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Dry season predictive technique for estimating the hydrocarbon degradation in a continuous discharge of wastewater in pond system

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A new correlation has been developed in this paper for predicting hydrocarbon degradation in a continuous discharge of wastewater in a pond system for dry season. The correlation was developed using force balance model on a fluid element in a pond (hydrodynamic model). Mathematical technique known as separation of variables was applied to the general solution obtained from the hydrodynamic model. The degradation rate of individual hydrocarbon was estimated and attributed to change in microbial growth, physico-chemical properties of wastewater due to momentum transfer experience on the system. An experimental study was as well conducted in examining the reliability of this method. The predictions of this correlation are in acceptable agreement with the theoretical data, demonstrating the reliability of this predictive technique for estimating the individual hydrocarbon degradation in a continuous discharge of wastewater in a pond system under the influence of momentum transfer. The predictive model for estimating the effect of momentum transfer on the hydrocarbon degradation in a pond system is given as:

$$U_{LI} = \frac{1}{t}\left[\frac{C_n \exp\left(\frac{1-V_I}{V_I^2}\right) g\,(S_o)\,L_I}{\mu_{\max}^S \left[\frac{S_I}{K_{mI}+S_I} \bullet \frac{S_2}{K_{m2}+S_2} \bullet \frac{S_3}{K_{m3}+S_3} \bullet \frac{S_4}{K_{m5}+S_5} \bullet\bullet \frac{S_n}{K_{mn}+S_n}\right]}\right] In\,\frac{X}{X_o}$$

Accurate experimental data on additional systems are needed to develop a reliable momentum transfer theory particularly for process representation at wind velocity higher than discharged velocity.

Key words: Hydrocarbon degradation, momentum transfer, correlation, microbial growth, model, dry.

INTRODUCTION

The current worldwide complain against environmental degradation has attracted the attention of environmentalist, geoscientist, engineers, etc. The exploration, production, transportation, refining and

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utilization, therefore have been a major player in environmental pollution. These activities have to be carried out in such a way as to protect and preserve the quality of the environment while still achieving desire economic benefits. In Nigeria, it is most pronounced in the Niger Delta area for both upstream and downstream sectors as their operations have rapidly increased. The essence of effluent water treatment is to protect the environment from further environmental degradation.

The present practice of most companies in wastewater disposal during exploration and production operation, to the receiving lakes, rivers, ocean and seas without treatment are unacceptable. Consequently, the increase in petroleum and gas production and inadequate treatment implies that the future of man in these region remain uncertain. Also, considering the current trends in Government, environmental regulations regarding the disposal of wastewater (effluent water), there is urgent need to evaluate alternative and acceptable way of reducing wastewater disposal into the environment.

Bioremediation treatment techniques are in use to enhance environmental clean up of polluted ponds, lakes, rivers, seas and the ocean (Abbey et al., 2003; De-Wildeman et al., 2004; Hong-gyu and Richard, 1990; Fuse et al., 2003; GEMS, 1992). Field and laboratory investigations reveal that the treatment technique can be influenced by temperature, pH, dissolved oxygen, biological oxygen demand, moisture content, solubility of the contaminants, etc. (Abbey et al., 2003; Abdel-salam and El-shafi, 2004; Ahmed, 2004; Ahmed et al., 2003; Bugni and Ireland, 2004; Carey et al., 2003; Chaloupkora et al., 2003; De-wildeman et al., 2004). Field and laboratory studies were conducted to predict the effect of continuous discharge of wastewater on the biodegradation of existing hydrocarbon concentration and as well as the momentum transfer on individual hydrocarbon degradation in a pond system. This arouses our interest to propose a multi-functional and multi-disciplinary approach in solving these environmental problems, such as possible inhibitor that may influence biodegradation of individual hydrocarbon. In, continuous discharge of wastewater, this process may alter the hydrocarbon composition in the pond, and likely influencing the performance or activities of the microbes present in the pond. This is possible because the change in the physicochemical properties of the pond system will influence hydrocarbon composition in the pond; this may result to increase or decrease in the microbial activities (Evans, 1963; Feng, 2004; Dror and Schlautman, 2004; Dyer, 2003; Grm et al., 2003; Haggblom et al., 2003; Kww, 2001; Metealf and Eddy, 1991; Oh et al., 1994; O'connor and Dobbins, 1958; Miller and Alexander, 1991).

The role of biodegradation in the chemical evolution of the residual petroleum hydrocarbon mixture has given rise to a new trend of technology in the petroleum industry (Mrarik et al., 2003; Kamanavalli and Ninnekar, 2004; Goldsmith and Balderson, 1989). The fundamental principles of this fast growing technology are to create conditions under which micro organisms grow and use the petroleum hydrocarbon as substrate. The result of this is the transformation of the residual petroleum hydrocarbons discharged into a pond system to carbon dioxide, biomass, heat released, etc. (Dyer et al., 2003, Dercova et al., 2003; Chen, 2004; Bailey and Oillis, 1986; Blunt et al., 2004). To enhance the degradation ability of petroleum hydrocarbon by microbes, various physicochemical properties of the medium (pH, temperature, dissolved solids, etc) need to be monitored and controlled.

The petroleum hydrocarbon concentration and physicochemical properties of the pond system in all the conditions prevalent in Nigeria was studied in relation with the effect of momentum and mass transfer experienced due to continuous discharge of wastewater. On the other hand, the importance of microbial and substrate kinetic as well as product kinetic for anaerobic and aerobe reactors for wastewater treatment is well known by many researchers (Bradley and Chapelle, 1996; Antai, 1992; Holliger and Zehnder, 1996; Islam, 1990; Jadulco et al., 2004; Peter et al., 2003; Rybkina et al., 2003; Ritch, 1973; Riggs et al., 1970; Schroll et al., 2004; Yeager et al., 2004), but the report lack the effect of momentum transfer on continuous discharge of effluent in such process.

The main objective of this study is for the development of models for the prediction of individual hydrocarbon degradation in pond system for continuous discharge of wastewater under the influence of momentum transfer and as well as to determine their effect on microbial growth rate and substrate concentration. The mathematical equation obtained in this paper can be found useful in monitoring, predicting and simulating the degradation and microbial growth rate kinetics on the characteristics of difference in wastewater (influent) discharged hydrocarbon concentration. The work presented in this paper can be applied in the characterization of the product inhibition due to momentum transfer in the pond system in terms of depth, distance and time.

CONCEPTUAL MODEL

The problem of momentum, heat and mass transfer in liquid or porous media for the conceptualization of bioremediation application in pond, lake, river, sea, ocean and land is very complex. In practice, there can be no exact mathematical representation of a real situation. The domain and properly of a real liquid mass cannot be represented mathematically in exact terms. In view of this, there is a need for some set of assumptions that represent a simplified perception of the real system under consideration. Only those features that are considered relevant to the problems are included in the model.

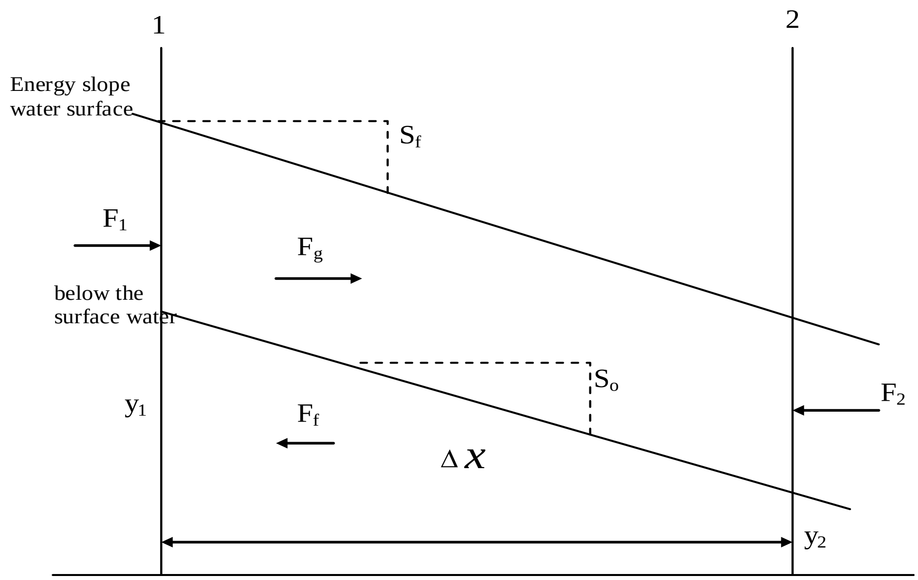

Figure 1. Force balance on a fluid element in a pond.

