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Research article

MODELING BACILLUS TANSPORT INFLUENCE BY KINETICS AND RETARDATION THROUGH ADSORPTION AND DESORPTION IN HOMOGENOUS VOID RATIO IN UNCONFINED FORMATION OF PORT HARCOURT METROPOLIS

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Abstract

Modeling bacillus transport in Port Harcourt metropolis under the influences of it kinetics including adsorption and desorption has been examined. Several conditions that cause the increase and decrease of bacillus deposition and migration were thoroughly defined in the system, this to ensure that every variables are captured to developed the governing equation that will defined the behaviour of bacillus in the study environments, the condition of the microbes were found to reflect from higher degree of void ratio deposition in the formation, such deltaic formation were found to deposit several minerals that developed adsorption and desorption in some region of the formation, preliminary examination previously done on risk assessment shows higher degree of void as a result of disintegration of the stratum in different beds producing higher percentage of void within the depositions, this influences the flow nets reflected on the velocity of bacillus migration in unconfined bed, the expressed generated equation integrate this variables derived to developed the model for the study, experts will definitely find the expressed model favuorable, because it will be used as a tool to monitor and prevent bacillus from further migration to ground water aquifers in the study environment.

Keywords: modeling bacillus, kinetics, retardation, adsorption and desorption void ration and unconfined formation.

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1. Introduction

Grain size, shape, and packing are characteristics of granular porous media that have a significant effect on groundwater flow, affecting both porosity and permeability. Hubbert [1940] determined that if uniform spheres are uniformly packed, porosity is not a function of grain diameter but permeability is a function of the square of the grain diameter. However, natural sediment does not consist of uniform grains and packing; it contains mixtures of finer and coarse grains of irregular shapes and complex packing arrangements. Nevertheless, the effects on porosity and permeability when sediment is not uniform in size and packing have been extensively explored but the effects on porosity and permeability when sediment is not uniform in shape needs to be explored further. Laboratory and field experiments have verified that grain size and packing affect porosity and permeability in unconsolidated clastic sediment [Freeze and Cherry, 1979; Marsily, 1986; Domenico and Schwartz, 1990]. Research has also been conducted on estimating hydraulic parameters, porosity and permeability, and the sediment parameters, grain size and packing. Koltermann and Gorelick [1995] worked to improve the knowledge of these relationships by modifying previous petrophysical models to more accurately predict the permeability of sediment mixtures. Kamann [2004] expanded on the work of Koltermann and Gorelick [1995] to account for five possible types of packing rather than the two types of packing upon which their fractional packing model was based. He took porosity and permeability Measurements on model bimodal sediment mixtures that varied in the volume fraction of finer grains, which he compared with predicted values. In keeping with Koltermann and Gorelick [1995], Kamann [2004] also modeled the porosity and permeability of bimodal sediment mixtures to address the effect of the volume fraction of fines. As the volume fraction of fines increases within a sediment mixture, porosity changes as the packing of the mixture changes. A porosity minimum occurs when the volume of the finer component equals the pore volume of the coarser component. Kamann.s [2004] used spherical grains to model poorly-sorted sands and sandy gravels. Spherical glass beads and marbles were used to represent fine sand, medium sand, coarse sand and pebble grain sizes. Kamann [2004] chose to use spherical grains to eliminate variations in shape. He assumed that the bimodal sediment mixtures of spherical glass beads and marbles provided an approximation of natural sediment. Conrad [2006] focused specifically on measurements taken at small support scales using the air-based method of determining permeability on mixtures of spherical grains. He revised the permeability procedures, improved the air-based permeameter correction model developed by Kamann [2004], replicated and improved upon the permeability measurements taken by Kamann [2004], and further confirmed the applicability of the petro physical model for permeability. The research conducted by Koltermann and Gorelick [1995], Kamann [2004] and Conrad [2006] explored the effect of grain size and packing on porosity and permeability. The focus of this research will explore the effect of grain size, shape, and packing on porosity and permeability by using bimodal mixtures of natural sediment This study will continue the work of Kamann [2004] and Conrad [2006] by replacing spherical glass beads and marbles with natural sand grains and pebbles to reexamine the effect of the volume fraction of fines on porosity and permeability. The goals of this study are to (1) measure porosity and permeability for mixtures of natural sediment that vary by percentages of the volume fraction of finer grains, (2) to evaluate if the model created by Kamann [2004] based on spherical grains is accurate for natural sediment grains and (3) to improve the confidence of estimating porosity and permeability [Peter 2005]. Soil and groundwater contamination remains a threat to public health and the environment despite decades of research. Numerous remediation technologies including bioremediation, thermal treatment, soil vapor extraction (SVE), zero-valent iron (ZVI), and in situ chemical oxidation (ISCO) have been developed over the past 30 years. Bioremediation is a cost-effective and simple remediation process for the degradation of contaminants such as benzene, toluene, ethylbenzene, and xylenes (BTEX) [Kao et al., 2010; Nebe et al., 2009]. However, bioremediation is constrained by the available microbial community and by its degradation capacity in a given environment [Steliga et al., 2009]. Due to the complexities of extending laboratory results to the field [Stenuit et al., 2008], the actual rate of degradation as a result of bioremediation is slow relative to other treatments and often relies on natural attenuation, where no treatment is applied and the contaminant degrades naturally (Kao et al., 2010). Bioremediation, SVE, and ZVI degrade or constrain a narrow range of contaminants and are generally unable to treat sorbed contaminants and dense no aqueous phase liquids (DNAPLs) due to mass transfer limitations [Watts and Teel, 2006; Watts, 1998]. Per sulfate is typically activated to promote contaminant degradation (Liang et al., 2004; aldemer et al., 2007; Furman et al., 2009). The activating agents include: iron- chelated activation [Liang et al., 2004], base activation [Furman et al., 2009], and organic activation [Ahmad, 2010].

