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Full Length Research Paper

Modelling of Gaseous Emission Rate for Obsolete Eposand Incineration Process in Placid Air Environment

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Abstract

Eposand chemical specie is an epoxy used for sand consolidation beneath the soil during drilling operations. The disposal of the absolete eposand specie is a problem due to its ignitability, corrosivity, reactivity and toxicity resulting to carcinogenic effect upon human exposure. Hence incineration option using scrubber facility is applied for its disposal procedure. Therefore, this work investigates gaseous emissions rate resulting from eposand chemical incineration process at no perturbation air interphase using Fibow Horizontal Multiphase Flow Chamber Incinerator (FHMFCI). In addition, a theoretical predictive emission rate model is developed using coupled integral and Abowei modified dimensional analysis approach. The predictive model provided a basis for the computation of bulk concentration as a function of eposand quantity, time and temperature. The theoretically developed model was simulated using MATLAB R2007b techniques and the results compared with those of the experimental. Both experimental and theoretical techniques demonstrated high degree of precision and compatibility.

Keywords: Concentration, Distribution, Eposand Incineration, Placid, Environment.

INTRODUCTION

Obsolete Eposand is a chemical component used for crude oil well sand solidification processes (Ichara and Opara, 1998; Jha et al., 1999). Its disposal required the use of high temperature incinerator due to the associated dangers resulting in human carcinogenic and nausea effects (Bonner, 1998; Biondo and Marten, 1977; Armud,1969). Previous studies/reports (no. FIBOW/ED/Shell/ 021, 2000) on health and safety aspect of eposand chemical incineration showed the need to investigate the emission rate of the gaseous components resulting from the incineration process. The outcome of the results for the gaseous components provides a basis to monitor the scrubber water dilution rate (Semrau, 1977). The chemical structural formula of a typical eposand composition is given in figure 1 (Mijovic et al., 1985; Mckiazie and Saunners 1981).

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The disposal via incineration process provides the oxides of the constituents, as contained in the sructural formula in figure 1. Interestingly, environmental existing laws, guidelines and standards required the gaseous emission concentration components into the air phase for the purpose of compliance monitoring (Department of Petroleum Resources, 1998). The gaseous components to be investigated in this work include SO_2, SO_3, NO_2, NO, CO, CO_2 and SPM. Also, theoretically developed predictive models and those of the experimental for gaseous emision concentration componenent were compared to ascertain the cohesiveness of the results.

MATERIALS AND METHODS

Theoretical Formulations

Considering molecular diffusion at no perturbation or placid air environment at constant temperature, the

Fick's law applies thus (Fick, 1858; Rajput, 1999; Bonazountas and Fiksel, 1982):

$$\frac{\partial C_p}{\partial t} = D_f \frac{\partial^2 C_p}{\partial x^2} \quad (1)$$

The initial boundary conditions governing equation 1 are

$$\left.\begin{aligned} C_p(x, O) &= C_F \qquad O \le x \le L \\ C_p(O, t) &= O \qquad O < x < T \\ \frac{\partial C_p}{\partial t}(L, T) &= O \qquad O < x \le T \end{aligned}\right\} \quad (2)$$

Direct integration of equation 1 results in

$$C_p = \frac{B}{t^{1/2}} \ell^{-x^2/4D_p t} \quad (3)$$

Where

B = Constant to be determined using the boundary condition in equation 2

C_P = Concentration of emission inputs (g/m^3)

L(h) = Distance (height of emission discharge in m)

D_p (D_f) = Diffusion coefficient (laminar flow regime)

T = Time interval up to a maximum of T

X = Cartesian co-ordinate of pollutants flow

Let M_p = quantity of emission input (Eposand) during the diffusion process at time (t) = 0

Then $C_P = M_p / V_P$

$$M_P = \int_{-\infty}^{\infty} C_P \, A \, d\, x \quad (4)$$

Integration of equation 4 with 3 substituted makes use of the probability integral as

$$\int_{-\infty}^{\infty} \ell^{-y^2} dy = \sqrt{\pi} \quad (5)$$

The constant B is determined by substituting the boundary conditions in equation 2 through equation 4 and equation 5 and the resulting simultaneous equation gives

$$B = M_p \Big/ \left[A(4\pi D_P)^{1/2}\right] \quad (6)$$

Equation 6 when substituted into equation 3 yields

$$C_P = \frac{M_P}{A(4\pi D_P t)^{1/2}} \ell^{-x^2/4D_p t} \quad (7)$$

The diffusion coefficient (D_P) is correlated to the works of ((Fisher, 1967; Adolf, 1858) in the diffusion co-efficient of gaseous systems as (Fisher, 1967).

$$D_P = 435.7 \frac{T^{3/2}}{\rho\left(V_A^{1/3} + V_B^{1/3}\right)^2} \sqrt{\frac{1}{M_A} + \frac{1}{M_B}} \quad (8)$$

Area $A = \pi r^2$ (9)

$M_P = \rho_p V_P$ (10)

Using equation 8, 9 and 10 into equation 7 is adopted for the temperature, time effect in concentration distribution at the ambient stack inter-phase.

$$C_P(x,t) = \frac{\rho_P V_P}{A(4\pi D_P t)^{1/2}} \ell^{-\left(x^2/4D_p t\right)} \quad (11)$$

Further simplification measures are developed in Model Analysis for Zero Turbulence section of this work for clearer evaluation.