The momentum model

Force balance model on a fluid element in a pond

The conservation of the momentum equation can be expressed in a linear or angular momentum form. Momentum is defined as a product of mass and its velocity. However, it is derived here in the interest to determine the effect of momentum transfer due to continuous discharge of wastewater on biodegradation of petroleum hydrocarbons in an oxidation pond system. From Figure 1, the force acting on the fluid element (petroleum hydrocarbons and other components) at length ΔX is expressed mathematically as:

Gravity $F_g = \rho g A \Delta x S_o$ (1)

Friction $F_f = \rho g A \Delta x S_f$ (2)

Hydrostatic $F_1 - F_2 = \frac{1}{2} \rho g \frac{\partial}{\partial x}\left(\bar{y}^2 A\right)$ (3)

The energy slope line, the water surface slope and below the water surface slope in this paper are assumed not to be the same. On this investigation, it is assumed that the energy line has a slope of S_f and below the water surface level has a slope of S_o. Then, the conservation of momentum equation is given as.

$$\left(\text{The rate of change of momentum for the volume element}\right) = \left(\text{The resultant of the forces acting on the volume element}\right) \quad (4)$$

$$\frac{dU}{dt} = F_g + (F_1 - F_2) - F_f \quad (5)$$

Substituting Equations 1, 2 and 3 into Equation 5 yields

$$\frac{d}{dt}(U) = \rho g A \Delta x S_o + \frac{1}{2}\rho \frac{\partial}{\partial x}\left(\bar{y}^2 A\right) - \rho g A \Delta x S_f \quad (6)$$

Since $\frac{d(U)}{dt} = \rho A \Delta x\left(\frac{\partial u}{\partial t} + V\frac{\partial u}{\partial x}\right)$ (7)

Therefore, substituting Equation 6 into Equation 7 and rearranging the equation obtained yields

$$\rho A \Delta X\left(\frac{\partial u}{\partial t} + V\frac{du}{\partial x}\right) = \rho g A \Delta X\left(S_o - S_f\right) + \frac{1}{2}\rho g \frac{\partial}{\partial X}\left(\bar{y}^2 A\right) \quad (8)$$

The investigation was conducted under the following conditions, a constant cross-section area and one-dimensional flow, thus Equation 8 becomes

$$\frac{\partial u}{\partial t} + V\frac{\partial u}{\partial x} = g\left(S_o - S_f\right) \quad (9)$$

In the wept season, there were friction losses during the investigation. These losses are due to the following reason, the water table level is high, inconsistence of flow water direction, and as well as the internal fluid friction, as each horizontal layer of fluid shears over the next layer, producing a shear loss. Therefore $S_f \neq 0$ and Equation 9 becomes useful, thus:

$$\frac{\partial u}{\partial t} + V\frac{\partial u}{\partial x} = g\left(S_o - S_f\right)$$

But in the dry season, It was assumed that there were no friction losses during the investigation, therefore $S_f = 0$ and Equation 9 becomes

$$\frac{\partial u}{\partial t} + V\frac{\partial u}{\partial x} = g(S_o) \qquad (9a)$$

Mathematical application on Equation (9a) using separation of variables

Recalling Equation 9 where $V = V_I$, thus

$$\frac{\partial u}{\partial t} + V_I\frac{\partial u}{\partial x} = g(S_o)$$

The momentum transfer process for the pond system can be described as a simple batch phenomenon under conditions where organic sedimentation, sediment reaction and loss of organic volatiles component of petroleum are negligible. Therefore Equation 9 can be resolved by the application of separation of variables. Equation 9 is expressed by considering the flowing boundary conditions such as:

$$at \quad x = 0,\ t = 0\ , U = C_n \qquad (10)$$

$$at \ x = L, t = t \qquad (11)$$

Using the boundary conditions in Equations 10 and 11, the mathematical application of separation of variables, when the real constant λ^2 is positive, the following solutions were obtained

(i) $$T_1 = C_3 e^{\lambda^2 t} \qquad (12)$$

(ii) $$x_1 = C_4 e^{-\frac{\lambda^2}{V_1}x_1} \qquad (13)$$

(iii) $$C_I = \frac{C_n}{C_2} \qquad (14)$$

(iv) $$\lambda^2 = \frac{g(S_o)}{V_I} \qquad (15)$$

(v) $$V_I = \frac{L_I}{t} \qquad (16)$$

(vi) $$U_{L(1)} = \left(C_1 e^{\frac{g(S_o)}{V_I}\bullet\frac{L_I}{V_I}}\right)\left(C_2 e^{-\frac{g(S_o)L_1}{V_I}}\right) \qquad (17)$$

(vii) $$U_{L(1)} = \left(\frac{C_n}{C_2} e^{\frac{g(S_o)}{V_I^2}L_I}\right)\left(C_2 e^{-\frac{g(S_o)L_1}{V_I}}\right) \qquad (18)$$

(viii) $$U_{L(1)} = \left(C_n e^{\frac{g(S_o)}{V_I^2}L_I}\right)\left(e^{-\frac{g(S_o)L_1}{V_I}}\right) \qquad (19)$$

(ix) $$\lambda^2 = \frac{V_I}{L_I(1-V_I)} \text{In}\frac{C_n}{U_{LI}} \qquad (20)$$

(x) $$S_o = \frac{V_I^2}{L_I(1-V_I)} \text{In}\frac{C_n}{U_{L_{=I}}} \qquad (21)$$

(xi) $$\frac{V_I^2}{1-V_I} = g(S_o)L_I \ \text{In}\frac{Cn}{U_L} \qquad (22)$$

The developed model in Equation 22 can be applied in monitoring the rate of degradation of the individual hydrocarbon, estimating the degree of influence of momentum transfer and the affected area, estimating the spreading rate and diffusion rate for each hydrocarbon component in the oxidation pond system upon the influence on internal fluid friction, as each horizontal layer of fluid shears over the next layer. The use of this Equation 22 is useful for the prediction as well as correlation of velocity and substrate concentration as a function of distance and time upon the influence of internal fluid friction for wet season. The velocity $\frac{V_I^2}{1-V_I}$ for the oxidation pond system was determined at the point of intercept on the $\frac{V_I^2}{1-V_I}$ coordinate and the slope of the graph was used in the determination of $g(S_o)\ \text{In}\ \frac{C_n}{U_{LI}}$ for wet season.

Model for correlation of momentum transfer and biokinetic

The correlation model was developed with and without the influence of momentum transfer in the pond system. Recalling the mathematical expression,

$$-\frac{1}{X}\frac{dS}{dt} = \mu^s \frac{X}{Y} \qquad (23)$$

Similarly, the mathematical expression for Monod equation for this typical aerobic pond reactor is given as:

$$\frac{dS}{dt} = \left(\mu^s_{\max}\frac{S}{K_m + S}\right)\frac{X}{Y} \qquad (24)$$

The mathematical expression in terms of microbial substrate relationship is given as

$$Y = \frac{X - X_o}{S_o - S} = \frac{dx}{dS} \quad (25)$$

Substituting Equation 24 into Equation 25 in terms of Y yields

$$\frac{dS}{dt} = \left(\mu^s_{\max} \frac{S}{K_m + S}\right) \frac{X}{dx/dS} \quad (26)$$

The mathematical expression obtained in Equation 26 is only for single component of the system. Therefore defining Equation 26 in terms of multiple component system yields

$$\frac{dS}{dt} = \mu^s_{\max} \begin{pmatrix} \frac{S_1}{K_{m_1} + S_1} \bullet \frac{S_2}{K_{m_2} + S_2} \bullet \frac{S_3}{K_{m_3} + S_3} \\ \bullet \frac{S_4}{K_{m_4} + S_4} \bullet \frac{S_5}{K_{m_5} + S_5} \bullet\bullet\bullet \frac{S_n}{K_{m_n} + S_n} \end{pmatrix} \frac{X}{dX/dS} \quad (27)$$

Recalling the general equation obtained in Equation 19 for mathematical application on dry season under the influence of momentum transfer; thus, the general expression for the momentum transfer in dry season is given as:

$$U_{L_I} = \left(c_n \ell^{\frac{g(S_o)}{V_I^2} L_I}\right)\left(\ell^{-\frac{g(S_o)}{V_I} L_I}\right)$$

The mathematical expression for momentum is defined as the product of mass multiple by velocity

$$U_L = mass \bullet velocity = MV \quad (28)$$

But velocity = $\frac{dS}{dt} = \frac{\text{change in substrate concentration}}{\text{change in time}}$ (29)

Substituting Equation 29 into Equation 19 yields

$$MV = \left(c_n \ell^{\frac{g(S_o)}{V_I^2} L_I}\right)\left(\ell^{-\frac{g(S_o)}{V_I} L_i}\right) \quad (30)$$

where M = mass and V = $\frac{dS}{dt}$ = velocity or specific rate.

