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Research article

MODELING DISPERSION OF ARSENIC AND AMMONIA INFLUENCED BY HOMOGENOUS POROSITY AND VELOCITY IN PENETRATING UNCONFINE BED IN COASTAL AREA OF EAGLE ISLAND, RIVERS STATE OF NIGERIA.

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Abstract

The development of mathematical model to monitor the deposition of ammonia and arsenic has been evaluated, these parameter are found to predominantly deposit in coastal area of eagle Island, the deposition of both parameters influences the reaction with deposited contaminants in unconfined bed, such conditions were expressed through evaluation of soil and water for risk assessment, the evaluation expressed formation characteristics such as homogeneous porosity and velocity to develop higher degree of formation influences, this is to ensure that the migrations of both parameters in coastal area of eagle island are thoroughly assessed, the study is imperative because it will serve as fundamental base line for experts on the assessment and prevention of ammonia and arsenic in the study location.

Keywords: modeling dispersion, arsenic and ammonia, homogeneous porosity and velocity, unconfined bed

1. Introduction

With over a billion individual cells and estimates of 104–105 distinct genomes per gram of soil (Gans et al 2005; Tringe et al., 2005; Fierer et al., 2007b Katherine, 2011), bacteria in soil are the reservoirs for much of Earth's genetic biodiversity. This vast phylogenetic and functional diversity can be attributed in part to the dynamic physical and chemical heterogeneity of soil, which results in spatial and temporal separation of microorganisms (Papke and

Ward, 2004 Eluozo and Afiibor 2013). Given the high diversity of carbon (C) – rich compounds in soils, the ability of each taxon to compete for only a subset of resources could also contribute to the high diversity of bacteria in soils through resource partitioning (Zhou et al., 2002 Katherine et al 2011). Indeed, Waldrop and Firestone (2004) have demonstrated distinct substrate preferences by broad microbial groups in grassland soils and C resource partitioning has been demonstrated to be a key contributor to patterns of bacterial co-existence in model communities on plant surfaces (Wilson and Lindow, 1994). The development of high-throughput tools to assess the composition of soil bacterial communities is rapidly contributing to an improved understanding of bacterial diversity and biogeographically distribution (Drenovsky et al., 2009; Lauber et al., 2009; Chu et al. 2010 Katherine et al 2011). However, our ability to assess the functions of different bacterial taxa has not kept pace (Green et al., 2008 Eluozo and Afiibor 2013). This limits our ability to interpret the functional consequences of shifts in community composition in response to environmental changes (Stein and Nicol, 2011).there several concept applied to monitor the trace of the bacteria For this reason, the use of tracer molecules such as stable-isotopes and the thymidineanalog, 3-bromodeoxyuridine (BrdU), have been widely adopted in an effort to connect phylogeny to function. Stable-isotopes, particularly the heavy carbon isotope 13C, have been frequently used to identify microbial community members capable of catabolizing particular substrates (Radajewski et al., 2000; Griffiths et al., 2004; Buckley et al., 2007; Feth El Zahar et al., 2007; Schwartz, 2007 Eluozo and Afiibor 2013). This technique requires separation of nucleic acids based on buoyant density, so high concentrations of isotopically labeled substrate are needed. Thus, this approach is costly and impractical for many complex organic compounds that are not commercially available. An alternative is the use of BrdU to monitor cell division following substrate addition. This approach was first applied to the study of bacterial populations over a decade ago (Urbach et al., 1999) and it has since been used to identify soil bacterial taxa that respond to various environmental stimuli (Borneman, 1999; Yin et al., 2000; Artursson and Jansson, 2003; Artursson et al., 2005). Recently, BrdU incorporation has been shown to detect a broad diversity of bacterial phyla in marine systems (Edlund et al., 2008) and fungal taxa in temperate (Hanson et al., 2008) and boreal forest soils (Allison et al., 2008).