Model Analysis for Zero Turbulence

Recall from equation 11 that;

$$C_p = \frac{M_p}{A(4\pi D_p t)^{1/2}} \exp\left[-x^2/4D_p t\right] \quad (12)$$

and for zero turbulence regime, Diffusivity Coefficient (Dp) is expressed as;

$$D_p = \frac{435.7 \cdot T^{3/2}}{\rho\left(V_A^{1/3} + V_B^{1/3}\right)^2} \cdot \sqrt{1/M_A + 1/M_B} \quad (13)$$

Collapsing the components volumes and mass values to depict bulk concentration, let;

$$\frac{1}{M_A} + \frac{1}{M_B} + - - + 1/M_Z = 1/M_P \quad (14)$$

and

$$V_A^{1/3} + V_B^{1/3} + - - + V_Z^{1/3} = V_P^{1/3} \quad (15)$$

Substituting equations 14 and 15 into equation 8 we have;

$$D_P = \frac{435.7 \cdot T^{3/2}}{\rho\left(V_P^{1/3}\right)^2} \cdot \sqrt{1/M_p} = \frac{435.7 \cdot T^{3/2} \cdot M_P^{-1/2}}{\rho\, V_P^{2/3}}$$

$$\therefore \quad D_p = \frac{435.7 \cdot T^{3/2}}{\rho V_P^{2/3} \cdot M_P^{1/2}} \quad (16)$$

Now substituting for 'D_P' in equation 7 using equation 14, thus;

$$C_P = \frac{M_P}{A\left[4\pi t\left(\frac{435.7 \cdot T^{3/2}}{\rho V_P^{1/3} \cdot M_P^{1/2}}\right)\right]^{1/2}} \cdot \exp\left[\frac{-x^2}{\left[4\pi t \frac{(435.7) \cdot T^{3/2}}{\rho V_P^{2/3} \cdot M_P^{1/2}}\right]}\right] z$$

$$C_P = \frac{M_P}{A\left[\frac{\sqrt{4X435.7\cdot\sqrt{\pi}}\cdot\sqrt{t}\cdot T^{3/4}}{\sqrt{\rho}\cdot V_P^{1/3}\cdot M_P^{1/4}}\right]}\cdot\exp\left[\frac{-x^2}{\frac{1742.8\cdot T^{3/2}\cdot t}{\rho V_P^{2/3}\cdot M_P^{1/2}}}\right]$$

$$C_P = \frac{M_P\cdot\sqrt{\rho}\cdot V_P^{1/3}\cdot M_P^{1/4}}{73.99At^{1/2}\cdot T^{3/4}}\cdot\exp\left[\frac{-x^2\cdot\rho\cdot V_P^{2/3}M_P^{1/2}}{1742.8\cdot T^{3/2}\cdot t}\right]$$

$$\therefore\ C_P = \frac{M_p^{5/4}\,\rho^{1/2}\cdot V_P^{1/3}}{73.99At^{1/2}\cdot T^{3/4}}\cdot\exp\left[\frac{-x^2\cdot\rho\cdot V_P^{2/3}\,M_P^{1/2}}{1742.8\cdot T^{3/2}\cdot t}\right] \quad 17$$

From equation 17,
Let;

$$\psi = \frac{-x^2\cdot\rho\cdot V_P^{2/3}\,M_P^{1/2}}{1742.8\cdot T^{3/2}\cdot t} \quad 18$$

Substitute equation 18 into equation 17, we have;

$$C_P = \frac{M_p^{5/4}\,\rho^{1/2}\cdot V_P^{1/3}}{73.99At^{1/2}\cdot T^{3/4}}\cdot\exp^{\psi} \quad 19$$

Recall that;

$$e^x = 1+x+\frac{x^2}{2!}+\frac{x^3}{3!}+\ --\ +\frac{x^n}{n!} \quad 20$$

Similarly

$$e^{\psi} = 1+\psi+\frac{\psi^2}{2!}+\frac{\psi^3}{3!}+\ --+\frac{\psi^n}{n!}$$

Therefore equation 19 becomes

$$C_P = \frac{M_p^{5/4}\,\rho^{1/2}\cdot V_P^{1/3}}{73.99At^{1/2}\cdot T^{3/4}}\left[1+\psi+\frac{\psi^2}{2!}+\frac{\psi^3}{3!}+\ --+\frac{\psi^n}{n!}\right] \quad 21$$

In other to normalize the integral model equations from (1-21), the modified Abowei (1991) dimensional analysis was applied to ascertain at least the approximate functional variables thus:
Let

$$C_{(x,t)} \Rightarrow \phi_M\left[T^a,\ Q_T^b, K^c, \rho^d, t^e,\ V^f, U^g\right] \quad 22$$

Where
C = Gaseous emission bulk concentration (g/m^3)
T = Temperature of the thermocouple (Incinerator) (^{o}C)
Q_T = total heat quantity in the incinerator (j/min)
K = Thermal conductivity of the furnace (j/min/m/^{o}C)
ρ = Density of waste (Eposand) material (g/m^3)
t = Exposure time frame for incineration process (min)
V = Volume of the eposand (m^3)
U = Velocity of flow (m/s)

Now applying dimensions as designated in equation 17

$$ML^{-3} \Rightarrow \phi_M\left[T^a,\ Q_T^b, K^c, \rho^d, t^e,\ V^f, U^g\right] \quad 23$$

Introduction to appropriate dimensions give,

$$ML^{-3} \Rightarrow \phi_M\left[F^a.\left(BT^{-1}\right)^b\cdot\left(BT^{-1}L^{-1}F^{-1}\right)^c\cdot\left(ML^{-3}\right)^d T^e\cdot L^{3f}\cdot L^g T^{-g}\right] \quad 24$$

Equaling with respect to corresponding dimensions as in equation 19 results in

M : d = 1 25
L : - C – 3d + 3f + g = - 3 26
T : - b – C + e – g = 0 27
F : a – c = 0 28
B : b + c = 0 29

Equations 25-29 can be solved simultaneously using induction principles as adopted by (Abowei and Wami, 1988) gives the dimensions as