Since V = $\frac{dS}{dt} = \frac{dX}{dt}$ (31)

Therefore substituting Equation 30 into Equation 31 yields

$$M\frac{dS}{dt} = \left(c_n \ell^{\frac{g(S_o)}{V_I^2} L_1}\right)\left(\ell^{-\frac{g(S_o)}{V_I} L_I}\right) \quad (32)$$

Therefore rearranging Equation 32 and then substituting it into Equation 27 yields

$$\frac{1}{M_{sm}}\left[\left(C_n \ell^{\frac{g(S_o)}{V_I^2} L_I}\right)\left(\ell^{-\frac{g(S_o)}{V_I} L_I}\right)\right] = \mu^S_{\max} \begin{pmatrix} \frac{[S_1]}{K_{m1} + S_1} \bullet \frac{[S_2]}{K_{m_2} + S_2} \bullet \frac{[S_3]}{K_{m_3} + S_3} \\ \bullet \frac{[S_4]}{K_{m_4} + S_4} \bullet \frac{[S_5]}{K_{m_5} + S_5} \bullet \frac{[S_n]}{K_{m_n} + S_n} \end{pmatrix} \frac{X}{dX/dS} \quad (33)$$

$$M_{sm} = \left[\left(C_n \ell^{\frac{g(S_o)}{V_I^2} L_I}\right)\left(\ell^{-\frac{g(S_o)}{V_I} L_I}\right)\right] \Bigg/ \mu^S_{\max} \begin{pmatrix} \frac{[S_1]}{K_{m1} + S_1} \bullet \frac{[S_2]}{K_{m_2} + S_2} \bullet \frac{[S_3]}{K_{m_3} + S_3} \\ \bullet \frac{[S_4]}{K_{m_4} + S_4} \bullet \frac{[S_5]}{K_{m_5} + S_5} \bullet \frac{[S_n]}{K_{m_n} + S_n} \end{pmatrix} \frac{X}{dX/dS} \quad (34)$$

Similarly, Equation 27 can be written as:

$$\frac{dX}{dt} = \mu^S_{\max} \begin{pmatrix} \frac{[S_1]}{K_{m1} + S_1} \bullet \frac{[S_2]}{K_{m_2} + S_2} \bullet \frac{[S_3]}{K_{m_3} + S_3} \\ \bullet \frac{[S_4]}{K_{m_4} + S_4} \bullet \frac{[S_5]}{K_{m_5} + S_5} \bullet \frac{[S_n]}{K_{m_n} + S_n} \end{pmatrix} X \quad (35)$$

Therefore

$$M\frac{dX}{dt} = \left(c_n \ell^{\frac{g(S_o)}{V_I^2} L_1}\right)\left(\ell^{-\frac{g(S_o)}{V_I} L_i}\right) \quad (36)$$

Substituting Equation 36 into Equation 35 and rearranging yields

$$M_{X\,sm} = \left[\left(C_n \ell^{\frac{g(S_o)}{V_I^2} L_I}\right)\left(\ell^{-\frac{g(S_o)}{V_I} L_I}\right)\right] \Bigg/ \mu^S_{\max} \begin{pmatrix} \frac{[S_1]}{K_{m1} + S_1} \bullet \frac{[S_2]}{K_{m_2} + S_2} \bullet \frac{[S_3]}{K_{m_3} + S_3} \\ \bullet \frac{[S_4]}{K_{m_4} + S_4} \bullet \frac{[S_5]}{K_{m_5} + S_5} \bullet \frac{[S_n]}{K_{m_n} + S_n} \end{pmatrix} X \quad (37)$$

But

$$U_{L_{ISm}} = MV = M_{Xsm}V = M_{Xsm}\frac{dx}{dt} \quad (38)$$

Therefore, Equation 37 becomes

$$U_{LISM} = \left[\left(C_n \ell^{\frac{g(S_o)}{V_I^2} L_I}\right)\left(\ell^{-\frac{g(S_o)}{V_I} L_I}\right)\right] \Bigg/ \mu^S_{\max} \begin{pmatrix} \frac{[S_1]}{K_{m1} + S_1} \bullet \frac{[S_2]}{K_{m_2} + S_2} \bullet \frac{[S_3]}{K_{m_3} + S_3} \\ \bullet \frac{[S_4]}{K_{m_4} + S_4} \bullet \frac{[S_5]}{K_{m_5} + S_5} \bullet \frac{[S_n]}{K_{m_n} + S_n} \end{pmatrix} X\frac{dX}{dt} \quad (39)$$

$$U_{LISM} = V\left[\left(C_n \ell^{\frac{g(S_o)}{V_I^2} L_I}\right)\left(\ell^{-\frac{g(S_o)}{V_I} L_I}\right)\right] \Bigg/ \mu^S_{\max} \begin{pmatrix} \frac{[S_1]}{K_{m1} + S_1} \bullet \frac{[S_2]}{K_{m_2} + S_2} \bullet \frac{[S_3]}{K_{m_3} + S_3} \\ \bullet \frac{[S_4]}{K_{m_4} + S_4} \bullet \frac{[S_5]}{K_{m_5} + S_5} \bullet \frac{[S_n]}{K_{m_n} + S_n} \end{pmatrix} X \quad (40)$$

Rearranging Equation 39 and then integrating yields

$$U_{LISM}\, t = \left[\left(C_n \ell^{\frac{g(S_o)}{V_I^2}L_I}\right)\left(\ell^{-\frac{g\ (S_o)}{V_I}L_I}\right)\right] \Bigg/ \mu_{\max}^{S}\left(\begin{array}{c}\frac{[S_1]}{K_{m1}+S_1}\bullet\frac{[S_2]}{K_{m_2}+S_2}\bullet\frac{[S_3]}{K_{m_3}+S_3}\\ \bullet\frac{[S_4]}{K_{m_4}+S_4}\bullet\frac{[S_5]}{K_{m_5}+S_5}\bullet\frac{[S_n]}{K_{m_n}+S_n}\end{array}\right) In\,\frac{X}{X_o} \tag{41}$$

Similarly, Equation 41 can be written as

$$U_{L_{I\,Ism}} t = \left[\left(C_n \ell^{\left(\frac{1-V_I}{V_I^2}\right)g(S_o)L_{II}}\right) \Bigg/ \mu_{\max}^{S}\left(\begin{array}{c}\frac{[S_1]}{K_{m1}+S_1}\bullet\frac{[S_2]}{K_{m_2}+S_2}\bullet\frac{[S_3]}{K_{m_3}+S_3}\\ \bullet\frac{[S_4]}{K_{m_4}+S_4}\bullet\frac{[S_5]}{K_{m_5}+S_5}\bullet\frac{[S_n]}{K_{m_n}+S_n}\end{array}\right)\right] \mathrm{In}\,\frac{X}{X_o} \tag{42}$$

Simplifying and rearranging Equation 42 yields

$$\mathrm{In}\left[\mu_{\max}^{S}\left(\begin{array}{c}\frac{[S_1]}{K_{m1}+S_1}\bullet\frac{[S_2]}{K_{m_2}+S_2}\bullet\frac{[S_3]}{K_{m_3}+S_3}\\ \bullet\frac{[S_4]}{K_{m_4}+S_4}\bullet\frac{[S_5]}{K_{m_5}+S_5}\bullet\frac{[S_n]}{K_{m_n}+S_n}\end{array}\right) U_{LI_{Ism}}\, t\ \mathrm{In}\,\frac{X_o}{X} \Big/ C_n\right] = \left(\left(\frac{1-V_I}{V_I^2}\right) g\left(S_o\ \ S_f\right) L_I\right) \tag{43}$$

The developed model in Equation 43 can be found useful in predicting and monitoring the microbial growth rate kinetics, substrate kinetics and the characteristics of the dynamic, stability and Monod chemostat parameters upon the influence of momentum transfer.

MATERIALS AND METHODS

The primary objective of this study is to identify and map out potential suitable approach for bioremediation of polluted ponds for continuous discharged and as well as effect of momentum transfer in biodegradation process. In order to have a better understanding on effect of momentum transfer on biodegradation of contaminants, investigation was conducted on contaminants distribution in surface, subsurface and as well with time. As mentioned earlier, the investigation is aimed to determine the following: (a) to determine the effect of momentum transfer on biodegradation of individual petroleum hydrocarbon contaminant, (b) to recommend the best approach of carrying out bioremediation process in oxidation pond system either by continuous discharged of wastewater or batchwise method of wastewater treatment, (c) provide suitable design for bioremediation in an oxidation pond process; (d) to recommend the best bioremediation programme.

Equipment and materials

The equipment and material used for the experiment are as follows: samples and Gas chromatography.