2. Theoretical background

Eagle Island is situated in the Niger Delta surroundings that have a lot of contamination challenges from manmade actions and natural origins. These conditions have generated lots of soil and water contamination in the study location. Such deltaic challenging conditions from manmade actions cannot be overemphasized because of the negative impact it has on human settlement. Based on these challenges pointed out, it is imperative to evaluate one of the challenging pollutants on humans in the study area. Arsenic content has been found to develop high percentage in Eagle Island. Generation of this contaminant is confirmed through hydrogeological examinations to have deposited in unconfined bed formation, which is known to penetrate unconfined beds. The formation strata, no doubt is a duplication of geological background of eagle Island depositing in penetrating unconfined bed attributed to formation characteristics, it is investigated to develop higher proportion among others, influencing arsenic and ammonia on migration process in the study area. The combination of this pollutant were established through some hydrological studies as earlier stated, while the formation characteristics were assessed from standard laboratory experiments using insitu method of sample collection. The analyses produced results but could not generate a permanent resolution that can avoid pollution transport arsenic and ammonia, high rate porosity deposition influence arsenic and ammonia in the study location. It has been confirmed from other experts about the deposition influences of microelements, but that of ammonia and arsenic deposit more through natural origin. The migration of arsenic depositing in unconfined bed formation are integrated with ammonia developing some physiochemical reactions, which will be expressed in further migration of the microbes. Focusing the study, the physiochemical reactions of these parameters is to investigate the rate of concentration on their migration process penetrating unconfined bed. Subject to this relation, the formations setting is influenced by deltaic nature of the strata. Thus, developing a better solution that will be applied as a baseline in preventing deposition of arsenic and ammonia any microbes in the formation, mathematical model where appropriate that will express penetrating unconfined beds as observed in the system formulation. This development generated a governing equation that will monitor the deposition of those parameters penetrating unconfined beds.

3. Governing equations

$$D_L \frac{\partial C}{\partial t} = \overline{\Phi V} \frac{\partial^2 C}{\partial Z^2} - \frac{\partial C}{\partial Z} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Homogeneous porosity in the governing equation and velocity has been expressed form the system, it deposits more influences penetrating unconfined bed, lots of formation influences were investigated but the stated parameters were found to develop more influence on the transport of arsenic and ammonia in the study location, such conditions were considered in the formation of the system that produce the governing equation stated above.

Boundary condition $C(o,t) = Co \ for \ t > 0 \ (z,o)$ and $(\infty,t) = Co \ for \ t \geq 0$

The Laplace transform for a function $f(t)$ which is defined for all values of $t \geq 0$ is given.

$$\rho f(z) = f(s) = \int_0^\infty e^{-sz} f(z) dz \ f(z) = \rho^{-1} f(s) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

$$\rho f(z) = s\rho = s\rho f(z) - f(o) \ where \ \rho^1(z) = \frac{\partial f}{\partial Z} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Taking the Laplace transform of the function c with respect to t eqn (1) changes to

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$$D_L\,\rho\left[\frac{\partial C}{\partial t}\right] = \overline{\Phi V}\left[\frac{\partial^2 C}{\partial Z}\right] - \rho\frac{\partial C}{\partial Z} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Where $D_L\,\rho\left[\frac{\partial C}{\partial Z}\right] = D_L\rho(c) - C\,(z,o)$

[*C* is a function of *z* and *t* i.e. *C (z, t) = f(t)*, therefore *ρf(t) = ρC(z, f)* = $\overline{C}$]

Let $\overline{C} = D_L\,\rho(c)\ then\ \rho\left[\frac{\partial C}{\partial Z}\right] = \frac{\partial}{\partial Z}\rho(C) = \frac{\partial\overline{C}}{\partial Z}\ and\ \rho\left[\frac{\partial^2}{\partial Z^2}\right] = \frac{\partial^2}{\partial Z^2}\,\rho(c) = \frac{\partial^2\overline{C}}{\partial Z^2}$

Where $\overline{C}(z) = \rho C(z,t)$, that is only t changes to s and z is unaffected and s is the Laplace parameter.

At $z = 0 : \overline{C}(z) = \int_0^\infty e^{-st}\,C(z,t)\,dt = \int_0^\infty e^{-st}\,C_o\,dt = \Big|_0^\infty -\frac{1}{s}e^{-st}C_o = \frac{C_o}{s}$

At $z = \infty : \overline{C}(z) = \int_0^\infty e^{-st}\,C(z,t) = 0$

Therefore at $z = 0,\ \overline{C}(z) = \frac{C_o}{s}$, and at $z = \infty,\ \overline{C}(z) = 0$

[Since this is one dimensional flow equation, partial derivative changes to the full derivative, *s* is a Laplace parameter, which disappears on taking the inverse].

