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Research article

MODELING OF CONSERVATION MASS TRANSPORT OF CRYPTOSPORIDIUM COCYSTS IN NON REACTIVE ISOTROPIC HOMOGENOUS AQUIFER UNDER STEADY STATE FLOW IN SILTY FORMATION IN PORT HARCOURT, NIGER DELTA OF NIGERIA

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Abstract

Mass transport of cryptosporidium oocysts has been expressed, the transport process are under the influences of non reactive isotopic condition in homogeneous aquifer. this condition is under in steady state flow, the study was carried in silty formation, the condition of the microbes implies that it is under conservative region of the formation where there is no reactive substance, such condition implies that the microbes are only influenced by formation characteristic deposited in the study locations, the deposition of such microbes at this stage develop fast migration of the contaminants in the formation, it also reduces the death rate of the microbes in the region of the formation, the expressed parameters were investigated through risk assessment previously carried out, this produced relevant results in the study area, but could not produce permanent solution to the pollution transport in the study location, base on this factors, mathematical model were appropriate to develop a better solution on the deposition of this microbes in the study area. The model was developing through the formulated system from the parameters that influences the deposition of cryptosporidium oocysts in the formation, the study express different phase under the influences of formation characteristics. The developed model will definitely monitor the transport of cryptosporidium oocysts in silty formation.

Keywords: modeling cryptosporidium, non reactive steady state, and silty formation

1. Introduction

Industrial activity and natural environmental conditions have led to the introduction of nickel into soil and aquatic environments as a result of anthropogenic and geogenic sources, respectively (Duke, 1980; Richter and Theis, 1980). Nickel is a relatively minor constituent of the earth's crust having an average concentration of less than 0.01% by weight and ranking 24th in terms of abundance. Nickel is very heterogeneously distributed among crustal rocks ranging from less than 0.0001% in sandstone and granite to 4% in coveted ore deposits (Duke, 1980). Nickel can be found in igneous, sedimentary, and metamorphic rocks as well as nickel ores. In soils, nickel ranges from 5 – 500 mg kg-1 (Lindsay, 1979). Serpentine clay-rich soils are noted for natural geogenic abundance of nickel and have been the focus for use of hyperaccumulating plants to phytomine nickel (Chaney et al., 1995). Nickel is one of the most mobile of the heavy metals in the aquatic environment. The mobility of nickel in the aquatic environment is controlled largely by competition between various sorbents to scavenge it from solution and ligands to form non-sorptive complexes. Although data are limited, it appears that in pristine environments, hydrous oxides and phyllosilicates control nickel mobility via co-precipitation and sorption. In polluted environments, the more prevalent organic compounds will keep nickel soluble by ligands complexation. In reducing environments, insoluble nickel sulfide may form. The movement of nickel in ground water will be restricted by partitioning reactions to aquifer sediments. Probable techniques' that influences nickel partitioning to subsurface solids include direct adsorption to clay minerals, adsorption and/or coprecipitation with metal oxides, complexation with natural organic particles, ion exchange with charged surfaces, and direct precipitation as an hydroxide, carbonate or sulfide (Snodgrass, 1980). The chemical speciation of nickel in solution exerts a significant influence on the extent and mechanism(s) of partitioning to aquifer sediments, which may be influenced by acid-base reactions, oxidation-reduction reactions influencing the speciation of complexion inorganic solution species (e.g., aqueous sulfate vs. sulfide), and interactions with dissolved organic compounds. In general, inorganic/organic species that form dissolved complexes with nickel tend to enhance transport of nickel in soil profiles to subsurface water (e.g., dissolved organic carbon; Christensen et al., 1996; Warwick et al., 1997; Christensen and Christensen, 2000; Friedly et al., 2002). Field studies on transport in the subsurface illustrate several general conditions that are anticipated to result in expanding nickel plumes, including 1) acidic conditions (Kjoller et al., 2004), 2) manganese- and iron-reducing conditions (Larsen and Postma, 1997), and 3) the presence of mobile organic compounds that form soluble nickel complexes (Christensen et al. 1996; Kent et al., 2002). Possible production concept that can be in a job for remediation of a ground-water plume containing nickel include physical removal of polluted soils or sediments that serve as a long-term source of nickel leached into ground water, extraction of the dissolved plume with some method of above-ground treatment, physical isolation of the dissolved plume, or in-situ treatment of a dissolved plume resulting in immobilization of dissolved nickel within the aquifer. Of these technologies, the use of permeable reactive barriers (PRBs) for the capture and immobilization of nickel plumes has been investigated and applied in field settings due to favorable performance and cost characteristics (Blowes et al., 2000). Both carbon- and metallic iron-based (or zero valent iron) reactive media have been employed for nickel removal from ground water. For carbon-based media, nickel removal is generally considered to occur.