Sampling

Samples were carried out at specific points in the pond using automatic pipette, attached on a slide rule to determine the various depths and the wastewater samples were collected in one of the oxidation pond in Niger Delta area of Nigeria, at various sampling point in the oxidation pond system. The collected samples were transferred into sample bottles and stored in cool container before transfer to the laboratory for analysis. Similarly, samples were collected at various distance (surface) inclined and vertical depth (subsurface).

Procedure/methodology/precautions

To successfully execute and come out with findings from the research work, the following sequential approach was used; collection of samples, the samples collected was stored at temperature below 4°C and analysis was conducted within 24 h, identification of microbes present in the samples and isolation of those microbes; (a) influent, (b) effluent, analysis for the determination of chemical composition was carried out (b) influent, and effluent: the samples was analyzed at one month interval using standard experimental techniques. The developed model was validated using experimental results and as well comparison was made between the experimental result and the theoretical values.

Experimental procedure

Figure 1 shows a schematic of the main oxidation pond system used in the experimental investigation of this work. Samples were collected at different surface distance, inclined and vertical depth (subsurface) at every 4 weeks for laboratory analysis to be carried on the following parameters: microbial activity was determined at different points of the oxidation pond system to ascertain the effect of momentum transfer. To ascertain the distribution of individual hydrocarbon concentration of the wastewater at different points of the oxidation pond system and as well to ascertain the rate of degradation as a result of momentum transfer effect.

The initial composition of the oxidation pond system was measured to determine microbial population and individual hydrocarbon concentration at different point in the oxidation pond system for dry season. The wastewater contaminants velocity was determined at various sampling points A_1, A_2, A_3, A_4, C_1, C_2, C_3, C_4, B_1, B_2, B_3 and B_4. These points established where the sampling area was considered during the investigation at various intervals of weeks and the results obtained from the analysis were recorded. The specific rate (velocity) on the substrate concentration, microbial concentration and physiochemical parameters were measured at various sampling points. Similarly, the substrate concentration and biomass concentration under investigation were determined experimentally. The experimental diagram for the investigation is illustrated in Figure 2; where, o is hydrocarbon, □ is particle, ∿∿ is wave formation created as a result of disturbance (continuous discharge of waste water into the oxidation pond, → is the direction of flow. A_0, A_1, A_2, A_3, A_4, B_0,B_1, B_2, B_3, B_4, C_0, C_1, C_2, C_3, and C_4 are sampling points.

RESULTS AND DISCUSSION

The experimental investigation was carried out to determine the effect of momentum transfer on the following parameters that governs the rate of degradation of petroleum hydrocarbon in oxidation pond system. The following results were obtained from the investigation on effect of momentum transfer in biodegradation of petroleum hydrocarbon in the oxidation pond system. These results are presented in Figures as shown in Figures 3-31. The results of the developed models for the prediction of functional parameters in hydrocarbon degradation in pond system indicate the effect of momentum transfer on the microbial growth rate and substrate utilization. This can be attributed to continuous

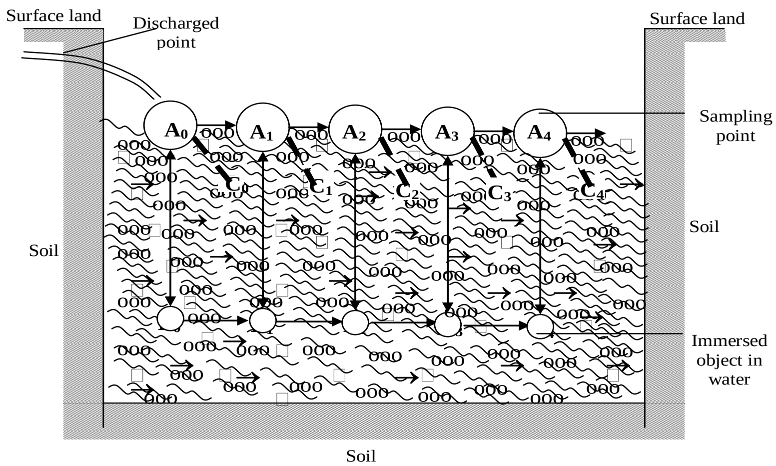

Figure 2. The main experimental investigation on the force acting on the immersed object-surface floater along side with the fluid element in a pond system (for continuous discharged of wastewater).

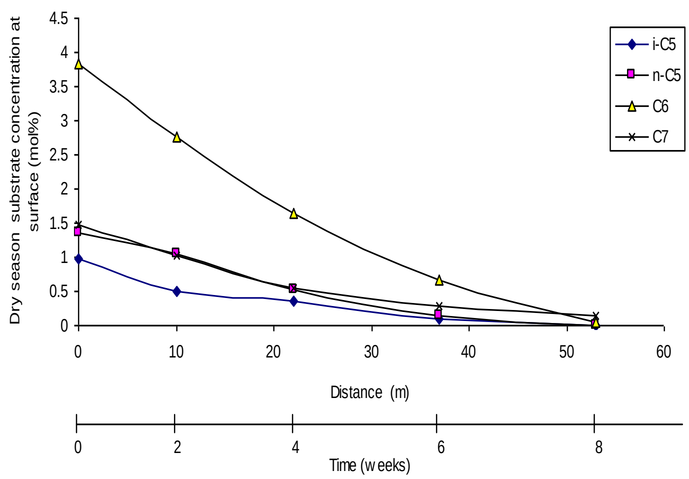

Figure 3. Dry season substrate concentration at surface versus distance and time.

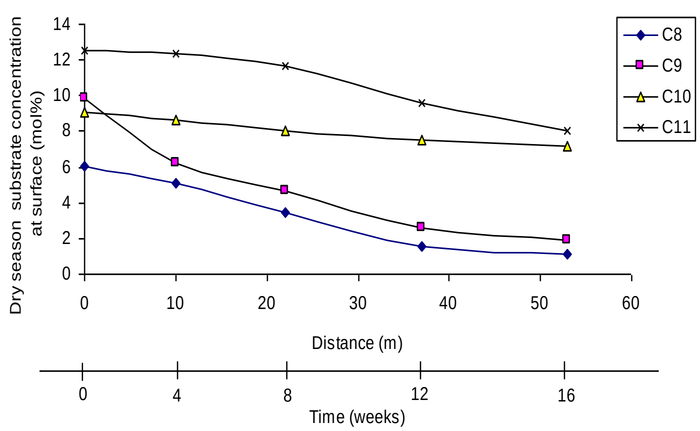

Figure 4. Dry season substrate concentration at surface versus distance and time.

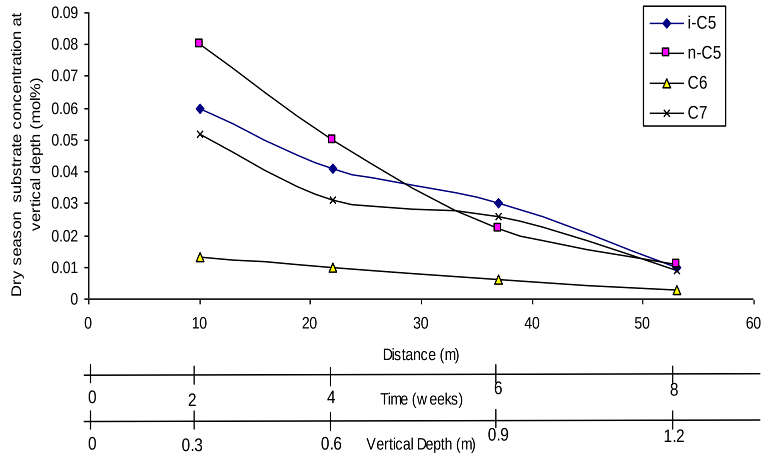

Figure 5. Dry season substrate concentration at vertical surface versus distance, time, and vertical depth (for B_0).

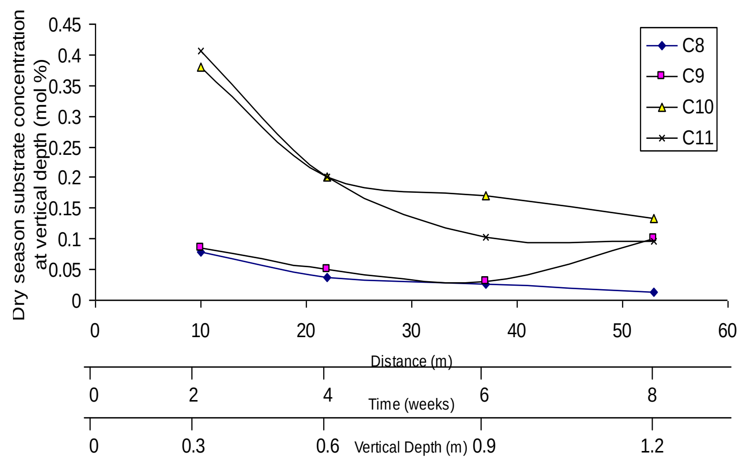

Figure 6. Dry season substrate concentration at vertical surface versus distance, time, and vertical depth (for B_0).