C = - 1, b = 1, a = -1, g = 1, e = 1, f = $-\frac{2}{3}$ 30

$$C_{(x,t)} \Rightarrow \phi_M\left[T^{-1}Q^1K^{-1}\rho^1 t^1 V^{-2/3}U^1\right] \quad 31$$

$$\therefore\ C \Rightarrow \phi\left[\left(Q\rho tU\right)/\left(TV^{2/3}K\right)\right] \quad 32$$

Where $\phi = \phi_M$

Equation 32 is the novel model developed to predict dimensional diffusion rate for the incineration of obsolete eposand chemicals while ϕ_M is a dimensionless constant.

$$\left.\begin{aligned} C &\Rightarrow \phi\left[\left(Q\rho tU\right)/\left(TV^{2/3}K\right)\right] \\ C_{(Bult)} &= \phi_M\left(\frac{Q\rho tU}{TV_P^{2/3}K}\right)\end{aligned}\right\} \quad 33$$

At zero turbulence comparing equations 12 and 33 gives dimensionless constant ϕ_M, thus

$$\phi_M = \left(\frac{Q\rho tU}{TV_P^{2/3}K}\right) = \frac{\rho_P\ V_\rho}{A\left(4\pi D_P t\right)^{1/2}}\ e^{\left(-x^2/4D_P t\right)} \quad 34$$

Assume $e^{\left(-x^2/4D_P t\right)} = \varphi$ 35

$$\phi_M = \frac{\frac{\rho_P\ V_\rho}{A\left(4\pi D_P t\right)^{1/2}}\ \varphi}{\left(\frac{Q\rho tU}{T\ V_P^{2/3}K}\right)} \quad 36$$

Equation 36 upon further simplification gives

$$\phi = \frac{\rho_P\ V_p'}{A\left(4\pi D_P t\right)^{1/2}}\ X\ \frac{T\ V_P^{2/3}K}{Q\rho tU}\ \varphi \quad 37$$

Eventually equation 37 is summarized to give;

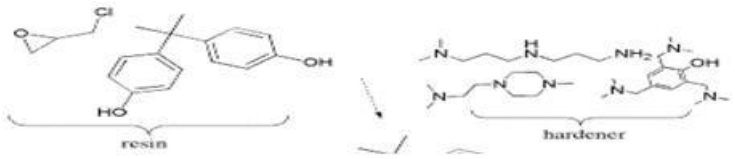

Figure 1. Typical Eposand Specie Structural Formula

$$\phi_M = \frac{V_P^{5/3}\ T\ K\varphi}{A(4\pi D_P t)^{1/2}\ Q t\ U} \quad 38$$

Equation 38 becomes the simplified model for one dimensional bulk concentration under placid air environment.

Where $\varphi = \left[1 + \psi + \frac{\psi^2}{2!} + \frac{\psi^3}{3!} + - - + \frac{\psi^n}{n!}\right]$ 39

and $\varphi = -\ [X^2 / 4D_p t]$

Simulation Technique

MATLAB R2007b computer program was used to simulate the model expressions developed in this work. Therefore, presented in figure 2 is a computational flow chart algorithm exploited for the evaluation of the emission rate components using the developed models in equations 1 to 39.

Experimental Works

Incineration Procedure

The cross-sectional drawing of the FHMFCI we used is presented in figure 1.

Fibow Horizontal Multiphase Flow Chamber Incinerator (FHMFCI) achieves maximum burning efficiency and completely eliminates carcinogenic and nausea odours that are deleterious to the environment. This incinerator is equipped with a special water design scrubber to purge the gas of excess fly ash which are deposited in water tank or sump that can be easily be emptied. The incinerator design temperature is 1999^{o}C, operating temperature ranges from 1000^{O}C to 1800^{o}C. Diesel to fire burner system at 2000ltrs capacity, three phase burner chambers with residence time relative to the calorific value of waste and auto ignition temperature, with scrubber stack height of 20m. In this experiment, we preliminary carry out concrete scientific confirmation of physical properties in line with existing regulatory guideline to ensure avoidance of explosion due to bund breakage. The obsolete eposand is fed into the liquid phase of the incinerator and the flame burners were triggered. The carcinogenic and nausea smoke were regulated by passing through a wet flushed scrubber unit. The scrubber unit is diluted to high volume of water to almost zero tolerance level of concentration of any traceable component. Figure 3 provide details of FHMFCI setup for this work.

Sampling Procedure

The entire sampling operation was "In-situ Measurement". Using the equipment as shown in figures 3, the incinerator was pre-heated to 200^{0}C followed by the suction of obsolete chemical specie via the liquid pump into the liquid chambers of the incinerator. At twenty (20) minutes interval, samples are taken at the stack of the incinerator, 20 meter height for about five hours with the increasing temperature range of 1800^{0}C to determine the concentration level of pollutants and recorded in the emissions monitoring data sheet. The concentration distribution of the Pollutants of interest namely NO_X, SO_X, CO_X, Cl_x, SPM and Dioxin/Furan determined for extrapolation.

RESULTS AND DISCUSSIONS

Results

Both theoretical and experimental results as a function of eposand quantity, temperature and time are well presented in figures (4-11)

Theoretical Results

The theoretical results developed as stated herein, are the output of simulated computation, based on data obtained from each analysis and analytical procedure of each experiment (for obvious reasons, only suspect pollutants were sampled and analysed). Figure 4-8

Experimental Results

The results of the analysis carried out at the incineration stack are presented below in Figures (9-11). The results as stated herein, are the output of detailed computation, based on data obtained from each analysis and analytical procedure of each experiment for obvious

