloys. The limitation of these currently approved metallic biomaterials is the disparity between the elastic moduli of the materials and that of natural bone tissue, in that these metals are significantly stiffer than bone, and results in stress shielding effects that can lead to reduced stimulation of new bone growth and remodeling decreased bone density around the implant site, both of which decrease implant stability [8].

Metallic materials can be used for production of medical devices which may be an intervertebral prosthesis, intravertebral prosthesis, or extravertebral prosthesis such as a bone plate, spinal rod, rod connector, or bone anchor. These materials are particularly advantageous for use in connection with fixation implants, such as, for example, anterior plates and screws, interbody fusion implants, such as cages, and components used in connection therewith, such as, for example, screws and anchors. A component for use in the spine is fabricated to exhibit suitable strength to withstand the biomechanical stresses and clinically relevant forces without permanent deformation. It was considered that for orthopedic devices that are not implanted in or around the spine, the component can be fabricated to withstand the biomechanical forces exerted by the associated musculoskeletal structures. The medical devices can be used to treat a wide variety of animals, particularly vertebrate animals and including humans [9].

The aim of this work is to derive a model for assessment of sulphur emission polluting laboratory atmosphere during thermo-chemical processing of Agbaja (Nigeria) iron ore designated for production of spinal rod. In this research work, powdered potassium chlorate was used as an oxidant.

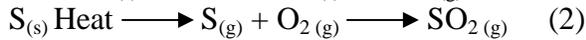
## 2. Materials and Methods

Agbaja iron ore concentrate used for this work was obtained from Nigerian Metallurgical Development Centre (NMDC) Jos. This concentrate was used in the as-received condition with particle size of 150mm. The dried concentrate as beneficiated was mixed in different proportions with solid  $\text{KClO}_3$  powder (obtained from Fisher Scientific Company Fair Lawn, New Jersey, USA) weighed with a triple beam balance at NMDC laboratory. Iron crucibles were filled with the sample mixtures containing varying masses of  $\text{KClO}_3$  (7-10g) and 50g of the ore concentrate. The samples in the crucibles were then heated at to a temperature of  $500^\circ\text{C}$  in a Gallenkamp Hot pot electric furnace at NMDC laboratory for 5 minutes and thereafter were emptied on a white steel pan for observation. It is important to state that this

temperature was chosen to prevent the melting of the ore during the process. The experiment was repeated three times in each case and the average values taken. A weighed quantity of the treated ore concentrate was taken in each case for chemical analysis (to determine percentage concentration of sulphur left in the ore) using wet chemical analysis method. These values of remnant sulphur were subtracted in each case from the initial iron ore sulphur concentration (before processing) to ascertain the concentrations of sulphur emission into the laboratory atmosphere during the thermo-chemical processing.

### 2.1 Model

The solid phase (ore) is assumed to be stationary, contains some unreduced iron remaining in the ore. It was found [10] 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.



### 2.2 Model Formulation

Results from the experiment (as shown in Table 1) were used for the model formulation

**Table 1: Variation of the concentration of sulphur emission with mass-input of oxidant ( $KClO_3$ )**

( $\beta$ )	( $\alpha$ )	%S
7	50	0.0220
8	50	0.0200
9	50	0.0280
9.5	50	0.0288
10	50	0.0300

Computational analysis of these experimental data gave rise to Table 2 which indicate that;

$$k_n[(\beta)^{\gamma\%S}] = T/\alpha \quad (\text{approximately}) \quad (3)$$

Taking logarithm of both sides,

$$\text{Log}(k_n[(\beta)^{\gamma\%S}]) = \text{Log}T/\alpha \quad (4)$$

**Table 2: Variation of  $k_n[(\beta)^{\gamma\%S}]$  with  $T/\alpha$**

$k_n[(\beta)^{\gamma\%S}]$	$T/\alpha$
9.9609	10
9.9549	10
10.0564	10
10.0713	10
10.0926	10

$$\text{Log}k_n + \text{Log}[(\beta)^{\gamma\%S}] = \text{Log}T - \text{Log}\alpha \quad (5)$$

$$\text{Log}k_n + \gamma\%S \text{Log}\beta = \text{Log}T - \text{Log}\alpha \quad (6)$$

$$\gamma\%S \text{Log}\beta = \text{Log}T - \text{Log}\alpha - \text{Log}k_n \quad (7)$$

$$\%S = \frac{\text{Log}T - \text{Log}\alpha - \text{Log}k_n}{\gamma \text{Log}\beta} \quad (8)$$

Introducing the values of  $\alpha$ ,  $T$ ,  $k_n$  and  $\gamma$  into equation (8) (since the are constants) and evaluating further, reduces it to:

$$\%S = \frac{0.0220}{\text{Log}\beta} \quad (9)$$

Therefore

$$\%S = \frac{D_f}{\text{Log}\beta} \quad (10)$$

where %S = Concentration of sulphur removed during the pyrometallurgical-oxidation process.