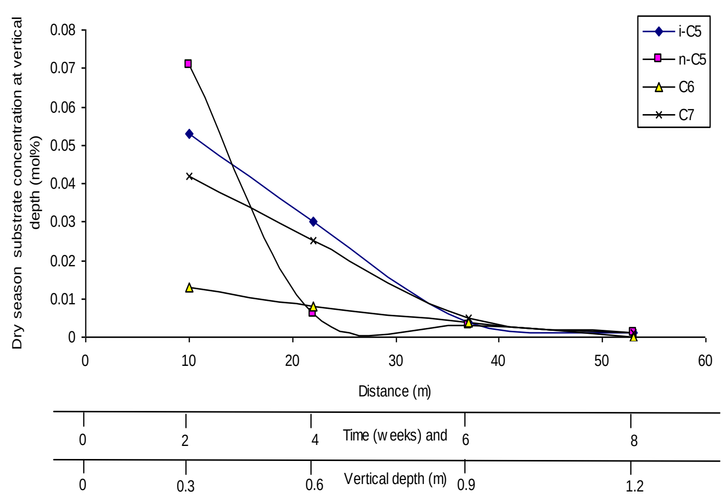

Figure 7. Dry season substrate concentration at vertical direction versus distance, time, and vertical depth (for B_1).

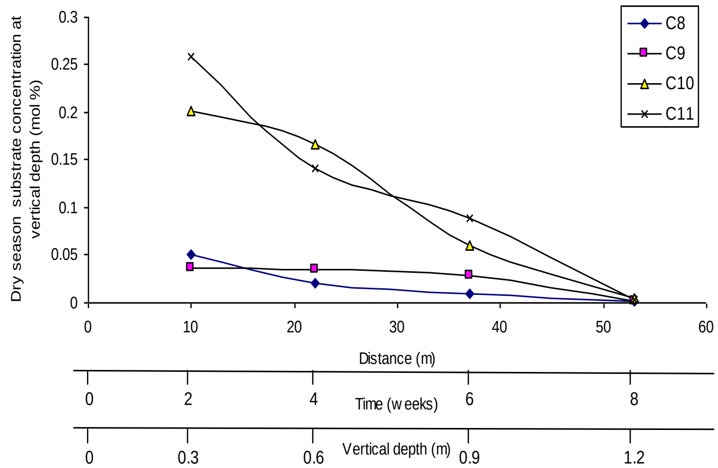

Figure 8. Dry season substrate concentration at vertical direction versus distance, time, and vertical depth (for B_1).

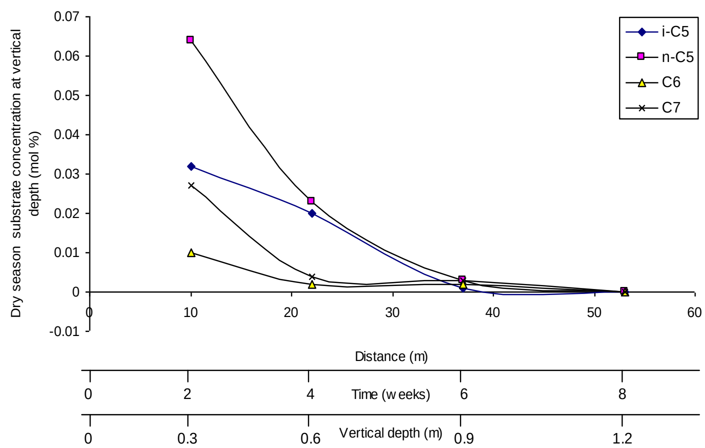

Figure 9. Dry season substrate concentration at vertical direction versus distance, time, and vertical depth (for B_2).

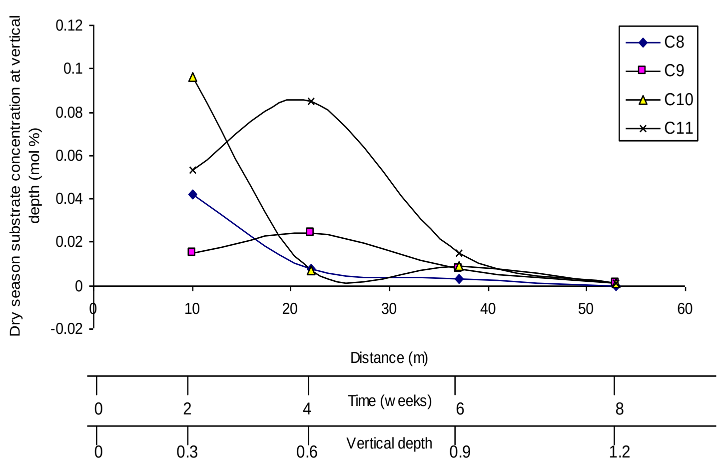

Figure 10. Dry season substrate concentration at vertical direction versus distance, time, and vertical depth (for B_2).

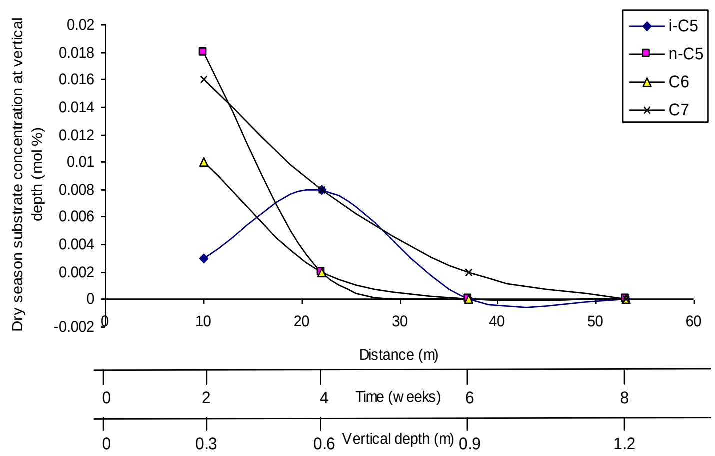

Figure 11. Dry season substrate concentration at vertical direction versus distance, time, and vertical depth (for B_3).

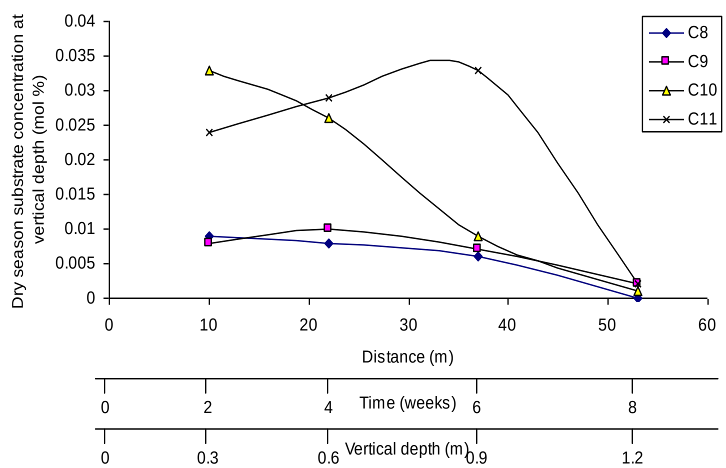

Figure 12. Dry season substrate concentration at vertical direction versus distance, time, and vertical depth (for B_3).

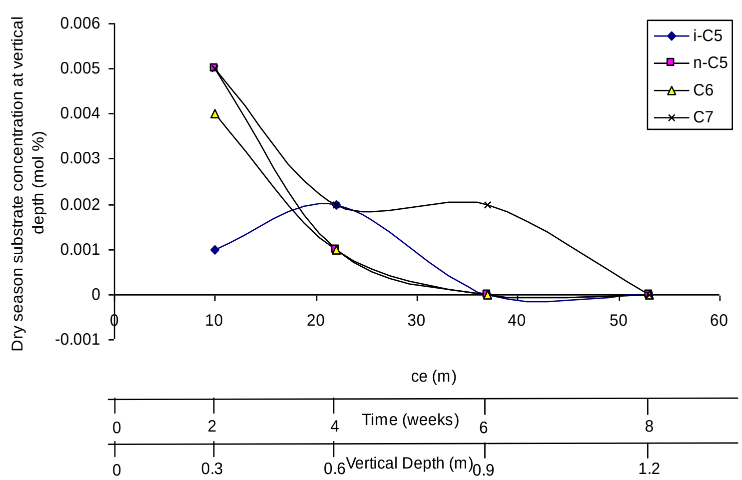

Figure 13. Dry season substrate concentration at vertical direction versus distance, time, and vertical depth (for B_4).