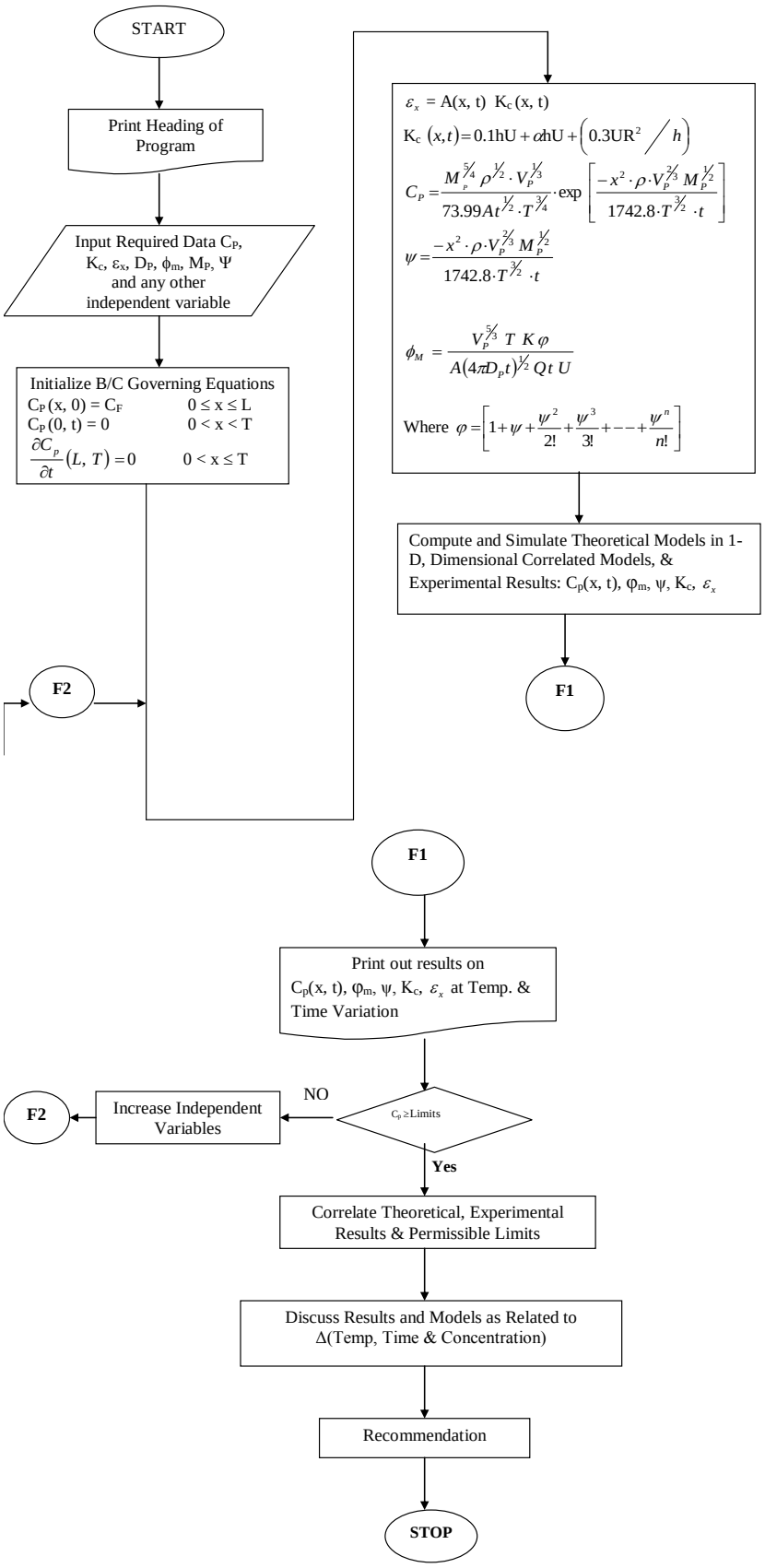

Figure 2. Flowchart showing computation procedure

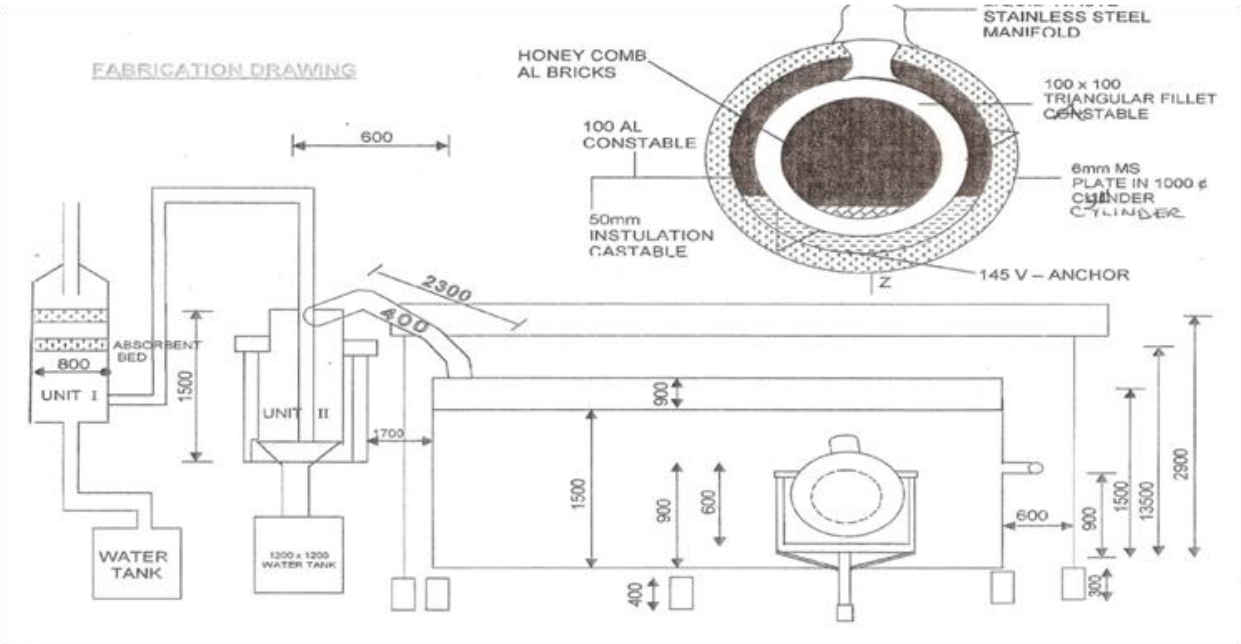

Figure 3. Cross Sectional View of FHMFCI

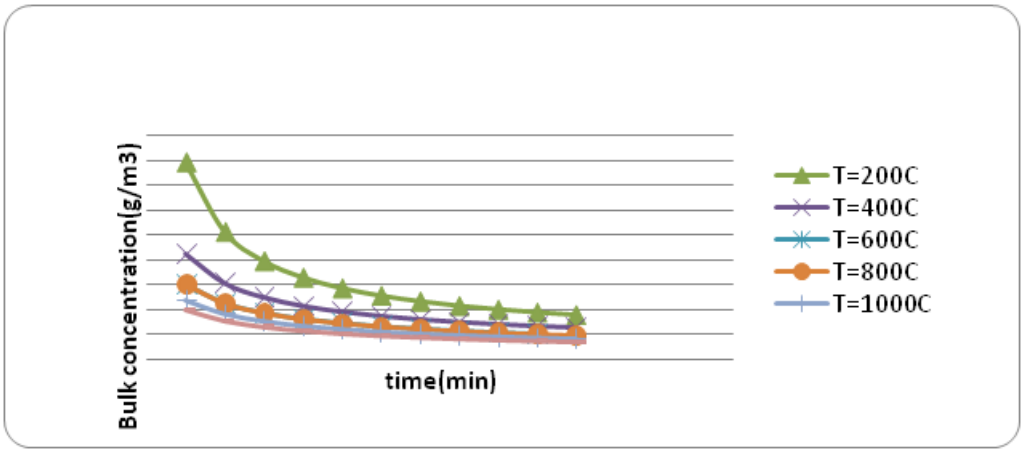