2. Theoretical Background

Retardation factors has been known to be a normal condition that take place in the transport process of microbes, but in most conditions here it varies due various level of formations influences in soil and water environments. The rate of retardation depends on the microbial specie, this are reflected on its kinetics, such condition were considered in the development of the system for bacillus deposition in port Harcourt metropolis, such deltaic formation develops several variation in its stratification depositing fluctuations in temperature of soil structures, void ratio, porosity permeability etc. The condition of the formation reflect the depositions of bacillus at different strata, the study considered this developments in formulating the system that generate the governing equation for the study, the variables stated in the study develop predominant parameters, this is observed from the previous preliminary study on risk evaluation about the deposition and migration of bacillus in the study environment, the deposition of high degree of void ratio are the paramount variables found to influences the deposition and migration of bacillus in the study location. The behaviour of this microbes were found to have migrated more in the study location were the degree of void ratio are very high, this implies that the depositions are base on the level of disintegration of porous rocks to various grain size with higher micropores, since it is structured in these condition, the rate of hydraulic conductivity will be very high, because it develop micropores that the flow directions may be numerous in the strata, the stratifications of the formation including the deposition are found to be homogeneous at a very high percentage in the study environment, the preliminary studies produced these results of the geological setting in the study location, since the formation characteristics has a relationships with other formation influence, there is no doubt that about variables in the formation pressuring the migration of bacillus in the study area, other developed influences that generated retardation adsorption and desorption of some bacillus are considered in the system, such condition generated variables that are integrated in the developed governing equation stated bellow.

3. Governing Equation

$$N\frac{\partial ho}{\partial t} = hs\frac{\partial h^f o}{\partial X} - VKy\frac{\partial h^f o}{\partial X} \quad \text{................} \quad (1)$$

Applying physical splitting techniques

Several conditions are found in the migration of bacillus in the transport system, these are variables deposited numerous influences on the deposition and migration of bacillus considered in the stated governing equation, the expression denoted it with various mathematical symbols to expressed their various variables represented in the stated governing equation.

