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Research article

MODELING OF BACTERIOPHAGES TRANSPORT OF FINE AND COARSE SAND ON PLUG FLOW APPLICATION IN PHREATIC AQUIFERS

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Abstract

Modeling of Bateriophages transport of fine and coarse sand on application of plug flow in phreatic aquifer has been carried out. Various groups and types of Bateriophages, deposited at various formations, but the bacteria are found to behave the same way. To monitor the microbes in fine and coarse formation, the structure of the microbes and the structural deposition of the formation were considered. The system established major variables that are independent in the system, various relationships between the independent and depended variables were considered,, these parameters established an equation through mathematical symbol. These equations were derived; the established governing equation developed a model to monitor the transport of Bateriophages. The transport process of the microbes are influenced by the considered variables in the system, these are microbial concentration, porosity and permeability, they are the major influence considered in the system, the study area is in deltaic environment, the model considered the variation of the study area, in terms of the geological formation. The formation characteristics may indefinitely influence the transport process of the microbes; these conditions also influence the concentration rate, death rate and population growth. The model can be applied to monitor the transport Bateriophages in fine and coarse sand. The model established will solve the problem of Bateriophages in coastal area where there is homogenous formation.

Keywords: modeling of Bacteriophages fine and coarse sand, plug flow and phreatic aquifers

1. Introduction

Studies has confirmed that Alluvium deposition generated homogenous formation and little lacucstrine that transit from Sombrero River Ahoada in Rivers State of Nigeria, it also generates little heterogeneous formation in some part of the study location. Due to the nature of the formation in the study area, there is high level of porosity, generating fast migration of microbes. The geological formations predominantly with alluvium deposition influenced by deltaic environment are confirmed to deposit a shallow aquifer in the study location. This influence the transport of bateriophages at a very short time, these conditions has produced a lot of pollution from bateriophages in River state. Therefore it is imperative to carry out this study, because a lot of people in the settlements are suffering from water related diseases emanating from microbial contaminant in Rivers state. Water is an essential natural for human utilization, it is a resource that sustaining life and environment. Alluvium deposition is known to be one of arid areas. Groundwater contributes only 0.6% of the total water resources on earth, it is the major and the available source of drinking water in rural areas well as urban areas, especially in Nigeria and every part of the world, in Nigeria each person consume 200 m3/day from the groundwater distributed in approximately 40 wells as the main water source. This vital resource is vulnerable to contamination and is being increasingly threatened by an array of pollutants from landfills, soil treatment systems, septic tanks and subsurface disposal wells [1, 2]. Rapid depletion of groundwater supplies as a consequence of continued population growth and industrialization threaten the quality of many aquifers in Iran just like Port Harcourt. For evaluating the suitability of groundwater for different purposes, understanding the chemical composition of groundwater is necessary. Further, it is possible to understand the change in quality due to rock-water interaction (weathering) or any type of anthropogenic influence. Such improved knowledge can contribute to effective management and utilization of this vital resource. In this view, monitoring the quality of groundwater (chemical, physical, and biological constituents) is as important as assessing its quantity [14, 12] Aquifers have the ability to store water. How this storage is accomplished differs depending on the whether the aquifer is confined or unconfined. When a well is pump in a confined aquifer, the declining hydraulic head in the vicinity of the well enables the pressurized water to expand slightly, adding a small volume of additional water. In addition, the decline in hydraulic head lets the aquifer collapse slightly, thereby, compensating for the volume of water that flow to the well. In an unconfined aquifer, the main source of water is the drainage of water from pores as the water table declines in response to pumping. For a comparable unit decline in hydraulic head, an unconfined aquifer release much more water storage than a confined aquifer. The storativity of an aquifer is defined as the volume of water that an aquifer releases from 0. Take into storage per unit change surface area of the aquifer per unit change in head. The ease which water can move through an aquifer is more explicit, it is the rate at which water prevailing kinematics viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. The concept of transmmissivity is similar to hydraulic conductivity. The main different is that transmmissivity is measurement that applies across the vertical thickness of an aquifer is b, the transmmissivity (T) is $T = bk$ where k is the hydraulic conductivity of the aquifer. Transmmissivity has unit of (L2/T) for example, ft2/day, m2 (day); [6, 7, 8, 9, 13, and 15]. Aquifers have the ability to store water. How this storage is accomplished differs depending on the whether the aquifer is confined or unconfined. When a well is pump in a confined aquifer, the declining hydraulic head in the vicinity of the well enables the pressurized water to expand slightly, adding a small volume of additional water. In addition, the decline in hydraulic head lets the aquifer collapse slightly, thereby, compensating for the volume of water that flow to the well. In an unconfined aquifer, the main source of water is the drainage of water from pores as the water table declines in response to pumping. For a comparable unit decline in hydraulic head, an unconfined aquifer release much more water storage than a confined aquifer. The storativity of an aquifer is defined as the volume of water that an aquifer releases from 0. Take into storage per unit change surface area of the aquifer per unit change in head [13, 14].