Figure 4. Bulk Concentration Gradient at Various Temp. Range under Placid Air Environment

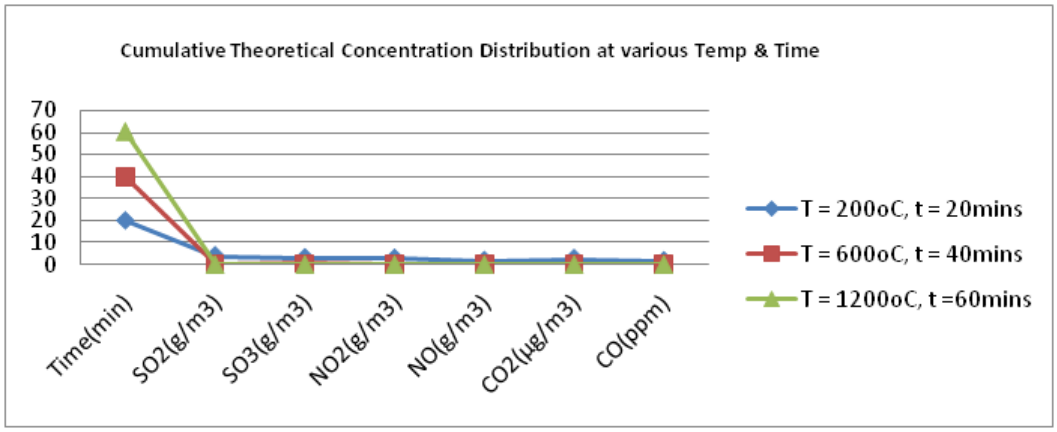

Figure 5. Cumulative Theoretical Concentration Distribution at Various Temp. and Time under Placid Air Environment