Precipitations of sulfide minerals. The conditions also include nickel sulfides, including coprecipitation of nickel with iron sulfides, (e.g., Ludwig et al., 2002; McGregor et al., 2002). There is also laboratory and field evidence that nickel immobilization can be enhanced through the addition of chemical amendments that promote nickel precipitation within soil or aquifer sediments (e.g., Lothenbach et al., 1997; Boisson et al., 1999; Seaman et al., 2001). The applicability and performance of these technologies will depend on the geochemical characteristics within the ground-water plume in conjunction with the velocities of ground water flow and the flux of beneficial and non-beneficial reactive components transported within the plume.

2. Theoretical background

Mass conservation is a process where microbes are deposited in highly populated area in an environment that is conducive for them on the transport system. Such protective dimension may be found in a deposited structural formation. Such conditions are developed depending on deposited micropores of the soil matrix. This integration of the rock mass is determined by the structural disintegration of the strata. This expressed the level of flow path, such condition determine the conservation of highly conserved cryptosporidium migration in a non-reactive isotropic aquifer that developed a homogeneous steady state condition in unconfined bed. An environment in the strata formation where the population of microbes conserved, it may definitely develop homogenous strata which are reflected on the steady state flow of the formation. the expression of the microbes at the formation of the strata in such conservative condition are found to deposit as in the formation, where there is no reaction with any deposited mineral, in this condition it implies that microbes are in the conservative region where there is no inhibition or experiencing any substrate. This implies that the microbes on protective environment will definitely migrate without any inhibition or degradation based on the conservative and unreactive condition they find themselves in the transport process. The study has defined the condition where microbes are deposited in a conservative environment, and nonreactive isotropic condition as expressed in the system, the behaviour of the microbes are determined base on this condition, expressing the behaviour on this conservative and nonreactive phase on the transport system, it implies that the microbes will developed different behaviour influenced by the stated condition .the steady state condition has been expressed in the system to have influenced by the structural setting of the strata in the study location. These conditions are reflected also on the migration state of cryptosporidium through the flow path deposited base on the micropoles in the strata.

3. Governing Equation

$$Vn\,\frac{\partial C}{\partial t}(x,t) \;=\; nV_x\,\frac{\partial C}{\partial x}(x,t) + nD\,\frac{\partial^2 C}{\partial x^2}(x,t) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\; (1)$$

The expression above is the governing equation that shows the deposition of mass conservation of cryptosporidium in non isotropic and non reactive environment, the expression in equation [1] were able to point out the parameters in the system noted, because the influential variables in the system determine the behaviour of the microbes on the transport system. The expressed governing equation has defined the condition of the formation and the microbe that has influences the transport and behaviour in the study area.

$$\frac{\partial C}{\partial t} \;=\; S^1C(t) \;-\; C(o) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\; (2)$$

$$\frac{\partial C}{\partial x} \;=\; S^1C(x) \;-\; C(o) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\; (3)$$

$$\frac{\partial^2 C}{\partial x^2} = S^{11}C(x) \;-\; S^1C(o) \;-\; C(o) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\; (4)$$

