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Research article

MODELING OF SHIGELLAE TRANSPORT ON BATCH SYSTEM APPLICATION IN HOMOGENEOUS FINE SAND COLUMN INFLUENCED BY POROSITY AND VOID RATIO IN COASTAL AREA OF BORIKIRI, NIGER DELTA OF NIGERIA

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Abstract

Modeling of shigellae transport on batch system application in homogeneous fine sand column influenced by porosity and void ratio has been expressed. The model were developed in phases, microbial deposition and it migration were monitored in exponential phase considering the concentration with respect to time and velocity of transport. Subject to the relation void ratio and porosity were integrated in the expression due to predominant influence of such parameters in the system. Homogeneous expressions were confirmed through hydrogeological studies. Based on these factors, the model equations were modified considering the system as a batch based on the uniformity of the soil stratification. The final derived model integrates all the models in phases that were considered depending on the behaviour and transport condition of the microbes. This final expressed model will definitely monitor shigellae transport in a homogenous fine sand column influenced by porosity and void ratio in the study location.

Keywords: Modeling, shigellae, homogeneous fine sand column, porosity, void ratio.

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1. Introduction

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 nonaqueous phase liquids (DNAPLs) due to mass transfer limitations (Watts and Teel, 2006; Watts, 1998). ISCO has numerous advantages for site remediation including the potential for rapid cleanup and destruction of sorbed contaminants and DNAPLs. The most common ISCO technologies include catalyzed hydrogen peroxide propagations (CHP), ozone, permanganate, and activated persulfate. CHP and ozone rapidly degrade a wide range of contaminants; however, both are unstable in the subsurface and consequently their radius of influence from an injection well is limited (Tsai et al., 2008; Watts and Teel, 2006). Additionally, ozone is less economical due to required on-site generation. Permanganate has greater longevity but is a weaker and more selective oxidant (Tsai et al., 2008; Watts and Teel, 2006). Though it does not react as rapidly as CHP, recent results suggest that it is more effective in removing some contaminants such as trichloroethylene and perchloroethylene DNAPLs in certain environments (Crimi and Siegrist, 2005). Persulfate is a strong oxidant and has greater longevity than CHP and ozone; therefore, it has the potential to remediate subsurface contamination (Tsai et al., 2008; Watts and Teel, 2006).

Persulfate is typically activated to promote contaminant degradation (Liang et al., 2004; Waldemer 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).Diffusion is the dominant mechanism of solute transport in fine-grained soils (Crooks and Quigley, 1984; Rowe et al., 1988). Therefore, a basic understanding of mass transfer theories is necessary for constructing a laboratory experiment and for understanding the analytical solutions used to estimate the diffusion coefficient. Solutes are transported through the soil by two primary mechanisms: advection and hydrodynamic dispersion (Freeze and Cherry, 1979). Advection describes the transport of the solute due to fluid flow at a rate equal to the seepage (pore-water) velocity. Hydrodynamic dispersion is the combination of two mechanisms, mechanical dispersion and diffusion. Mechanical dispersion is the transport process produced by fluid mixing and diffusion is the movement of molecules due to a concentration gradient.

Slow infiltration can develop in sandy loam soils with low organic matter content (Singer and Oster, 1984). Low infiltration in medium and coarse textured soils can be caused by restrictive layers at the surface (crusts, seals) or below the surface (compacted layers, hard pans, fine-textured strata, cemented layers). It can also result from dispersion of the fine particles due to sodicity, or lack of sufficient divalent cations such as calcium (Oster et al., 1992). Many soil properties are known to influence the HC and IR of soils. Organic matter and iron oxides, clay mineralogy, texture, and exchangeable cations composition have all been studied. With regard to the latter, the effect of adsorbed potassium on the hydraulic properties of soil is controversial because results vary or conflict, possibly due to differences in clay mineralogy and sample preparation procedures (Levy and Van Der Watt, 1990). Lado and Ben-Hur (2004) found that examination of the differences in texture, exchangeable sodium percentage (ESP), organic matter and pH of various soils could not explain the differences in the final IR values between the stable and the unstable soil groups. This led to the important conclusion that it was the mineralogy of the clay fraction that was the deciding factor in reduced IR between the soils studied.