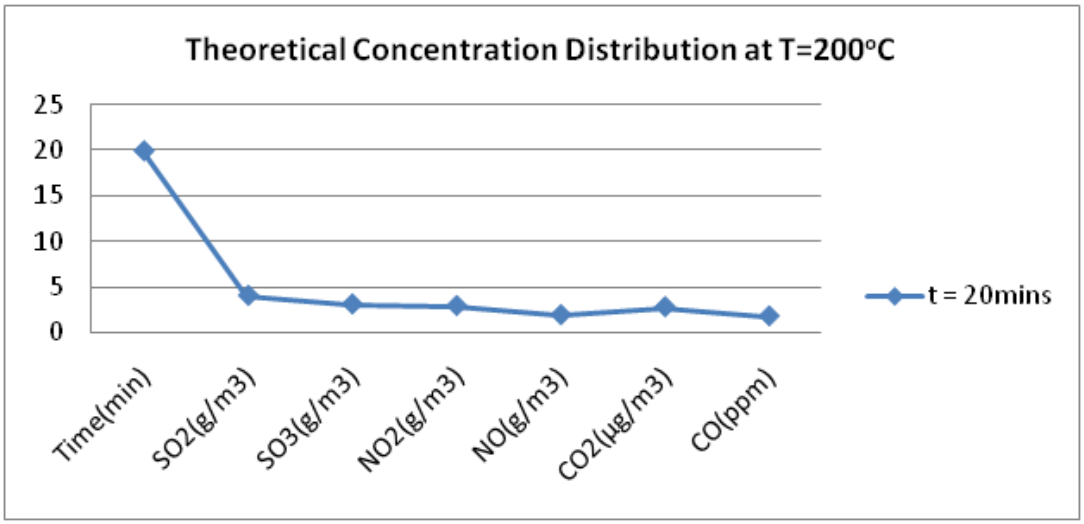

Figure 6. Theoretical Concentration Distribution at T =200oC, t=20mins

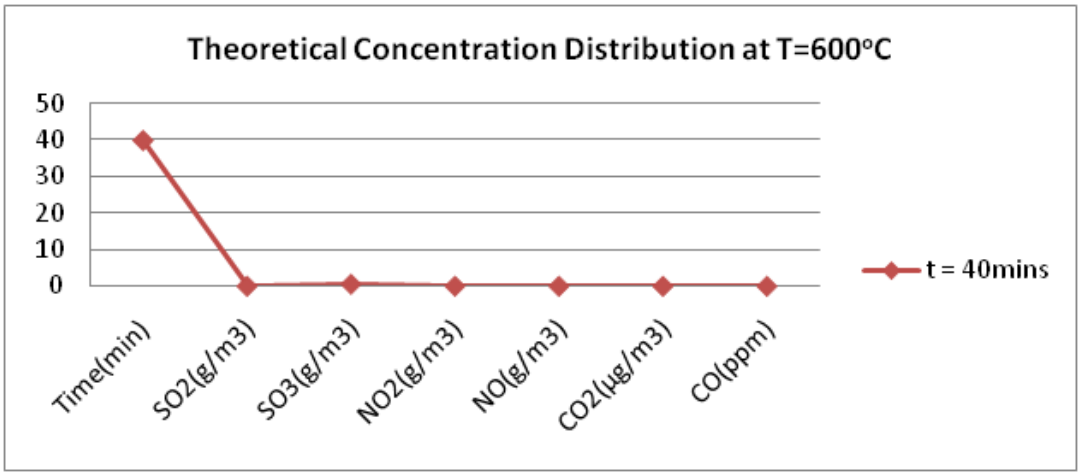

Figure 7. Theoretical Concentration Distribution at T =600oC, t=40mins

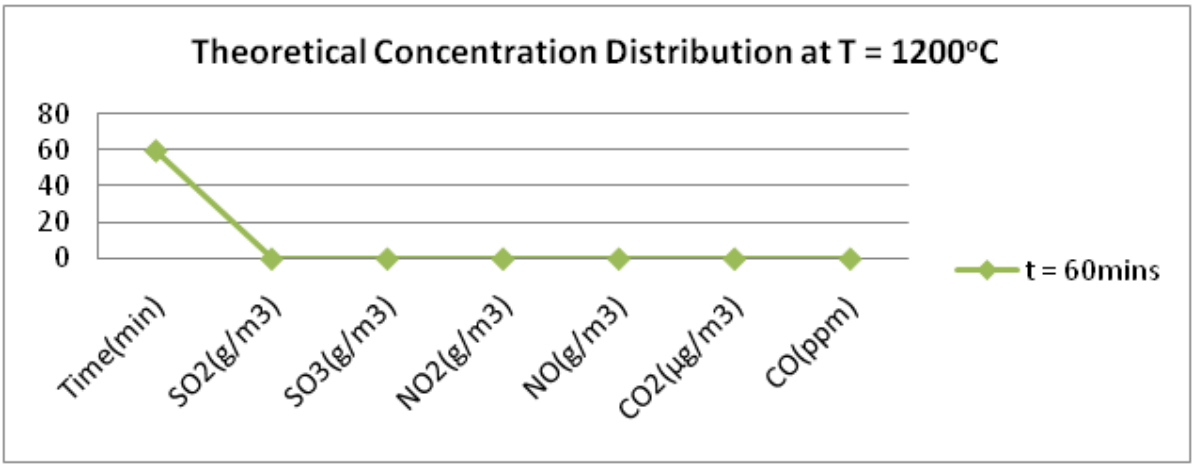

Figure 8. Theoretical Concentration Distribution at T =1200oC, t=40mins

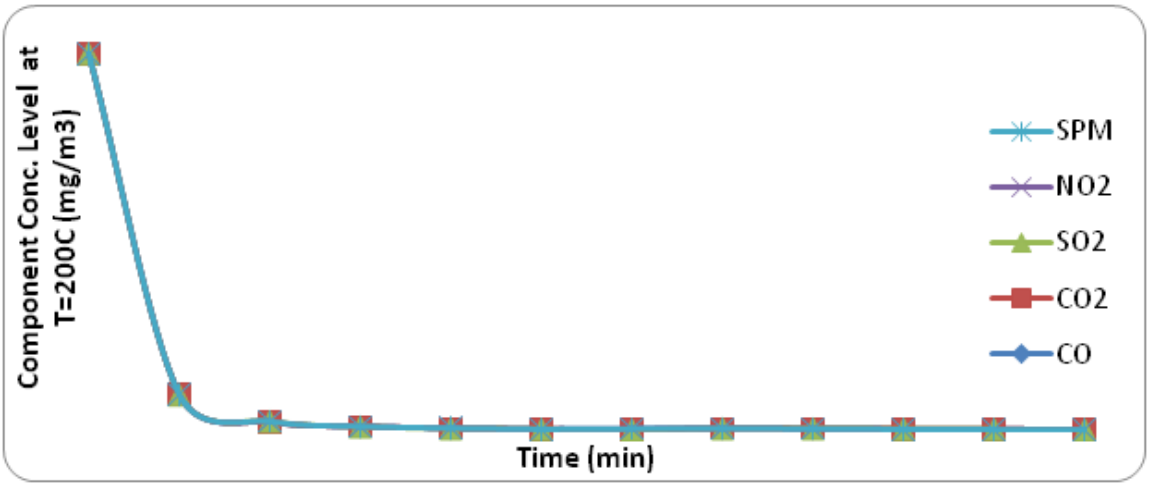

Figure 9. Concentration Gradient of Component Pollutants at T= 2000C

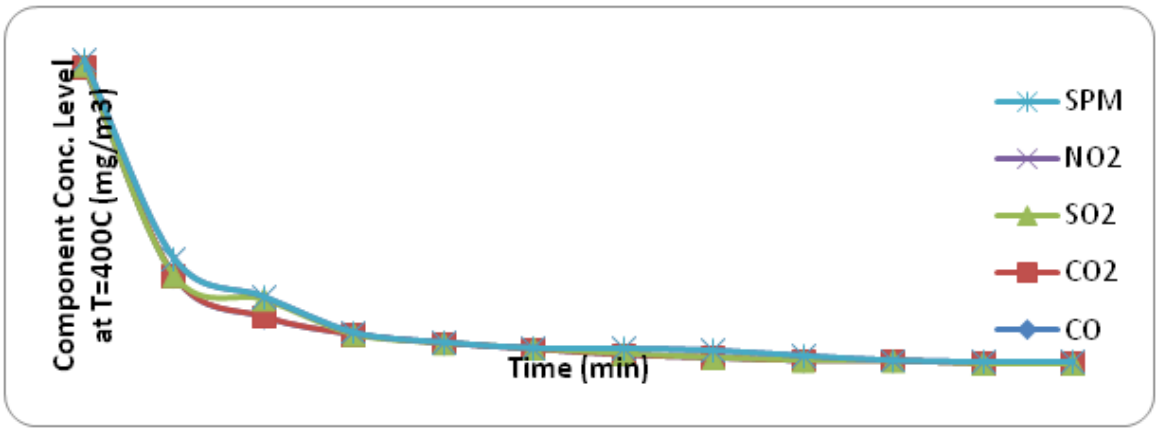

Figure 10. Concentration Gradient of Component Pollutants at T= 4000C

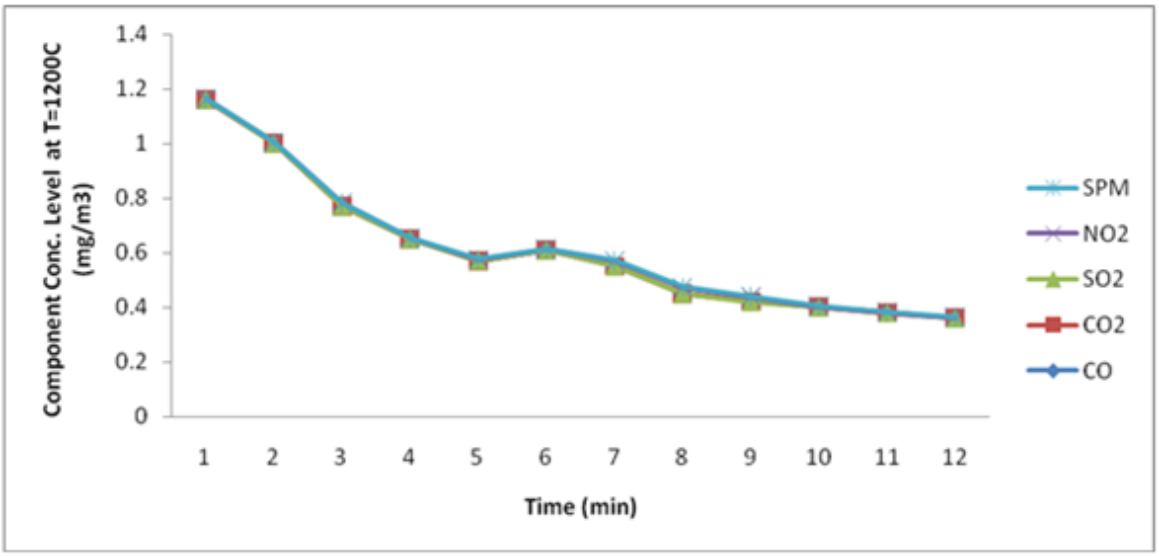

Figure 11. Concentration Gradient of Component Pollutants at T= 12000C

reasons, only suspect pollutants were sampled and analyzed.

DISCUSSIONS

In other to get the concentration distribution for each pollutant parameter, the following computational techniques were employed as in figure 2.

Carrying out a comparative analysis of the theoretical approach, experimental work and that of the permissible limits, it infers that the theoretical work expressed the concentration gradients of effluents from the emission stack as a lumpsum of all suspected pollutants, though when compared with the summed component results of the experimental results it was quite compatible as reflected in table 2-6 and are far below the regulatory limits as stipulated in Department of Petroleum Resources (DPR, 1998) requirements

From the graphical orientation presented above it is obvious that increase in temperature of the thermocouple with respect to time results in decrease in concentration of the pollutants emitted into the ambient air regime.