Modeling microbial processes in porous media is essential to improving our understanding of the biodegradation of contaminants and the movement of pathogens. Microbial processes incorporate physicochemical processes and biological processes. Microorganisms and their transport in the environment is a complex issue of growing concern. Most reactive transport models only consider physicochemical processes. The impact of biological processes in a flowing groundwater system can only be evaluated within this physicochemical framework [4,5]. The physicochemical processes are primarily based on the physical structure and chemical properties of the subsurface flow system and porous media. Microbial mobility dominated by physicochemical interaction with the porous media is mainly described with the colloid infiltration model

The transport behavior of microorganisms in the subsurface environment is of great significance with respect to the fate of pathogens associated with wastewater recharge, riverbank filtration, septic systems, feedlots, and land application of biosolids. A common element to most of these applications is that the associated aqueous solutions typically have relatively high concentrations of dissolved organic carbon. Thus, the potential influence of DOC on pathogen transport is of interest. The factors affecting the transport and fate of viruses and bacteria in the subsurface have received significant attention (e.g., [2,3 4 and 5]. Bacteriophages are often used as a surrogate to evaluate the transport and fate of pathogenic viruses. They serve as useful models because they are similar in size and structure to many enteric viruses, do not pose a human-health hazard, and are relatively inexpensive. MS-2 Bacteriophages was used in this study, and is considered a model virus for use in transport studies because it is relatively persistent during transport (e.g., Schijven, et al. 1999). MS-2 has been classified as a group I virus, which are those whose transport is considered to be influenced by soil characteristics such as pH, exchangeable iron, and organic matter content [11]. Several prior studies have examined the transport of MS-2 in porous media [1,2, 6.and 12]. The objective of this study was to investigate the influence of dissolved organic carbon on MS-2 Bacteriophages transport in a sandy soil. Miscible-displacement experiments were conducted to examine the retention and transport of MS-2, at two influent concentrations, in the absence and presence of DOC. The experiments were conducted by Alexandra Chetochine. The results of the experiments were analyzed with a mathematical model that incorporated inactivation and rate-limited attachment/detachment