$$N\frac{\partial h^f o}{\partial t} = hs\frac{\partial h^f o}{\partial X} \quad \text{................} \quad (2)$$

$$\left.\begin{array}{l} x = 0 \\ t = 0 \\ h_{(o)} = h_o \\ \left.\frac{\partial ho_1}{\partial t}\right|_{t = 0} = 0 \end{array}\right\} \quad \text{..................} \quad (3)$$

$$N\frac{\partial ho_2}{\partial t} = -VKy\frac{\partial h^f o_2}{\partial X} \quad \text{................} \quad (4)$$

$$\left.\begin{array}{l} x = 0 \\ t = 0 \\ h_{(o)} = h_o \\ \left.\frac{\partial ho_2}{\partial t}\right|_{t = 0,\, B} = 0 \end{array}\right\} \quad \text{..................} \quad (5)$$

$$hs\frac{\partial h^f o}{\partial X} = -VKy\frac{\partial h^f o}{\partial X} \quad \text{................} \quad (6)$$

$$\left.\begin{array}{l} x = 0 \\ t = 0 \\ h_{(o)} = h_o \\ \left.\frac{\partial ho_3}{\partial t}\right|_{t = 0,\, B} = 0 \end{array}\right\} \quad \text{..................} \quad (7)$$

Apply direct migration on (2)

$$N\frac{\partial h^f o}{\partial t} = Nhs + Ki \quad \text{................} \quad (8)$$

Again, integrate equation (8) directly yields

$$Nhs + Nhst + Kt + K_2 \quad \text{................} \quad (9)$$

$$hsh_o = K_2 \quad \ldots\ldots\ldots\ldots\ldots.. (10)$$

And subjecting equation (8) to (3)

$$0 = hsh_o + K_2 \quad \ldots\ldots\ldots\ldots\ldots.. (11)$$

So that, we put (10) and (11) into (9), we have

$$Nhs = h_o hst - hsh_o t + Nh_o \quad \ldots\ldots\ldots\ldots\ldots.. (12)$$

$$Nh_{o1} = hsh_o t = Nh_o - hsh_o t \quad \ldots\ldots\ldots\ldots\ldots.. (13)$$

$$\Rightarrow h_{o1}\,(N - hst) = h_o\,(N - hst)$$

$$\Rightarrow h_{o1} = h_o \quad \ldots\ldots\ldots\ldots\ldots.. (14)$$

Hence, equation (14) entails that at any given distance x, we have constant concentration of the contaminants in the system

The formation in most case are found to establish homogenous stratification in the study environments, such condition may reflects on the concentration of the microbes, the derived solution considered this circumstance as it is integrated in derived solution in [14], the concentration reflecting homogeneous in some region may also change when it migrates to other area were the formation is not homogeneous establishing heterogeneous concentration.

$$\frac{Nh^f o}{\partial t} = -VKy\frac{\partial h^f o}{\partial X} \quad \ldots\ldots.. (4)$$

We approach the system by using the Bernoulli's method of separation of variable

$$h^f o = XT \quad \ldots\ldots\ldots\ldots\ldots.. (15)$$

i.e. $$\frac{\partial h^f o_2}{\partial t} = XT^1 \quad \ldots\ldots\ldots\ldots\ldots.. (16)$$

$$\frac{\partial ho_2}{\partial X} = X^1 T \quad \ldots\ldots\ldots\ldots\ldots.. (17)$$

Put (16) and (17) into (15), so that we have

$$NXT^1 = VKy\,X^1 T \quad \ldots\ldots\ldots\ldots\ldots.. (18)$$

i.e. $$\frac{NT^1}{T} = VKy\,\frac{X^1}{X} = -\lambda^2 \quad \ldots\ldots\ldots\ldots\ldots.. (19)$$

Hence

$$\frac{NT^1}{T} + \lambda^2 = 0 \quad \ldots\ldots\ldots\ldots\ldots.. (20)$$

$$X^1 + \lambda^2 X = 0 \quad \ldots\ldots\ldots\ldots\ldots.. (21)$$

i.e.