Substituting (2), (3), (4) into equation (1) gives

$$S^1C(t)\;\;(t) - Vn\left[S^1C(x) \;-\; C(o)\right] = Vn\left[SC(x) \;-\; C(o)\right] + nD$$
$$\left[S^2C(x) \;-\; SC(o) - \;C(o)\right] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\; (5)$$

$$S^1(t) \;\; - VnS^1C(o) = nVx\,S^1C(x) \;+\; nDS^{11}C(x) \;-\; S^1C(x) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\; (6)$$

$$C(x)\;\frac{1}{S}\;\left[VnS^1C(t) \;-\; nVx\,S^1C(x) \;+\; nDS^{11}C(x) \;-\; S^1C(x)\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\; (7)$$

$$C(x)\;\frac{1}{S^1}\;\left[VnS^1C(t) \;-\; nVx\,S^1C(x) \;+\; nDS^{11}C(x) \;-\; S^1C(x)\right]\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (8)$$

$$C(x) \;=\; \frac{VnS^1C(t) \;-\; nVx\,C(x) \;+\; nDS^1}{S} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\; (9)$$

$$C(x) = VnC(t) \;-\; nVxC^1(x) \;+\; nDC^{11} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\; (10)$$

$$C(x) = \frac{VnS^1C(t) = nVx \;+ nDS^1}{S} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\; (11)$$

$$C(x) = \left[Vn - nVx \; + nDS^{11}\right]C(t) \qquad \ldots\ldots\ldots\ldots (12)$$

$$S^{1}C(x) = \left[Vn - nVx \; + nDS^{11}\right]C(t) \qquad \ldots\ldots\ldots\ldots (13)$$

$$C(x) \;=\; \frac{S^{1}C(x)}{Vn + nVxS^{1} \;+\; nDS^{11}} \qquad \ldots\ldots\ldots\ldots (14)$$

$$C(t) \;=\; \frac{S^{1}(x)}{Vn + nVx \;+\; nD} \qquad \ldots\ldots\ldots\ldots (15)$$

Furthermore, considering the boundary condition, we have

$$\text{At } t = 0 \quad C^{1}(o) = C(o) \;=\; 0 \qquad \ldots\ldots\ldots\ldots (16)$$

$$VnS^{1}\,C(t) - \; nVxS^{1}\,C(x) + nDS^{11}\; S^{1}C(x)C(o) = 0 \qquad \ldots\ldots\ldots\ldots (17)$$

$$C(t) \;=\; \frac{0}{Vn \,-\, nVxS^{1} + nDS^{11}} \qquad \ldots\ldots\ldots\ldots (18)$$

Considering the following boundary condition when

$$\text{At } t > 0 \qquad C^{1}(o) \;=\; Co \qquad \ldots\ldots\ldots\ldots (19)$$

Applying the boundary condition into this equation

$$VnS^{1}C(t) - VnC(o) - Vn - nVxS^{1}\,C(x) - nVxCo - S(x) + nDS^{11}$$

$$C(x) + nDCo + S^{1}C(x) \qquad \ldots\ldots\ldots\ldots (20)$$

$$VnC(t) - VnxC(x) = nVxS\,C(o)\;VnCo - nVx\,Co + nDC(o) \qquad \ldots\ldots\ldots\ldots (21)$$

$$C(t) \;=\; \left[VnS \,-\, Vn \,-\, nVx + \,nD\right]Co \qquad \ldots\ldots\ldots\ldots (22)$$

$$C(t) \;= VnS \,-\, Vn \,-\, nVx + \,nD\;Co \qquad \ldots\ldots\ldots\ldots (23)$$

$$C(t) \;= \left(\frac{VnS - Vn - nVx + nD}{VnS - Vn - nVx + nD}\right) Co \qquad \ldots\ldots\ldots\ldots (24)$$

The expression from equation [16 and [19] are boundary conditions; this implies that the deposition and migration on conservative environment will always has some limits of migration in soil and water environment. The boundary values express various parameters limits with respect to time and distance under the stated influential parameters in the study area. The boundary conditions are integrated in the derived solution at every considered phase of the study; it is integrated according to the rate and region the influential parameter deposition in the strata.

Applying quadratic expression to determine denomination for the equation

$$Vn - nVx + nD = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (25)$$

Applying quadratic expression, we have

$$s = \frac{-b \pm \sqrt{b^2 - 4ac}}{2ac} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (26)$$

In other to express the condition of the microbes in accordance's with their various change in concentration, degradation and microbial population and other developed influences on the transport system will be defined, the application of quadratic expression were fined suitable, because it express detail functions of the parameters and integrate their various functions together expressed in the derived solution, this will definitely establish a relation between various parameters in the system as it is expressed below through the formula state above.