$k_n = 9.75$  (Decomposition coefficient of  $KClO_3$  relative to the treatment temperature ( $500^\circ\text{C}$ )) determined using C-NIKBRAN [11]

( $\gamma$ ) = 0.5 (Temperature coefficient relative to the treatment temperature) determined using C-NIKBRAN [11]

( $\beta$ ) = Mass of  $KClO_3$  added as oxidant (g)

$T$  = Treatment temperature used for the process ( $^\circ\text{C}$ )

$D_f = 0.0220$  (Assumed desulphurization enhancement factor)

( $\alpha$ ) = Mass-input of iron oxide ore (g)

### 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). Mass-input of iron oxide ore used; (50g), and treatment time; 360secs. were used. Treatment temperature;  $500^\circ C$ , ore grain size;  $150\mu m$ , and masses of  $KClO_3$  (oxidant); (7-10g) 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.

**4. Model Validation**

The formulated model was validated by direct analysis and comparison of concentrations of the sulphur emission  $S$  as predicted by the model and as obtained from the experiment. Analysis and comparison between these  $S$  values reveal deviations of model-predicted  $S$  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 ( $KClO_3$ ) (under the influence of the treatment temperature) which were found to have played vital roles during the thermo-chemical processing of the ore were not considered during the model formulation. This necessitated the introduction of correction factor, to bring the model-predicted  $S$  values to those of the experimental  $S$  values.

Deviation ( $D_v$ ) (%) of model-predicted  $S$  values from experimental  $S$  values is given by

$$D_v = \left( \frac{S_p - S_e}{S_e} \right) \times 100 \tag{11}$$

where

$D_p$  = Predicted  $E_1$  values from model

$D_E$  = Experimental  $E_1$  values

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

$$C_f = -D_v \tag{12}$$

Therefore 
$$C_f = - \left( \frac{S_p - S_e}{S_e} \right) \times 100 \tag{13}$$

Introduction of the corresponding values of  $C_f$  from equation (13) into the model gives exactly the corresponding experimental  $S$  values.

**5. Results**

The derived model is given in equations (9) and (10) as  $\%S = 0.0220 / \text{Log } \beta$ . Computational analysis of experimental results in Table 1 gave rise to Table 2 where the values of both sides of the expression:  $k_n [(\beta)^{\gamma\%S}] = T / \alpha$  are correspondingly approximately equal to 10. The predicted results show that the model is valid at all oxidant mass-input range (7-10g), within which maximum deviation is less than 27%.

**6. Discussion**

Table 2 also agrees with equation (3) following the values of  $k_n [(\beta)^{\gamma\%S}]$  and  $T/\alpha$  evaluated from Table 1 as a result of corresponding computational analysis. The value 0.0220 has a direct relationship with the value of  $\%S$  as shown in equation (9). This indicates that the constant contributes directly (as a multiplying factor) to the predicted concentration of sulphur emission from the ore. Based on the foregoing, the constant is denoted as desulphurization enhancement factor  $D_f$ .

It is important to state that the sulphur emission through diffusion to the laboratory atmosphere is as a result of openings around the treatment furnace.

Critical comparative analysis of the bars in figure 1 shows that both concentrations of the sul-

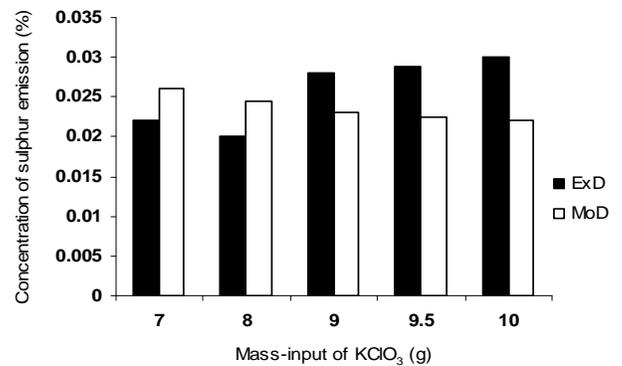
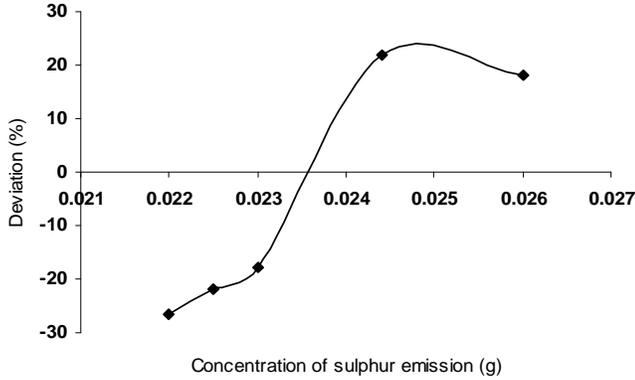