2. Theoretical Background

In developing country like Nigeria estimated to be 167 million populace living in both urban and rural areas.The main source of drinking water is groundwater. Groundwater may be contaminated when waste infiltrated into the soil and recharge groundwater via leaking sewage system from manure waste water or sewage sludge spread by farmers on fields, waste water from animal feed lots, waste from healthcare facilities, leakages from waste disposal sites and landfills or artificial recharge of treated waste water. If the distance source of pollution to point of abstraction is small, there is a chance of abstracting pathogens. The factors that control the transport of bacteria are not well understood. While the study of microbial movement in the field under saturated flow condition has just received only few limited study. Advection, dispersion, deposition, clogging and entrainment (declogging) are all processes that affect transport in a noticeable way. The survival of microorganism is affected by numbers of environmental factors such as bacteria type, sunlight, rainfall, soil moisture, and holding capacity, temperature, soil composition, pH, presence of oxygen and nutrient and availability of organic matter and the opposition from soil micro flora. More so, groundwater contains many species of bacteria with several survival rates. Numerous known and unknown factors increase and decrease bacteria number in groundwater. Certainly, groundwater not only migrate bacteria but sustain bacteria growth. To monitor these conditions mathematical expressions were modified in accordance with this threat that has constituted several ill health's in the study location; the derived mathematical equations were expressed to predict the migration of shigellae on homogeneous fine sand in coastal area of Borikiri. The geological setting from hydrogeological study were predominant with homogeneous fine sand depositing shallow short fresh water aquifers and deep fresh water aquifers that is capital-intensive to abstract.

$$KC(x)\frac{\partial V(x)}{\partial t} = \frac{V\partial C(x)}{\partial t} \qquad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \qquad (1)$$

The expressions in equation (1) govern the migration of shigellae in homogeneous fine sand column; this is application of batch system because the geological systems from the hydrological study were confirmed to be homogenous fine sand in the study location. The developed mathematical equation considered significant variables that influence the system to contaminate the coastal short fresh water aquifers predominantly abstracted in the study location.The governing equation were derived to integrate the influential parameters in the system and express their functions that aid the transport to fresh water aquifer

$$\frac{V\partial C(x)}{\partial t} = KC(x)\frac{V(x)}{\partial t} \qquad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \qquad (2)$$

$$\frac{V\partial C(x)}{\partial t} = -KC(x)\frac{VX}{t} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (3)$$

$$\left(V/_{VX}\right)\frac{\partial C(x)}{\partial(x)} = \frac{-K\partial t}{t} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (4)$$

$$V/_{V} = \int\left(1/_{C(x)}\right)\partial C(x) = -K\int\frac{\partial t}{t} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (5)$$

$$V/_{V(x)}\left[\ln C_{(x)} = -K\ln\frac{t_o}{t}\right] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (6)$$

$$\ln\frac{C_{(x)}}{C_{(x)_o}} = -\frac{KV_{(x)}}{V}\ln\frac{t}{t_o} = \ln\left(\frac{t}{t_o}\right) - \frac{KV_{(x)}}{V} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (7)$$

$$\frac{C_{(x)}}{C_{(x)_o}} = \left(\frac{t}{t_o}\right) - \frac{KVX}{V} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (8)$$

$$\frac{C_{(x)}}{C_{(x)_o}} = \ell^{-K\ln\left(t/_{t_o}\right)VX/_{V}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (9)$$

$$C_{(x)} = C_{(x)}\,\ell^{-K\ln 1/_{t}\,VX/_{V}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (10)$$

$$C_{(x)} = \beta\ell^{-K\ln 1/_{t}\,VX/_{V}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (11)$$

$$\boxed{\beta = C_{(x)_o}\,\ell^{\frac{V(x)}{tV}}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (12)$$

This expressed model is considered to monitor the microbial concentration with respect to velocity of transport and time. The concentration is at initial point of pollution discharge of the biological waste. Constant deposition unifies constant generation of these concentrations with respect to time through velocity of transport. The expressed model in (12) considered the microbial transport through influence of initial point of discharge and velocity of transport.

The model can be applied to monitor the transport of Shigellae on a batch system influenced by porosity and void ratio.Integrating both parameters into the model Equation it will yield

$$= C_{(x)} = \beta\,\ell^{-\alpha nVt} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (13)$$

The geological settings in the area are predominant with homogeneous fine sand column, the formation characteristics found to develop high percentage of transport influenced by degrees of porosity and void ratio in the study area.The expressed parameters wereintegrated into the mathematical expression to yield equation 13

Where α is void ratio, n is porosity V is velocity and t is the time.

Take Laplace transform of (13), we have

$$C_{(o)} = \frac{\beta}{\alpha nV + S} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (14)$$

So that,

$$C_{(o)}\left[\alpha nV + S\right] = \beta$$

i.e. $C_{(o)}\,\alpha nV + S + C_{(o)}s = \beta$

$$\Rightarrow \quad C_{(o)}\,\alpha nV + C_{(o)}s - \beta = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (15)$$

The expressed equations in 13 were transform into Laplace in other for the influential variable to express there functions and also relate with other variables in the system. These derived expressions yield the equation in 15.