2. Theoretical Background of the model

Bacteriophages are virus that only infects bacteria, some Bacteriophages are comparable in size and behaviour to human enteric viruses and they are relatively easy to detect and enumerate. Various groups and types of Bacteriophages, particularly those of coliform bacterial (coliphages) and those of bacteria des spp., have been proposed as indices of faecal pollution (and possible enteric virus presence) and as indicators of treatment efficiency for both water and waste water treatment processes. The study [1] has reviewed the literature on the use of Bacteriophages and concludes that they have significant limitations as indices of faecal pollution and enteric viruses. However, other published evidence indicates that Bacteriophages have potential value as indices of faecal contamination and indicators of treatment effectiveness [2, 6], the number of varieties of the microorganism in natural water vary greatly in different placers and under different conditions. Bacteria are washed into the water from the air, the soil and from almost every conceivable object. Significant numbers of bacteria can move through media even when the percentage retained is very high. The faeces of animals contain vast number of bacteria and may enter natural water systems. The size of opening in subsurface material can be assumed to be variable and are generally not measured, but porosity and permeability measurements on aquifer sediment indicate that adequate spaces for bacteria exist in many sediment types, even in some rather dense porous rocks [3, 4]. The intensities of the shallow aquifer sediment can easily accommodate bacteria and probably protozoa and fungi as well as larger organisms will be excluded from most subsurface formation, except for gravel and cavernous aquifer (Shores and Wilson, 1988).

Mass balance on plug flow system in soil porosity and permeability can be expressed as

3. Developed Equation and material Balance

INPUT – OUTPUT – REACTION = ACCUMULATION

$$VoCAf \ = \ V \bullet \left[Vo\left(CAf \ + \ d\,CAf \right) \right] \bullet \left[\left(Vav \right) \partial Z \right] = \frac{\partial}{\partial t} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (1)$$

CAf = Concentration of the contaminant

t = Time of concentration

v = Velocity

K_d = Decay rate constant

n = Porosity of the soil

K = Permeability of the soil

M3 = Reactor

Y_{Af} = Reaction fluid

Z = Distance

The variables were applied to develop materials balance of the system where we have the system express in the form:

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The mathematical expression stated in equation represent variables in the system that are established to monitor the transport of Bacteriophages in fine and coarse sand applying the law of plug flow in phreatic aquifers. These variables were represented by mathematical symbol. The expression denotes the following variables:

$$q\partial CAf \bullet \partial Z \quad \ldots\ldots \quad (2)$$

Dividing the equation by *dz* and taking limit *adz* $\rightarrow$ *0* ………….. (3)

$$\varepsilon = \frac{\partial CAf}{\partial t} + Vo\frac{\partial CAf}{\partial z} + Vav = 0 \quad \ldots\ldots \quad (4)$$

But for first order reaction fluid only

$$YAv\left[\frac{Mol}{M^3\ reactor}\right] - \frac{1}{V}\frac{\partial NA}{\partial z} + Kd(nk)CAf \quad \ldots\ldots \quad (5)$$

Where,

n = Porosity and

K = permeability of the soil

$$\frac{\partial CAf}{\partial z} = 0$$

Therefore, $Vo\dfrac{\partial C}{\partial z} + K(nk)CAf = 0$ ……………………………. (6)

Considering the function of height integrating with *CAf* = *CAf* at *Z* = *0*

$$X_A = \left[\frac{CAf}{CAf\ in} - \right] - \exp K_1^n\left((nk)Z\right) \quad \ldots\ldots \quad (7)$$

Balance on solid state

- ∂A (Fluid) + (Solid) $\rightarrow$ Product
- Input – Output reaction = Accumulation
- Over increment of ∂Z: Input = *0* Output = *0*.

$$-(YSv -)(nk)\frac{\partial C}{\partial t} - \Delta Z \quad \ldots\ldots \quad (8)$$

$$\frac{\text{Porosity and permeability}}{M^3\ of\ reactor\ volume} \qquad \frac{Mol}{M^3\ reactor}$$

$$(nk)\frac{\partial C}{\partial t} + YSv = 0 \qquad \text{...} \quad (9)$$

$$-(YSv) = \alpha(YSv) \qquad \text{...} \quad (10)$$

$$(nk)\frac{\partial C}{\partial t}Af + \frac{\partial CAf}{\partial Z}Af + Y\alpha v = 0 \qquad \text{...} \quad (11)$$