Recall Bulk Concentration Gradient at Various Temp. Range under Placid Air Environment Chart above, at (temperature $T=200^0C$ and time t=5mins) the bulk concentration value is maximum at 22,894.13g/m^3 with increase in time it further reduces to 189.71 g/m^3. As the temperature increases the bulk conc. also reduces, therefore at temp. $=1200^0C$ and time = 5mins bulk conc. also reduce as extracted. This characteristic behavior is demonstrated in tables 6- 7

From Tables 2-4, the decrease in bulk concentration at temperature ranging $T=200- 1200^OC$ is as a result higher thermal cracking condition during the incineration process as expressed explicitly in Figures 4-5 of this work. Considering the theoretical simulated results under turbulent flow regime, there is a sharp increase in the bulk concentration gradient from 148.31g/m^3 to 152.46g/m^3. This was due to the fact that the incinerator was pre-heated to temperature $T=200^OC$. Hence at the introduction of the obsolete ignitable eposand chemical, a flashing occurs with respect to the initial velocity. After the uniform temperature distribution within the wall of the incinerator, a cascade of decreasing bulk concentration values set in with increase in time.

Recall equation 32 otherwise called Abowei-Asiagbe predictive dimensional diffusion rate model for bulk gaseous components emission (Asiagbe, 2009) during incineration process of eposand chemical. The model is useful to predict 1-D bulk concentration distribution under laminar flow regime. A correction factor was derived and upon the simulation and comparison; a minimal and negligible correlation values were obtained as depicted in table 7.