And

$$VKyX^{1} + \lambda^{2}X = 0 \qquad \text{……………..} \quad (22)$$

From (21)

$$T = ACos\frac{\lambda}{\sqrt{N}}t + B\,Sin\frac{\lambda}{\sqrt{VKy}}x \qquad \text{……………..} \quad (23)$$

And (16) gives

$$X = \partial h^{f}o\,\ell^{\frac{-\lambda^{2}}{VKy}x} \qquad \text{……………..} \quad (24)$$

By substituting (23) and (24) into (15) we get

$$ho_{2} = \left[ACos\frac{\lambda}{\sqrt{N}}t + BSin\frac{\lambda}{\sqrt{N}}t\right]ho\,\ell^{\frac{-\lambda^{2}}{VKy}x} \qquad \text{……………..} \quad (25)$$

The behaviour of the microbes in some condition are influence by some region were porosity may deposit very high degree, this implies that the concentration may rapidly increase in population under the pressure of high deposited degree of porosity in the study area, the derived solution considered this circumstance to generated model for such condition reflecting exponential stage, influencing high degree of porosity in some region of the formation on transport process. So the developed model in [25] is a representation of such condition in the formations.

Subject equation (25) to conditions in (5), so that we have

$$h^{f}o = Ac \qquad \text{……………..} \quad (26)$$

$\therefore$ Equation (26) becomes

$$ho_{2} = ho\,\ell^{\frac{-\lambda^{2}}{VKy}x}Cos\frac{\lambda}{\sqrt{N}}t \qquad \text{……………..} \quad (27)$$

Again at $\left.\frac{\partial ho_{2}}{\partial t}\right| \begin{matrix} = 0, & x = 0 \\ t = 0, & B \end{matrix}$

Equation (27) becomes

$$\frac{\partial h^{f}o_{2}}{\partial t} = \frac{\lambda}{\sqrt{N}}h^{f}o\,\ell^{\frac{-\lambda^{2}}{VKy}x}\,Sin\frac{\lambda}{\sqrt{N}}t \qquad \text{……………..} \quad (28)$$

i.e. $0 = \frac{-h^{f}o\lambda}{\sqrt{VKy}}\,Sin\frac{\lambda}{\sqrt{VKy}}\,0$

$$\frac{h^f o}{\sqrt{N}} \neq 0$$ Considering NKP

The exponential condition of microbes were found to be influences by this factors in the study area, this situation in when microelement deposit in some region of the formation, microelements are substrate utilizations for microbial growth, this increase the population of microbes in the formation were they deposit, such condition were found in some region and it is been integrated in the derived solution as it is expressed above

Which is the substrate utilization for microbial growth (population), so that

$$0 = \frac{-h^f o}{\sqrt{N}} Sin \frac{\lambda}{\sqrt{N}} B \qquad \ldots\ldots\ldots\ldots\ldots.. \qquad (29)$$

$$\Rightarrow \frac{\lambda}{\sqrt{N}} = \frac{n\pi}{2} \quad n = 1,2,3 \qquad \ldots\ldots\ldots\ldots\ldots.. \qquad (30)$$

$$\Rightarrow \lambda = \frac{n\pi\sqrt{N}}{2} \qquad \ldots\ldots\ldots\ldots\ldots.. \qquad (31)$$

So that equation (27) becomes

$$ho_2 = ho\,\ell^{\frac{-n^2\pi^2 N}{2VKy}x} Cos \frac{n\pi\sqrt{VKy}}{2\sqrt{VKy}} t \qquad \ldots\ldots\ldots\ldots\ldots.. \qquad (32)$$

$$h^f o = ho\,\ell^{\frac{-n^2\pi^2 N}{2VKy}x} Cos \frac{n\pi}{2} t \qquad \ldots\ldots\ldots\ldots\ldots.. \qquad (33)$$

Now, we consider equation (6) which is the steady flow state of the system

The homogeneity of strata are reflected in these conditions were steady state flow may be found to express it deposition on the rate of concentration, the behaviour of bacillus may be pressured by this homogeneity of some strata in the study environment, the rate void depositing homogeneous degree of micropores will definitely establish steady state flow, this condition are expressed in the velocity of flow in those region of the formation, therefore steady state flow on the transport system are imperative to be considered in the study environments

$$hs \frac{\partial h^f o}{\partial X} = -VKy \frac{\partial h^f o}{\partial X} \qquad \ldots\ldots.. \qquad (6)$$