From the substitution Eq

$$D_L\,s\overline{C} = \overline{\Phi V}\left[\frac{dc}{\alpha z}\right] - \left[\frac{d\overline{c}}{dz}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Let $\overline{C} = Ae^{\lambda z}$ be the solution of the above linear ordinary differential equation. [This is a standard way of solving this class of equations].

The $\frac{d\overline{c}}{dz} = A\lambda e^{\lambda^2}\ and\ \frac{d^2\overline{c}}{dz^2} = A\lambda^2 e^{\lambda^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$

Solution of these values in Eq (5) gives

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$$D_L\ A\lambda^2 e^{\lambda^2} = \overline{\Phi V} A\lambda e^{\lambda^2} - \phi\lambda e^{\lambda^2}\ or\ \left[e^{\lambda^2} = \lambda^2 \frac{\overline{\Phi V}}{D_L}\lambda - \frac{s}{D_L} \right] \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (7)$$

This will be a solution of the auxiliary equation or the characteristics Equation = 0, this implies that

$$\left[\lambda^2 - \frac{\overline{\Phi V}}{D_L}\lambda - \frac{s}{D_L} \right] = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (8)$$

Equation (8) is the standard quadratic equation and the solution is expressed in this form.

$$\lambda = \frac{\dfrac{\overline{\Phi V}}{D_L} \pm \sqrt{\dfrac{\overline{\Phi V}^2}{{D_L}^2} + \dfrac{4s}{D_L}}}{2}$$

That is $\lambda_1 = \dfrac{\overline{\Phi V} + \sqrt{\overline{\Phi V}^2 + 4sD_L}}{2D_L}$ *and* $\lambda_2 = \dfrac{\overline{V} - \sqrt{\overline{\Phi V}^2 + 4sD_L}}{2D_L}$

Therefore, either $\overline{C} = Ae^{\lambda,z}$ *or* $\overline{C} = Ae^{\lambda^2 z}$ is a solution. However, only the latter satisfies the boundary condition.

At $z = \infty$, $\overline{C} = \dfrac{C_o}{s}$, $e^{-\infty} = 0$ {because λ_2 is -ve and λ_1 is +ve}

Therefore $\overline{C} = A\left[e^{\frac{\overline{\Phi V} - \sqrt{\overline{\Phi V}^2 + 4sD_L}}{2D_L}} \right]^{z}$ is the solution

At $Z = 0$ $\overline{C} = \dfrac{C_o}{s}$ give $A = \dfrac{C_o}{s}$

$$\text{Therefore } \overline{C} = \frac{C_o}{s}\left[\exp\left[\exp^{\frac{\overline{\Phi V} - \sqrt{\overline{\Phi V}^2 + 4sD_L}}{2D_L}} \right]\right] \text{ is the solution} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (9)$$

From Equation (9) $C(z,t)$ can be determined as $\rho^{-1}\overline{C}(z)$

Equation (9) can further be expressed as:

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$$C_o \exp\left(\frac{\overline{\Phi V} z}{2D_L}\right) - \frac{1}{\phi s} \exp\left[\frac{-z}{\sqrt{D_L}}\left(\frac{\overline{\Phi V}^2}{4D_L} + s\right)^{\frac{1}{2}}\right]$$

Application of the inverse Laplace transform to the above equation gives

$$C(z,t) = \rho^{-1}\overline{C}(z) = \rho^{-1}\left[C_o \exp\left(\frac{\overline{\Phi V} z}{2D_L}\right) - \frac{1}{s} \exp\left[\frac{-z}{\sqrt{D_L}}\left(\frac{\overline{\Phi V}^2}{4D_L} + s\right)^{\frac{1}{2}}\right]\right]$$

$$= \quad C(z,t) = \rho^{-1}\overline{C}(z) = \rho^{-1}\left[C_o \exp\left(\frac{\overline{\Phi V} z}{2D_L}\right)\rho^{-1}\left[\frac{1}{s} \exp\left[\frac{-z}{\sqrt{D_L}}\left(\frac{\overline{\Phi V}^2}{4D_L} + s\right)^{\frac{1}{2}}\right]\right]\right] \ldots\ldots\ldots \quad (10)$$

From the Laplace transform table

$$\rho^{-1}\left(\frac{1}{s} \exp\left(-\alpha\sqrt{\beta^2 + s}\right)\right) = \int_0^t \frac{\alpha}{2\sqrt{\pi,\beta}} \exp\left[-\left(\frac{\alpha^2}{4u} + \beta^2 u\right)du\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