Further affirmation was also inferred that at (temperature $T=200^OC$, (time t=5min), $\phi = 1.02 \times 10^{-7}$), (t=30min) $\boldsymbol{\phi}$ $=2.92 \times 10^{-8}$ and at t=60min $\boldsymbol{\phi}$ further reduces to

7.13×10^{-9}. Hence increase in time yields a higher accuracy of Abowei - Asiagbe predicted dimensional diffusion rate for the incineration parameter and the 1-D predicted model as variation becomes minimal. Increase in temperature also results in decrease in correction factors.

Recalling the experimental approach, the methodologies adopted where DPR certified and was able to detect all the pollutants of interest at defined temperatures. Temperature $T=200^OC$ produced the maximum concentration level for each of the measured pollutants. X-raying into component pollutant concentration limits of monitored pollutants (CO_2, NO_x, SO_x, CO, SPM and SiO_x). The SPM levels at the various temperatures are significantly higher. CO_2, NO_x, SO_x, and CO values are closely related thus fall within the range of ($0.001 \leq X \leq 0.81$) mg/m^3 where X = other monitored pollutants. Though when compared with the limits of DPR/FMENV regulatory guidelines; the theoretical and experimental values were far more below the DPR requirements depicting that the environment is not polluted in response to our waste management approach.

CONCLUSIONS

Model equations for the prediction of gaseous emissions into air interphase during obsolete eposand incineration process were developed using integral and modified Raleigh dimensional analysis approach. The models of the integral and dimensional analysis approach were compared to establish a corrective constant in evaluating the concentration distribution of gaseous emission into the air interphase. The one dimensional predictive models describe emission diffusion into air interphase for both at ambient perturbation (turbulent flow) and at no perturbation (Laminar flow regime). The developed models were simulated using Microsoft excel 2007 visual basic computer programme. The results of bulk concentration distribution were found to be decreasing with increase in time at no perturbation (Laminar) for constant eposand volume. Similarly at perturbation turbulent ambient air flow regime, the concentration distribution decreases with increase in time for constant eposand volume. Experimental works were also carried out for the concentration distribution of gaseous emissions into the air interphase to establish the authenticity of the predictive models. Results of the theoretically formulated models were compared with those of experimental and found to be very compatible and reproducible.

Sampling and analysis of gaseous emissions (for pollutants of interest) from the stack of the incinerator used for the disposal of the obsolete Eposand chemical was made.

Table 1. Molecular Weight of Pollutants

S/N	COMPONENT POLLUTANT	MOLECULAR WEIGHT
1	Sulphur dioxide (SO_2)	64g
2	Sulphur trioxide (SO_3)	80g
3	Nitrogen dioxide (NO_2)	46g
4	Nitrogen monoxide (NO)	30g
5	Carbon dioxide (CO_2)	44g
6	Carbon Monoxide (CO)	28g
7	Chlorine (Cl_2)	70.9g
8	Suspended Particulate Matter (SPM)	Nil
9	Dioxin/Furan	Nil
	TOTAL MOLECULAR WEIGHT	362.9g

Table 2. Theoretical Conc. Distribution at T=200^{0}C

S/N	Time(min)	$SO_2(g/m^3)$	$SO_3(g/m^3)$	$NO_2(g/m^3)$	$NO(g/m^3)$	$CO2(\mu g/m^3)$	CO(ppm)
1	20	4.037	3.091	2.901	1.892	2.775	1.766

Table 3. Theoretical Conc. Distribution at T=400^{0}C

S/N	Time(min)	$SO_2(g/m^3)$	$SO_3(g/m^3)$	$NO_2(g/m^3)$	$NO(g/m^3)$	$CO2(\mu g/m^3)$	CO(ppm)
1	40	0.04815	0.6019	0.03686	0.02257	0.0331	0.0216

Table 4. Theoretical Conc. Distribution at T=1200^{0}C

S/N	Time(min)	$SO_2(g/m^3)$	$SO_3(g/m^3)$	$NO_2(g/m^3)$	$NO(g/m^3)$	$CO2(\mu g/m^3)$	CO(ppm)
1	60	0.02849	0.03561	0.02047	0.01235	0.01958	0.03156

Table 5. Comparative Analysis of Experimental Results and Permissible Limit

			Concentration Level	
S/N	Pollutant	Units	Component Experimental	Permissible Limit
1.	SPM	mg/m^3	22.11	120-230
2.	NO_2	µg/m3	0.001	150-400
3	SO_2	µg/m3	0.001	26-150
4.	CO	ppm	0.001	10
5.	CO_2	% vol	0.031	

Table 6. Temperature Effect on Bulk Concentration

Time (min)	Concentration Distribution at Varying Temp.		
	200^{o}C	600^{o}C	1200^{o}C
5	22,894g/m^3	273.05g/m^3	161.56g/m^3
30	221.68g/m^3	74.46g/m^3	52.95g/m^3
60	189.71g/m^3	50.57g/m^3	36.63g/m^3

Table 7. Representation of Error Factor (ϕ)

Time (min)	Correction Factors at Varying Temp.		
	200^{o}C	600^{o}C	1200^{o}C
5	1.02×10^{-7}	1.02×10^{-6}	9.8×10^{-7}
30	2.92×10^{-8}	2-16 $\times 10^{-8}$	1.39×10^{-8}
60	7.13×10^{-9}	4.06×10^{-9}	2.51×10^{-9}

A comparison of the pollutants concentration levels, also obtained from the analysis, and the permissible limits for such pollutants, as set in the FMENV and DPR (Abowei and Wami, 1988; Fick, 1858) guidelines, was made. Generally the emissions were below the guideline limit. Compliance with laid-down regulation is thus confirmed.

The efficiency of the pilot plant as it was constituted – incinerator and scrubber facility based on the results obtained can thus be upheld.

A simple theoretical model of the prediction of the diffusion co-efficient and diffusion rate in one-dimension, of the gaseous emissions from the incineration process was developed and simulated.

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