Using Bernoulli's method, we have

$$h^f o_3 = XT \qquad \ldots\ldots\ldots\ldots\ldots.. \qquad (34)$$

$$\frac{h^f o_3}{\partial X} = XT^1 \quad \text{................} \quad (35)$$

$$\frac{h^f o_3}{\partial X} = X^1 T \quad \text{................} \quad (36)$$

Put (35) and (36) into (6), so that

$$hsX^1 T = -VKy\, X^1 T \quad \text{................} \quad (37)$$

i.e. $hs\frac{X^1}{X} = -VKy\frac{X1}{X} = \varphi$ .... (38)

$$hs\frac{X^1}{X} = \varphi \quad \text{.........} \quad . \quad (39)$$

$$-VKy\frac{X^1}{X} = \varphi \quad \text{................} \quad (40)$$

$$\therefore\ X = A\ell^{\frac{\varphi}{hs}x} \quad \text{................} \quad (41)$$

And $X = B\ell^{\frac{\varphi}{VKy}x}$ .... (42)

Put (41) and (42) into (34), gives

$$h^f s_3 = A\ell^{\frac{\varphi}{hs}x} \bullet B\ell^{\frac{-\varphi}{VKy}x} \quad \text{................} \quad (43)$$

Subject equation (44) to (7) yields

$$ho_3 = (0) = h^f o \quad \text{................} \quad (44)$$

So that equation (45) becomes

$$h^f o_3 = h^f o\,\ell^{(x-x)\frac{\varphi}{VKy}} \quad \text{................} \quad (45)$$

The reflection of steady state flow is the expressed model in [45], the developed model considered the circumstances of homogenous flow reflected from uniform void ratio of some strata in the study environment, therefore the generated model in [45] reflected this condition, but the migration process may be found to be under progressive stage of the microbes in the study environment.

Now, assuming that at the steady flow there is no NKP for substrate utilization, our concentration is zero so that equation (46) becomes

$$ho_3 = 0 \qquad \text{……………..} \quad (46)$$

There are some regions were the depositions of substrate are not found in the region of the formation, this implies that the microbes may not increase in population rather degradation will be experienced in those regions of the formation. Such circumstances are considered in [46] to express the behaviour of the microbes in such condition, the developments of the system showcase such condition as it is reflected on the derived solution stated in [46].

Therefore, solution of the system is of the form

$$h^f o = h^f o_1 + h^f o_2 + h^f o_3 \qquad \text{…………….} \quad (47)$$

We now substitute (14), (33) and (47) into (48), so that we have the model of the form

$$h^f o = h^f o + h^f o \, \ell \frac{-n^2\pi^2 N}{2VKy} t \; Cos \frac{n\pi}{2} x \qquad \text{…………….} \quad (48)$$

$$\Rightarrow \left[h^f o = h^f o \left(1 + \ell \frac{-n^2\pi^2 N}{2VKy} \; Cos \frac{n\pi}{2} x \right) \right] \qquad \text{…………….} \quad (49)$$

The expression here in [49] is the final developed model for the study, the developed model integrates several condition derived at various stage stated in the study, this developed model couples together other derived model that represent different condition considered in the study area, the expressed model ensure that every variables in the system defined are represented in every derived stage model generated above, coupling them together through integrations generated the final expressed model state in [49]. The study were able to establish numerous condition base on the factors that developed the geological setting of the study environment, the influences from the geological setting of the area were found to developed high degree of influences on the deposition and migration of bacillus in the study area. Such circumstance implies that the deltaic nature of the formation should be determined in every study carried out to ensure that the rates of deposition and migration of bacillus are determined in the study environment.

4. Conclusion

The rate bacillus deposition and migration process has been expressed, these conditions were necessary because the study environment has several influences from the surface of the soil to ground water aquifers. Preliminary studies for risk evaluation of microbial contaminant were previously carried out; this expressed several deposited influences that should pressure the deposition and migration of bacillus in the study environments. Void ratio were one of the paramount variable among other formation characteristics that pressure other variables in the study area, other variables like the desorption and adsorption deposition from some mineral were found in the formation through risk preliminary studies, the influences from such deposition are reflected on the rate of retardations in some region of the formation were the microbes experienced degradation in its population. The kinetics of the microbes was influences by the deposited mineral that generates adsorption and desorption in the study area. The study is imperative because experts will definitely monitor the deposition and migration through this model that have considered several condition, it may be experiences in the deposition and migration of bacillus in the study environment.

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