Substituting *YAf* equation (12) yields

$$\frac{\partial Cs}{\partial t} + \frac{Y\alpha v}{\alpha(nk)} = 0 \qquad \text{...} \quad (12)$$

$$\frac{\partial Cs}{\partial t} + \frac{Y\alpha v}{\alpha(nk)} - 0 \qquad \text{...} \quad (13)$$

$$\frac{\partial CAf}{\partial Z} - \frac{\partial Cs}{\partial t} = 0 \qquad \text{...} \quad (14)$$

$$C^1Af = f(Z,t) \qquad \text{...} \quad (15)$$

$$C^1s = f(Z,t) \qquad \text{...} \quad (16)$$

E. coli transport is a continuous process as reflected in plug system application influenced by porosity and permeability.

The equation express the concentration behaviour in the reactor volume in *x* direction, the expression, assume the concentration to be in specified volume, considering the influence of microbial transport, porosity and permeability to be the major influence of the contaminant with fast migration in a continuous process, the condition developed equations (9-16) where the two variables porosity and permeability developed their major influence in the system the parameters were separated to determine their relationship

Solve

$$\frac{\partial CAf}{\partial Z} - \alpha(nk)\frac{\partial C}{\partial t} = 0 \qquad \text{...} \quad (17)$$

Considering when *CAf* = Cs, thus equation (17) can be written as

This condition developed is to restructure the equation considering some condition, the expressed in equation (17) were written as stated above where CAf denotes Cs, application of variables separation where prominent, because it is the source of determining the Z coordinate in terms of time dependent. Therefore, equations (19 to 34) expressed the variable relation, by integration the variable in this expression at different condition. Bacteriophages transport by plug flow application. This condition were suitable because the formation of soil where these microbes are found are at different soil structural deposition and those condition influence the behaviour of Bacteriophages in the system

$$\frac{\partial C}{\partial Z} - \frac{(nk)}{Vo}\frac{\partial C}{\partial t} = 0 \qquad \ldots\ldots (18)$$

Where $C = CAf = Cs$ ………………………………………. (19)

Applying separation of variables considering the coordinate of *Z* in terms of time dependent, thus equation (18) can be expressed as

$C = TZ$

Integrating boundary conditions are $t = 0, \quad C = CoZ$

Therefore, $$\frac{\partial C}{\partial Z} = TZ^1 \qquad \ldots\ldots (20)$$

$$\frac{\partial C}{\partial Z} = T^1 Z \qquad \ldots\ldots (21)$$

Integrating equation (20) and (21) into equation (18) yield

$$TZ^1\left(\ell^{nk}\right)T^1 Z = 0 \qquad \ldots\ldots (22)$$

Therefore

$$TZ^1 = \ell^{(nk)}\,T^1 Z = 0 \qquad \ldots\ldots (23)$$

$$\frac{Z}{Z} = \ell^{nk}\frac{T^1}{T^1 Z} = \lambda^2 \qquad \ldots\ldots (24)$$

$$Z^1 = \lambda^2 \qquad \ldots\ldots (25)$$

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$$\frac{1}{Z}\frac{\partial Z}{\partial Z} = \lambda^2 \qquad \text{...} \qquad (26)$$

$$\int \frac{\partial Z}{\partial Z} = \int^{-\lambda^2} \partial Z \qquad \text{..} \qquad (27)$$

$$Ln\ Z = -\lambda^2 Z + C_1 \qquad \text{..} \qquad (28)$$

$$Z\lambda^2 + C_1 = \ell^{-\lambda^2 Z} \qquad \text{..} \qquad (29)$$

$$Z = A_0 - \ell^{\lambda^2 Z} \qquad \text{..} \qquad (30)$$

$$\ell^{(nk)}\frac{T^1}{T} = \lambda^2 \qquad \text{..} \qquad (31)$$

$$Ln\ T = \frac{\lambda nk}{\alpha} + C_2 \qquad \text{...} \qquad (32)$$

$$\ell^{-\lambda^2 \frac{nkt}{\alpha}} \bullet \ell^{C_2} \qquad \text{..} \qquad (33)$$