Here $\frac{Z}{\sqrt{D_L}}$ *and* $\beta = \frac{\phi\overline{V}}{2\sqrt{D_L}}$

Therefore

$$C(z,t) = \rho^{-1}\overline{C}(z) = C_o \exp\left(\frac{\overline{\Phi V} z}{2D_L}\right)\left[e^{-\alpha\beta}\int_0^t \frac{\alpha}{2\sqrt{\pi,\beta}} \exp\left[-\frac{\alpha^2}{4u} - \beta^2 u + \alpha\beta du\right]\right] \ldots\ldots\ldots\ldots \quad (12)$$

The term in the bracket = $\left[e^{-\alpha\beta}\int_0^t \frac{\alpha}{2\sqrt{\pi,\beta}} \exp\left[\frac{(\alpha - 2\beta u)^2}{4u} du\right]\right]$ ……………. (13)

$$= e^{-\alpha\beta}\int_0^t \left[\frac{\alpha + 2\beta u}{4\sqrt{\pi u^3}} + \frac{\alpha - 2\beta u}{4\sqrt{\pi u^3}}\right] \exp\left[-\frac{(\alpha - 2\beta u)^2}{4u} du\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (14)$$

$$= e^{-\alpha\beta}\left[\int_0^t \left[\frac{\alpha + 2\beta u}{4\sqrt{\pi u^3}}\right] \exp\left[\frac{(\alpha - 2\beta u)^2}{4u} du\right] + e^{2\alpha\beta}\int_0^t \frac{\alpha - 2\beta u}{4\sqrt{\pi u^3}}\right] \exp\left[\frac{(\alpha + 2\beta u)^2}{4\sqrt{\pi u^3}} du\right]\right] \ldots\ldots\ldots \quad (15)$$

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Let $\dfrac{\alpha - 2\beta u}{\sqrt{4u}} = A \; and \; \dfrac{\alpha + 2\beta u}{\sqrt{4u}} = B$ ……………. (16)

Differentiating the term in Equation (16) give

$$\frac{dA}{du} = \frac{\sqrt{4u}(0-2\beta) - 2\frac{1}{2}\sqrt[\frac{1}{2}]{u}\,(\alpha - 2\beta u)}{4u} \quad and \quad \frac{\sqrt{4u}(0+2\beta) - 2\frac{1}{2}\sqrt[\frac{1}{2}]{u}\,(\alpha - 2\beta u)}{4u} \quad \text{…….} \quad (17)$$

Or $\dfrac{dA}{du} = \dfrac{-4\beta\sqrt{u}\dfrac{-\alpha}{u} + 2\beta\sqrt{u}}{4u} = \dfrac{-2\beta u - d}{4\sqrt{u^3}} = \dfrac{-(\alpha + 2\beta u)}{4\sqrt{u^3}}$

And $\dfrac{dB}{du} = \dfrac{4\beta\sqrt{u}\dfrac{-\alpha}{u} - 2\beta\sqrt{u}}{4u} = \dfrac{2\beta u - d}{4\sqrt{u^3}} = \dfrac{-(\alpha - 2\beta u)}{4\sqrt{u^3}}$

Or $dA = \dfrac{-(\alpha + 2\beta u)}{4\sqrt{u^3}} du \; and \; dB = \dfrac{-(\alpha - 2\beta u)}{4\sqrt{u^3}} du$ ……………. (18)

$$C(z,t) = C_o \exp\left(\frac{\Phi V z}{2D_L}\right)\left[-\int_0^{\frac{\alpha - 2\beta t}{\sqrt{ut}}} \exp\left(-A^2\right)\frac{dA}{\sqrt{\pi}} - e^{2\alpha\beta}\int_{\infty}^{\frac{\alpha + 2\beta t}{\sqrt{4t}}} \exp\left(-\beta^2\right)\frac{dB}{\sqrt{\pi}}\right] \quad \text{……….(19)}$$

For the limit when $u = 0$

$$A = \frac{\alpha - 2\beta.0}{0} = \infty B = \frac{\alpha + 2\beta.0}{0} = \infty, and\ when$$

$$u = t, A = \frac{\alpha - 2\beta t}{\sqrt{4t}} = and \;\; B = \frac{\alpha + 2\beta : t}{\sqrt{4t}} du$$