Figure 1: Comparison of the concentrations of sulphur emission as obtained from experiment and derived model

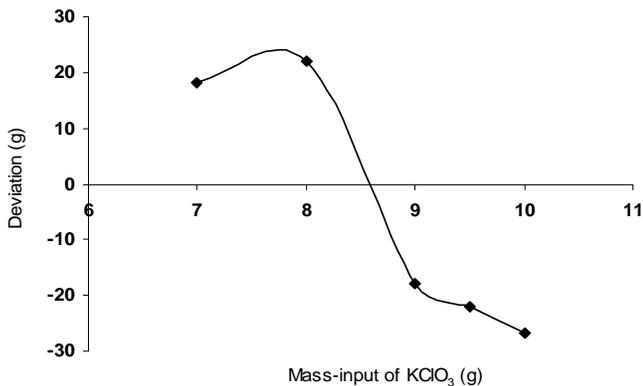


**Figure 2:** Variation of model-predicted concentration of sulphur emission with its associated deviation from experimental values.

phur emission as obtained from the experiment (bar ExD) and the derived model (bar MoD) in relation to the mass-input of oxidant ( $\text{KClO}_3$ ) are generally quite close hence, depicting proximate agreement

### 6.1 Variation of model-predicted concentration of sulphur emission and mass-input of oxidant with the associated deviations

Figures 2 and 3 indicate that the highest and least deviations; -26.67 and -17.86% are associated with mass-input of  $\text{KClO}_3$ ; 10 and 7g as well as concentrations of sulphur emission; 0.022 and 0.026% respectively. It is pertinent to state that the extent of deviation is a function of just the magnitude of the value while the mathematical sign preceding the

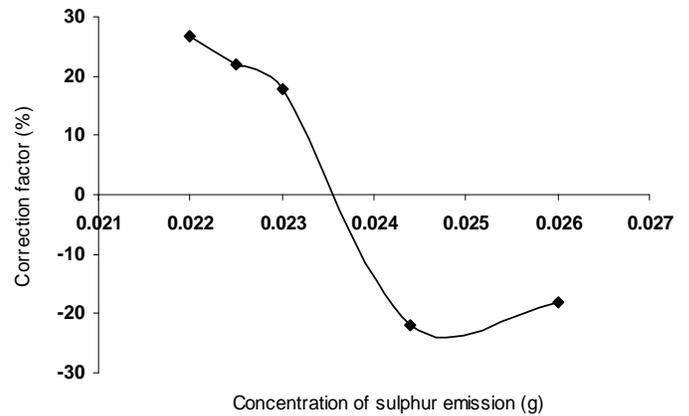


**Figure 3:** Variation of mass-input of  $\text{KClO}_3$  with the associated deviation from experiment results.

value indicates whether the deviation is deficit or surplus

### 6.2 Variation of model-predicted concentration of sulphur emission and mass-input of oxidant with the associated correction factors

Figure 4 shows that the highest and least correction factors (+26.67 and -17.86%) also correspond to the mass-input of  $\text{KClO}_3$ ; 10 and 7g and model-predicted concentrations of sulphur emission: 0.022 and 0.026% respectively. Comparison of Figures 2-4 shows that the curve for correction factor is opposite that of the deviation. This is attributed to the fact that correction factor is the negative of the deviation as shown in equations. (12) and (13). It is



**Figure 4:** Variation of model-predicted concentration of sulphur emission with its associated correction factor

believed that the correction factor takes care of the effects of the surface properties of the iron oxide ore and the physiochemical interaction between the ore and the oxidant ( $\text{KClO}_3$ ) which (affected experimental results) were not considered during the model formulation.

## 7. Conclusion

The model gives an assessment of sulphur emission polluting laboratory atmosphere during thermochemical processing of iron ore designated for production of spinal rod. The concentration of sulphur emission is dependent on the mass-input of the oxi-

dant ( $\text{KClO}_3$ ) which decomposes and releases oxygen for production of the emitted  $\text{SO}_2$ . Predicted results show that the maximum deviation of model-predicted concentrations from the corresponding experimental values is less than 27%. The validity of the model is rooted in the expression  $k_n[(\beta)^{\gamma\%S}] = T/\alpha$  where both sides of the expression are correspondingly approximately equal to 10.

It is important to state that this sulphur emission through diffusion to the laboratory atmosphere is as a result of openings around the door of the treatment furnace. It is therefore needful of furnace manufacturers to keep the areas around the furnace door very tight.

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