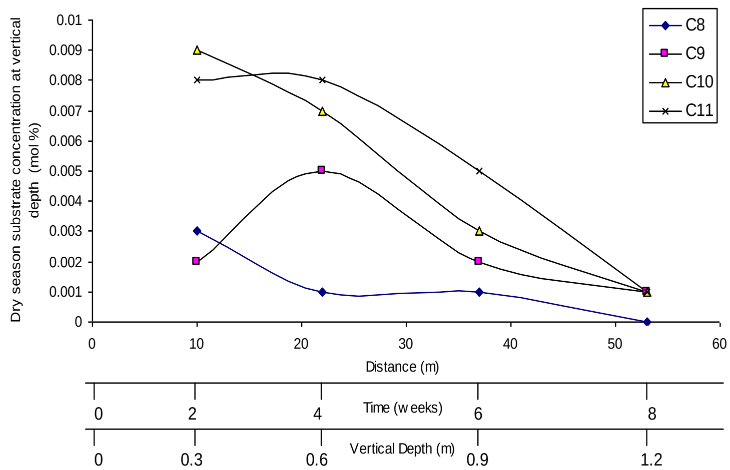

Figure 14. Dry season substrate concentration at vertical direction versus distance, time, and vertical depth (for B_4).

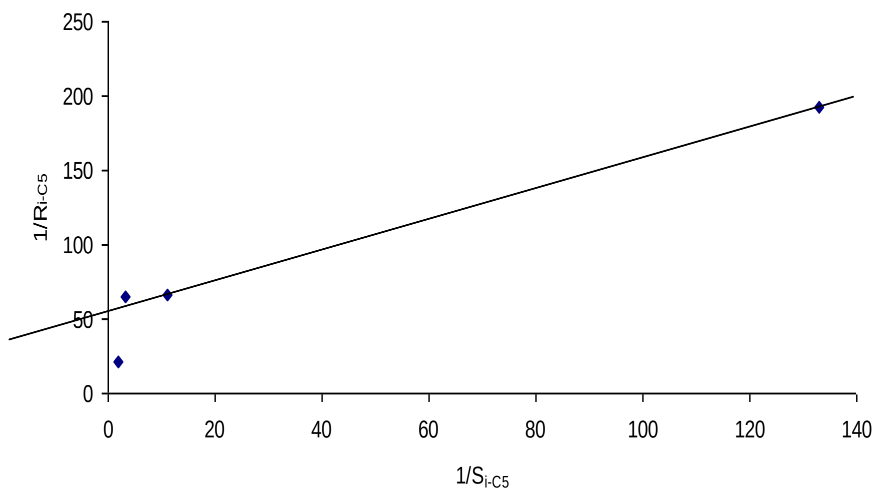

Figure 15. Dry season line weaver bulk plot for $1/R_{i\text{-}C5}$ versus $1/S_{i\text{-}C5}$.

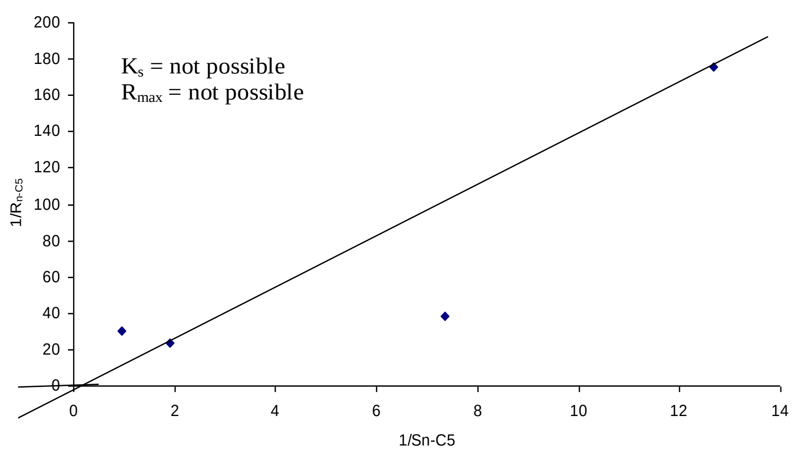

Figure 16. Dry season line weaver bulk plot for $1/R_{n\text{-}C5}$ versus $1/S_{n\text{-}C5}$.

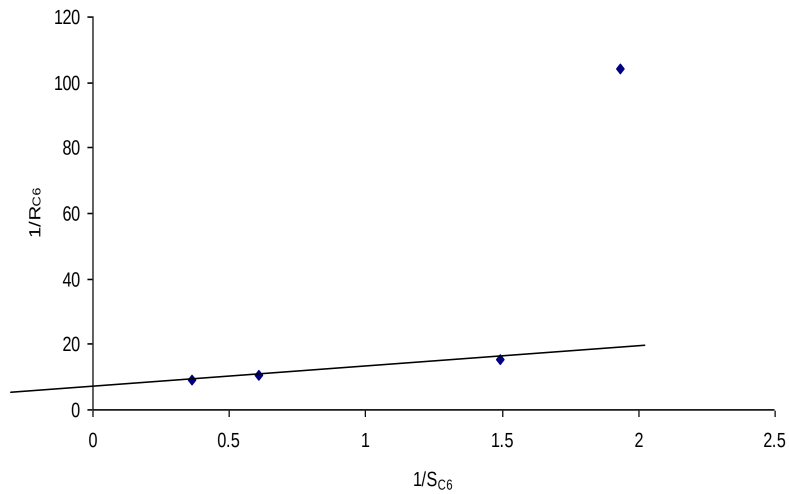

Figure 17. Dry season line weaver bulk plot for $1/R_{C6}$ versus $1/S_{C6}$.

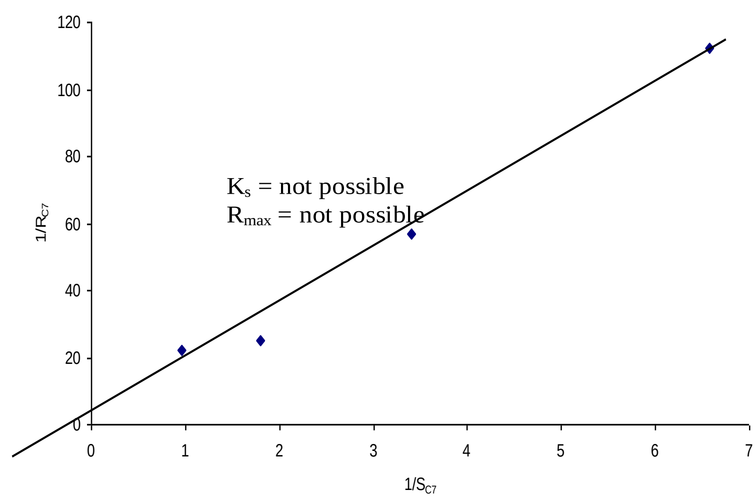

Figure 18. Dry season line weaver bulk plot for $1/R_{C7}$ versus $1/S_{C7}$.

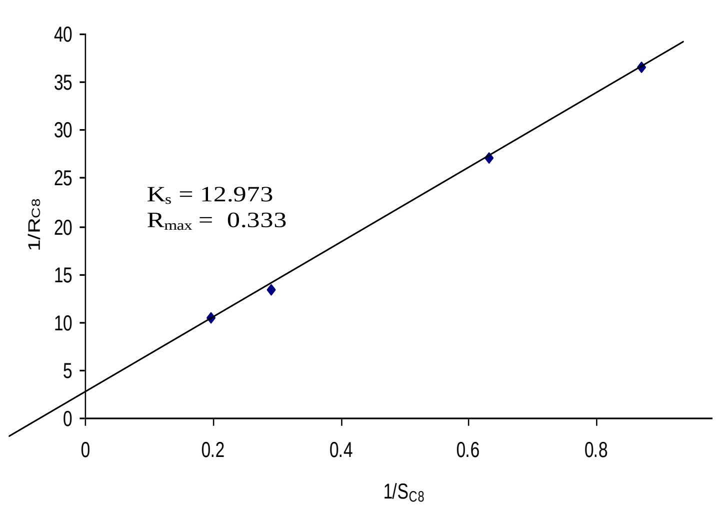

Figure 19. Dry season line weaver bulk plot for $1/R_{C8}$ versus $1/S_{C8}$.