Changing the integral limits in Equation (19), it is given as

$$\frac{1}{2}\frac{2}{\sqrt{\pi}}e^{-\alpha\beta}\int_{\frac{\alpha - 2\beta t}{\sqrt{4t}}}^{\infty} \exp\left(-A^2\right)dA + \frac{1}{2}\frac{2}{\sqrt{\pi}}e^{\alpha\beta}\int_{\frac{\alpha - 2\beta t}{\sqrt{4t}}}^{\infty} \exp\left(-B^2\right)dB \quad \text{…………….} \quad (20)$$

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The complimentary error function is defined as $erfc\,x = \frac{2}{\sqrt{\pi}} \int_{\frac{\alpha-2\beta t}{\sqrt{4t}}}^{\infty} \exp\left(-t^2\right)dt$

For which Equation (20) changes to

$$\frac{e^{-\alpha\beta}}{2} erfc \frac{\alpha-2\beta t}{\sqrt{4t}} + \frac{e^{-\alpha\beta}}{2} erfc \frac{\alpha+2\beta t}{\sqrt{4t}} \qquad \ldots\ldots\ldots\ldots\ldots \qquad (21)$$

The various combinations of α and β can be simplified as follows:

$$\alpha\beta = \frac{Z}{D_L} \frac{\overline{\Phi V}}{2\sqrt{D_L}} = \frac{\overline{\Phi V z}}{2\sqrt{D_L}};\ \frac{\alpha+2\beta t}{\sqrt{4t}} = \frac{\frac{Z}{\sqrt{D_L}} + \frac{\overline{\Phi V t}}{\sqrt{D_L}}}{2\sqrt{t}} = \frac{Z + \overline{\Phi V t}}{2\sqrt{D_L{}^t}} \text{ and}$$

$$\frac{\alpha-2\beta t}{\sqrt{4t}} = \frac{\frac{Z}{\sqrt{D_L}} + \frac{\overline{\Phi V t}}{\sqrt{D_L}}}{2\sqrt{t}} = \frac{Z - \overline{\Phi V t}}{2\sqrt{D_L{}^t}}$$

Using these, equation (21) changes to

$$\frac{e\frac{\overline{\Phi V Z}}{2D_L}}{2} erfc \left[\frac{Z - \overline{\Phi V t}}{2\sqrt{D_L{}^t}}\right] + \frac{e\frac{\overline{\Phi V Z}}{2D_L}}{2} erfc \left[\frac{Z + \overline{\Phi V t}}{2\sqrt{D_L{}^t}}\right]$$

Therefore finally, Equation (11) with equation (14) changes to

$$C(z,t) = C_o \exp\left(\frac{\overline{\Phi V z}}{2D_L}\right)\frac{1}{2}\exp\left(-\frac{\overline{\Phi V z}}{2D_L}\right) erfc\left[\frac{Z - \overline{\Phi V t}}{2\sqrt{D_L{}^t}}\right]\frac{1}{2}\exp\left(\frac{\overline{\Phi V z}}{2D_L}\right) erfc\left[\frac{Z + \overline{\Phi V}}{2\sqrt{D_L{}^t}}\right]$$

Or $C(z,t) = \frac{C_o}{2}\left[erfc\left[\frac{Z - \overline{\Phi V t}}{2\sqrt{D_L{}^t}}\right] + \exp\left(\frac{\overline{\Phi V z}}{D_L}\right) erfc\left[\frac{Z + \overline{\Phi V t}}{2\sqrt{D_L{}^t}}\right]\right]$ ……………. (22)

The expression in [22] is the developed final model, several mathematical applications has applied in the process to develop the final model, this condition implies that the developed model has been develop considering several phase of the transport system as expressed in the formulation of the system. These conditions produced the governing equations. The developed governing equations ensure that influential parameters are integrated so that the developed model can monitor the deposition of arsenic and ammonia in the study area.

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4. Conclusion

Velocity of fluid flow and dispersion influences from high degree of void ratio has been evaluated to influences the transport of arsenic and ammonia in the study location. The developed governing equation were expressed from the system formulated, this expression of the variable produced the governing equation, several mathematical conditions has been applied by other experts, although it has some better solution, but the modeling were only done for stratum, but this developed model are for strata sequential to unconfined bed. The model were developed to ensure that the predominant contaminants are prevented from further migration dispersing all the entire area of unconfined bed, the study is imperative because different approach that monitor\ the transport of these contaminants has developed.

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