Subject (15) to quadratic formula, yields

$$C_{(x)} = \frac{-S \pm \sqrt{S^2 + 4^2 \beta nV}}{2\alpha nV} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (16)$$

Looking at these microbes in an exponential direction quadratic expression was applied. These is because of the nature of the formation, the strata are found to deposit homogeneous fine sand, the condition of these type of formation does not have any impermeable layer, therefore the transport of the microbes will be on exponential phase, base on these factors quadratic function were find suitable to express the behaviour of microbial transport at this phase

Now, we replace *S* with αnV, so that equation (16) yields

$$C_{(x)} = \frac{-\alpha nV \pm \sqrt{\alpha^2 n^2 V^2 + 4^2 \alpha\beta nV}}{2\alpha nV} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (17)$$

At this point, the general solution is

$$A\exp\left[\frac{-\alpha nV + \left(\alpha^2 n^2 V^2 + 4\alpha\beta nV\right)^{1/2}}{2\alpha nV}\right]t \; +$$

$$\beta \exp\left[\frac{-\alpha nV-\left(\alpha^2n^2V^2+4\alpha\beta nV\right)^{1/2}}{2\alpha nV}\right]t \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (18)$$

Subject equation (18) to the below boundary and value conditions

At this point, the general solution is:

$$A \exp\left[\frac{-\alpha nV+\left(\alpha^2n^2V^2+4\alpha\beta nV\right)^{1/2}}{2\alpha nV}\right]t \; +$$

$$\beta \exp\left[\frac{-\alpha nV-\left(\alpha^2n^2V^2+4\alpha\beta nV\right)^{1/2}}{2\alpha nV}\right]t \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (19)$$

Subject equation (19) to the below boundary and initial value conditions$x = 0$ $C_{(o)} = 0$, $t = 0$, so that our equation (19) can have a particular solution of the form:

Boundary conditions were established, this is to determine the limits at which the microbes can migrate within the region in homogeneous fine sand column. Such expressions were considered and the boundary values were stated above, the boundary values were integrated in the derived equation stated bellow.

$$C(x) = A\exp\left[\frac{-\partial nV+\left(\partial^2n^2V^2+4\partial\beta nV\right)^{1/2}}{2\partial nV}\right]t - \exp\left[\frac{-\partial nV-\left(\partial^2n^2V^2+4\partial\beta nV\right)^{1/2}}{2\partial nV}\right]t \qquad (20)$$

Using the expansion $2Sinx = \ell^{x} - \ell^{-x}$ so that Equation (20) becomes

$$=> \qquad C(x) = 2Sin\left[\frac{-\alpha nV+\left(\alpha^2n^2V^2+4\alpha\beta nV\right)^{1/2}}{2\alpha nV}\right]t \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (21)$$

The expression in (20) is the finally developed model to monitor shigellae transport in homogenous fine sand column, the model considered some parameters relevant to the system, the parameters are base on the geological formation through hydrogeological studies of the area, theparameters considered are found to play major roles influencing the migration of the microbes to fresh ware aquifers. The developed mathematical models also considered the exponential phase of the microbial transport, this condition were imperative because the stratification of the formation deposit homogeneous strata, thus develop model that expressed the application of batch system in the study area.

4. Conclusion

Predicting the presence of shigellae including pathogen in water, a separate group of microorganisms is usually used. Several microbes has been confirmed to be microbial indicator of fecal pollution but the most effective one applied to indicate the presence of fecal coliform in groundwater is shigellae from the group E. coli. These microbes are in the family of fecal coliform including shigellae. In such homogenous formation, there is no doubt that microbe of such types deposit a high rate of concentration due to constant regeneration from indiscriminate biological waste dumping in the study location. Homogenous settings were related to batch system since the stratification of the soil is predominantly homogenous. This concept was applied to ensure that the microbial transport in such homogenous formations are monitored based on its level of stratification deposition.Formation in such unconfined aquifer were found to deposit high degree of porosity influenced by high velocity, the rate of transport can be expressed on the degree of micropores through the predominant homogeneous stratification in the soil. High level of environmental factors displayed a lot of influence through change in climatic conditions under the influence of deltaic environment.The developed mathematical model that expressed these influential parameters is to monitor the migration of shigellae in homogeneous fine sand column influenced by porosity and void ratio. Finally, experts will find it imperative in monitoring and assessment of coastal fresh water aquifers in the study location.

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