$$T = \beta \ell^{\frac{\lambda^2 nkt}{\alpha}} \qquad \text{...} \qquad (34)$$

But $C = TZ$

$$\boxed{C = \beta^{\frac{\lambda^2 nkk}{\alpha}} \bullet A\ell^{-\lambda^2 Z}} \qquad \text{...} \qquad (35)$$

$$\text{i.e. } C = A\beta^{\frac{\lambda^2 nk}{\alpha}t\ -Z} \qquad \text{..............................} \qquad (36)$$

At $0\ Zo = C_{(o)} = Co$

$$C = C_o \ell^{\frac{\lambda^2 (nktZ)}{\alpha}} \qquad \text{..} \qquad (37)$$

Therefore, Transfer in the above equation into sinusoidal curve, so that we have

$$C = C_o Sin\left(\frac{nk}{\alpha} t + Z \right) \quad \text{...} \quad (38)$$

$$\boxed{C = C_o Sin\left(\frac{nk}{\alpha} t + Z \right) V} \quad \text{..} \quad (39)$$

The expression of the model established in equation (35) detailed the variables relationship on the transport process in terms of distance, the application of plug flow, whereby the migration of the microbes move from one formation to another formation, in a distance, generated a lot of dynamic in the system, the behaviour are influenced by other constituent deposition along the distance travel, the major variables that where considered on the fast transport of the microbes are porosity and permeability, the model expresses their relationship between all the parameter consider, but time of transport death and increase on population were not considered in equation (35). So the established model equations are only taking care of the transport of Bacteriophages in terms of distance.

Expressing the model equation further, time of transport and distance at various formation where seen to be imperative in the system, this condition were found imperative, because the microbes is a living organism, the concentration at every formation varies, and their death rate, therefore the rate of concentration and in degradation, varies in terms of migration and degradation, the concentration at every formation varies, also the death rate, therefore the rate of concentration and degradation are caused by a lot of factors that take place with respect to period in the transport process, in some conditions the formation of the soil might cause the life span of the microbes to either increase or decrease, this condition may take the two parameters imperative in terms of transport process of microbes. This condition has no doubt established a concrete relationship between time and distance on application of plug flow method, in microbial transport in soil and water environment. The microbial behaviour in terms of growth, transport, degradation are influenced by dynamic condition in the system, the expression of the model equation were found necessary to be transformed into sinusoidal curve method, where equations (38) and (39) are transformed into sinusoidal curve, the final model equation were developed to accommodate the behaviour of the dynamic condition of Bacteriophages in terms of increase and decrease, degradation in various conditions that includes population, death rate, decay rate from the formation characteristics in phreatic aquifers

4. Conclusion

Modeling of Bacteriophages transport in fine and coarse sand on application of plug flow system has been developed, this condition were to monitor the behaviour in terms of migration and other factors. The study were able to monitor the causes of the microbes experiencing degradation, the study also explain the tendency of detachment and attachment processes of the microbes intercalating at the sediment of the formation.

Models were able to streamline the condition of the stratum fine and coarse sand as a porous medium of fast migration of Bacteriophages. These formations developed high hydraulic conductivity, permeability and porosity in the system, the transport process are influenced by these variables, more so transport processes also considered distance travel of the microbes that influence the concentration in terms of increase and decrease at different formations, the depth varies and therefore influence the life span of the microbes. Time of concentration and death rate are in relation with distance travel of the microbes, this is because of the continuous process of migration, this condition of transport process observed the law of plug flow application, variation of the formation and characteristics where streamline, variation of velocity of transport were also expressed n the system. Finally, Bacteriophages as a coliform family is a contaminant to groundwater aquifers, the model express all this parameters, that the developed model, it can be simulated for validation and can be applied to monitor the transport of Bacteriophages in coastal formation of homogenous fine and coarse sand.

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