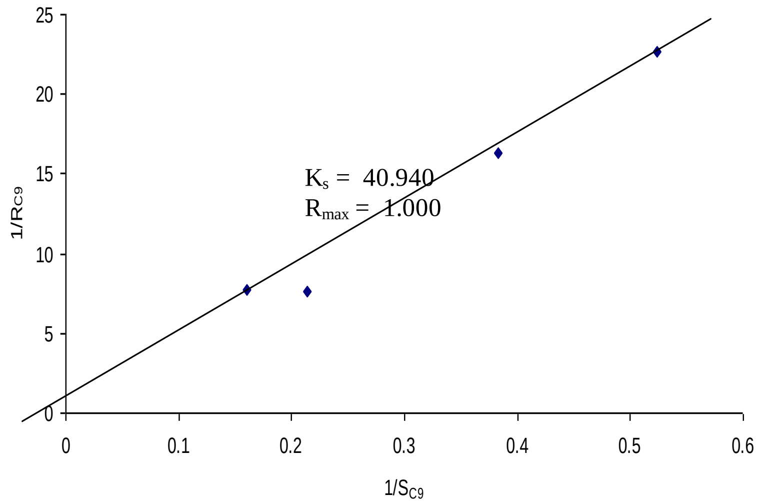

Figure 20. Dry season line weaver bulk plot for $1/R_{C9}$ versus $1/S_{C9}$.

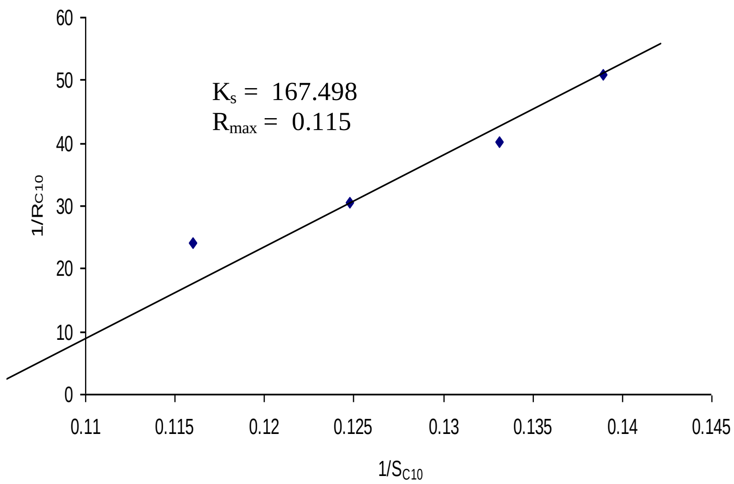

Figure 21. Dry season line weaver bulk plot for $1/R_{C10}$ versus $1/S_{C10}$.

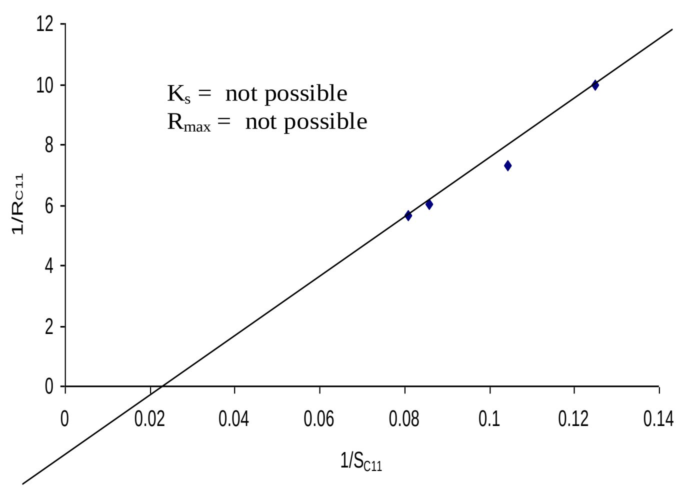

Figure 22. Dry season line weaver bulk plot for $1/R_{C11}$ versus $1/S_{C11}$.

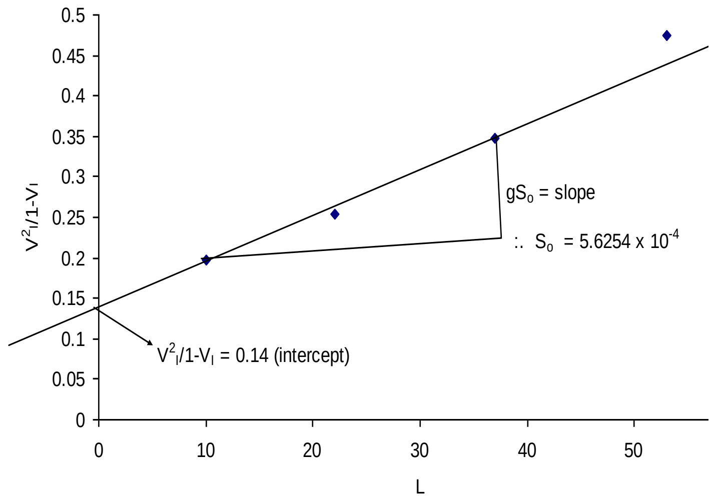

Figure 23. $V^2_i/1\text{-}V_i$ versus L.

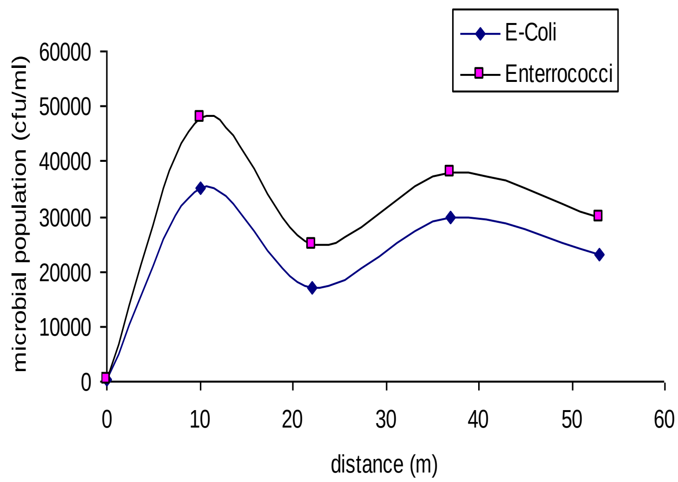

Figure 24. Dry season microbial population versus distance.

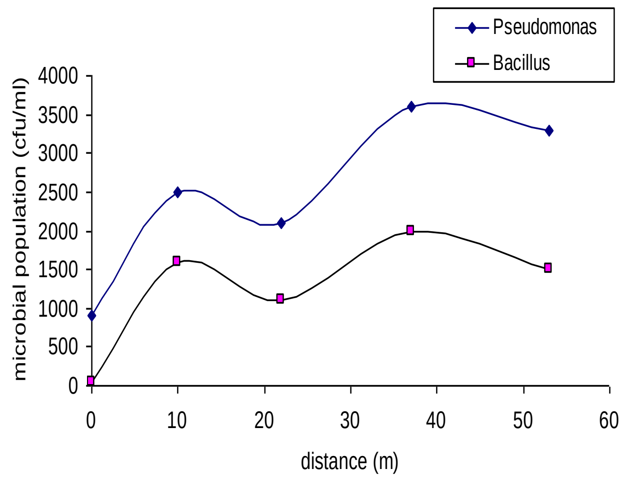

Figure 25. Dry season microbial population versus distance.

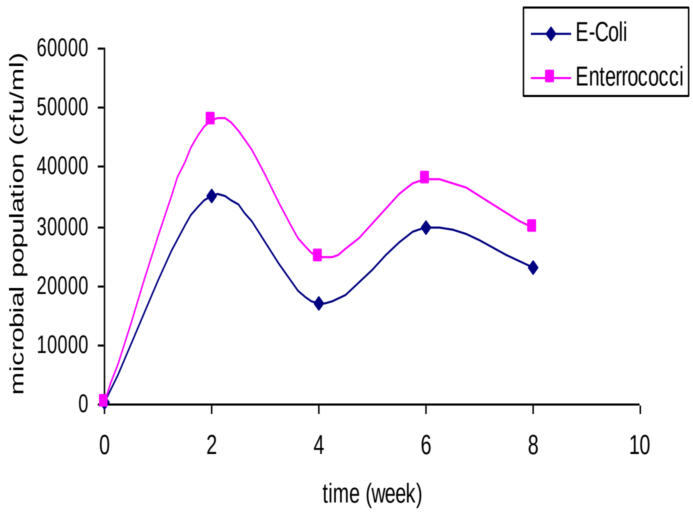

Figure 26. Dry season microbial population versus time.

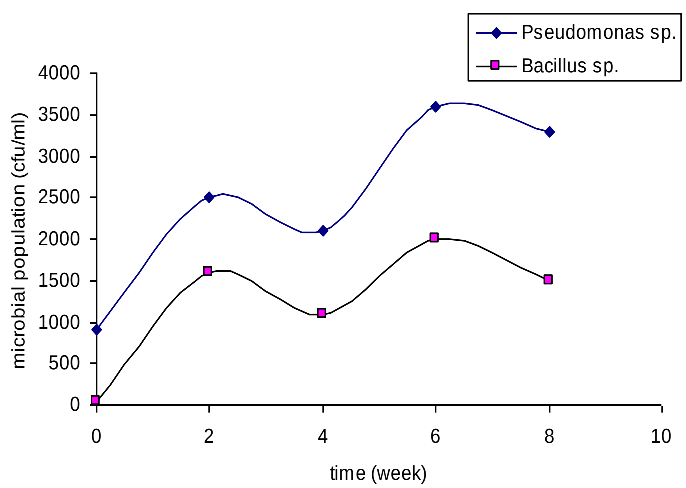

Figure 27. Dry season microbial population versus time.

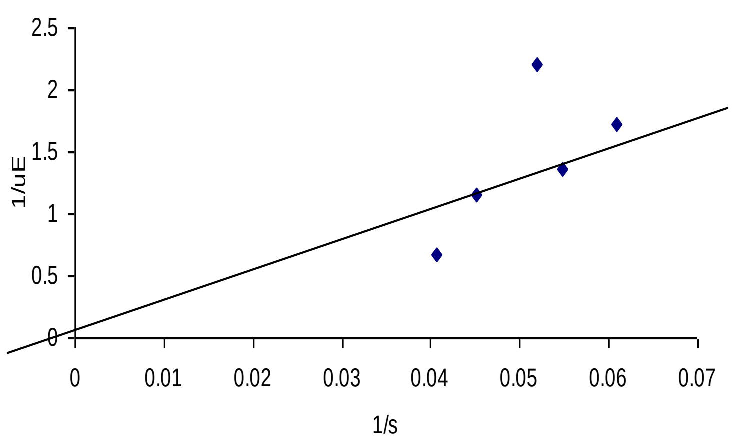

Figure 28. Dry season line weaver bulk plot for $1/u^E$ versus 1/s.

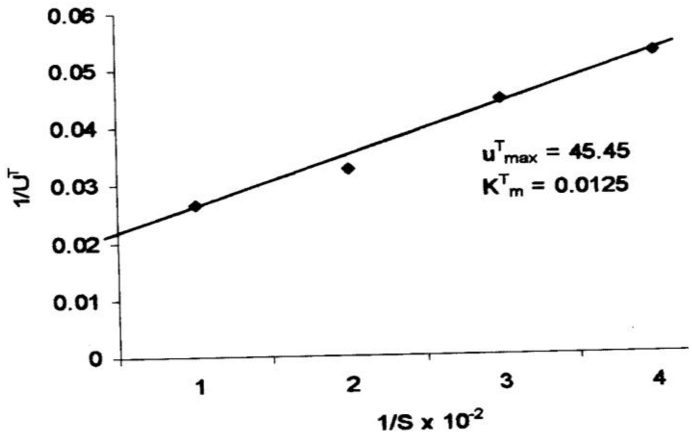

Figure 29. Dry season line weaver bulk plot for $1/U^T$ versus 1/S.

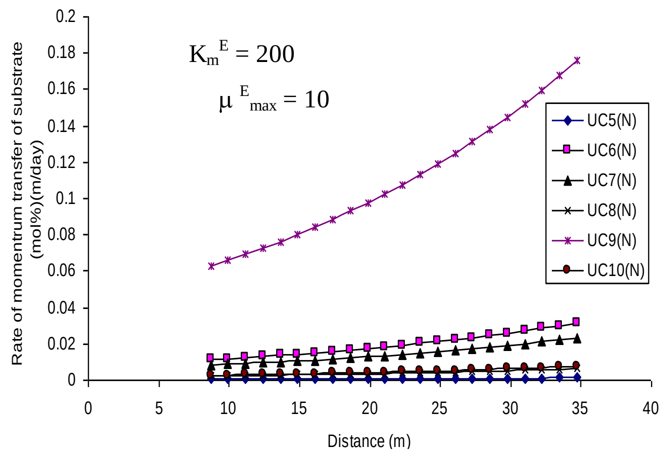

Figure 30. Dry season rate of momentum transfer of substrate concentration versus distance.

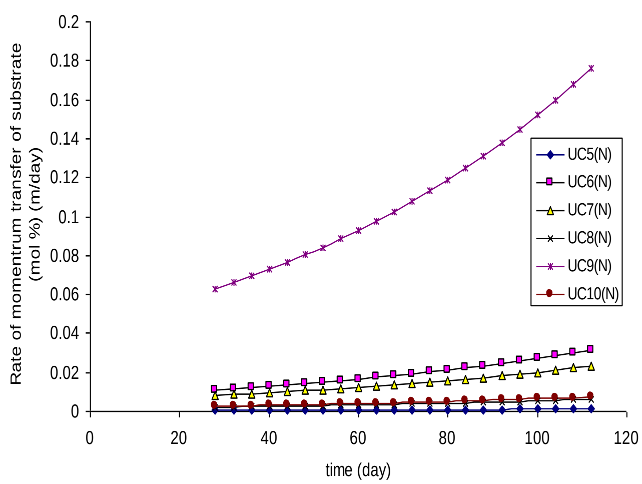

Figure 31. Dry season rate of momentum transfer of substrate concentration versus distance.

discharge of wastewater and alteration on microbial activity and degradation rate.

Conclusion

The research work was conducted to study the importance of momentum transfer on biodegradation of petroleum hydrocarbon in the oxidation pond system. Various research works have been done in developing mathematical models for the biodegradation of petroleum hydrocarbon, viz on the following areas: substrate kinetic, microbial kinetic, in biodegradation of petroleum hydrocarbon mixture. The report showed a clear deficiency in the area enumerated. In fact, it confirmed that no comprehensive and feasible models have been developed for the biodegradation of petroleum hydrocarbon on the influence of momentum transfer.

The agreement between the experimental and theoretical results shows fairly good match. Thus, indicating the suitability of these models for predicting the effect of momentum transfer on biodegradation of petroleum hydrocarbon in oxidation pond systems.

In the present study, substrate concentration and microbial distribution in the oxidation pond systems upon the influence of momentum transfer was examined for wet season. The following results were obtained: overall wet season theoretical velocity (V_{IITS}) in terms of surface distance was 0.292 (m/day), overall wet season theoretical velocity (V_{IIT}) in terms of subsurface distance was 0.1.083 (m/day), the wet season specific rate (R) is within the range of 0.002 to 0.2325 (mol/m), the wet season maximum specific rate (R_{max}) is within the range of 0.0034 to 0.2632 (mol%/m), the wet season dissociation rate constant (R_s) is within the range of 0.0264 to 4.9310, the coefficient of velocity is $\frac{V_{II}^2}{1-V_{II}} = 0.64$ subsurface distance of wet season, the coefficient of velocity is $\frac{V_{II}^2}{1-V_{II}} = 0.12$ for surface distance of wet season. The overall theoretical momentum transfer rate U_{LII} is within the grange of 2.86E-07 to 2.56E-05(mg) (m/day) for wet season.

Similarly, the developed models was useful in the following areas of application: monitory and predicting the kinetic study of bioreactors, to quantity and characterize the biomass built up in a bioreactor, monitoring and predicting the performance of petroleum hydrocarbon degraders, monitoring and predicting the effects of the physicochemical parameters in a bioreactor, monitoring bioremediation of polluted area, identification of effects of momentum transfer on the biokinetics of the substrate and microbial in a bioreactor, estimating the biodegradation period, predicting the lag phase progressive stationary and decline phase of the bioreactor, predicting the best period to carry our bioremediation programme, monitoring and predicting the microbial growth and microbial decay rate in a bioreactor, finally, the investigation was conducted to determine the effect of momentum transfer in biodegradation of petroleum hydrocarbon in the oxidation pond systems. Based on the successful application of these models, it is suggested that momentum transfer on the physicochemical parameter and as well as the substrate and microbial concentration attributed to the sudden changes in the system, thereby resulting to multiple lag, progressive, stationary and death phase in the bioreactor system.

Nomenclature: V_{II}**=V,** Velocity or specific rate (m^3/week); F_I, Hydrostatic force (N); F_g, gravity force (N); F_f, friction force (N); F_2, hydrostatic force (N); Δx, change in distance (m); S_o, subsurface slope; S_f, Surface slope; ρ, density (kg/m^3); **g,** acceleration due to gravity (m/S^2); **A,** cross sectional areas (m_2); **U,** Momentum (kgS/m); **t,** time (week); C_n, concentration of substrate (mol%); X^2, constant; C_3,C_4, constants; S_i—S_n, substrate concentration (mol%); K_{mi} –K_{mn}, Monod constant; μS_{max}, maximum specific growth rate (cfu/ml/week); **X,** biomass concentration (cfu/ml); X_0, initial biomass concentration (cfu/ml); $\frac{dx}{dt}$, biomass concentration (cfuIml); $\frac{dS}{dt}$, substrate concentration per unit time (mol %/week).

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