Where $a = Vn$, $b = nVx$ and $c = nDCo$

$$s = \frac{-nVx \pm \sqrt{nVx^2 - 4Vn\,nDCo}}{2nVx} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (27)$$

$$s_1 = \frac{-nVx + \sqrt{nVx^2 - 4Vn\,nDCo}}{2nVx} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (28)$$

$$s_2 = \frac{-nVx - \sqrt{nVx^2 - 4Vn\,nDCo}}{2nVx} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (29)$$

If $S = A\ell^{s_1 t} + B\ell^{s_2 t}$

$$\Rightarrow S = S = A\exp\frac{\left\lfloor -nVx + \sqrt{nVx^2 - 4Vn\,nDCo} \right\rfloor}{2nVx}t +$$

$$B\exp\frac{\left\lfloor -nVx - \sqrt{nVx^2 - 4Vn\,nDCo} \right\rfloor}{2nVx}t \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (30)$$

If $A = B = 1$

$$S = \exp\frac{\left\lfloor -nVx + \sqrt{nVx^2 - 4Vn\,nDCo} \right\rfloor}{2nVx}t \ \exp\frac{\left\lfloor -nVx - \sqrt{nVx^2 - 4Vn\,nDCo} \right\rfloor}{2nVx}t \qquad (31)$$

The expression in [31] defined the condition where the microbes on the transport process experience exponential phase, the condition of cryptosporidium deposition in non reactive isotopic condition may develop increase in microbial population as stated in the defined parameters, the developed governing equation expressed the parameters that defined the condition of the study, it is derived to consider the exponential phase of the transport system.

Applying inverse Laplace of the equation yield

$$C(t) = \left[{}^{Vn}\!/_{t} + Vn + nVx \right] Co \; \ell \frac{\left\lfloor nVx + \sqrt{nVx^2 - 4Vn\,nDCo} \right\rfloor}{2nVx} t \; +$$

$$\left[\frac{\left[nVx - \sqrt{nVx^2 + 4Vn\,nDCo} \right]}{2nVx} \right] t \; - \; \left[\frac{\left[nVx - \sqrt{nVx^2 + 4Vn\,nDCo} \right]}{2nVx} \right] t \qquad (32)$$

$$C(t) = \left[\frac{nVx}{t^2} Co \right] \frac{\left[nVx + \sqrt{nVx^2 - 4Vn\,nDCo} \right]}{2nVx} \; \ell \left[\frac{\left[nVx \sqrt{nVx^2 - 4Vn\,nDCo} \right]}{2nVx} \right] +$$

$$\ell \left[\frac{\left[nVx \sqrt{nVx^2 - 4Vn\,nDCo} \right]}{2nVx} \right] t \; \left[\frac{\left[nVx \sqrt{nVx^2 - 4Vn\,nDCo} \right]}{2nVx} \right] t \qquad (33)$$

At this point $Co = 0, \; t \neq 0$

For equation (30) at $t = 0 \; C(o) = Co,$ we have

$$Co = \left[Vn + nVx\; nD \right] Co\; (1+1+1) = 0 = \left[Vn + nVx\; nD \right]$$

Hence $Vn + nVx\; nD = 0$

Equation (33) becomes

$$C(t) = Co \left[\frac{Vn}{t} + 2 \right] \frac{\left[nVx + \sqrt{nVx^2 - 4Vn\,nDCo} \right]}{2nVx} t \left[\frac{\left[nVx \sqrt{nVx^2 - 4Vn\,nDCo} \right]}{2nVx} \right] \qquad (34)$$

The expression in [34] is the final model that will monitor the microbes; the study has lots of influential parameters considered in the system to generate the governing equation for the study. The derived expressed equation considered several conditions base on the depositions of the influential parameters in the transport system. The study defined the deposition of cryptosporidium and other formation deposited influence that express various condition under the influences of formation characteristics in the study area.

4. Conclusion

Cryptosporidium cocysts were found to deposit in silty formation, the study examine several conditions that was investigated through risk assessment carried out, the investigation produces some relevant information, but could not address the problem, such condition defined the limits of the assessment that could develop better solution to the problem. The conditions of the study area worsen because the assessment done only produces results, but could not solve the problem. The behaviour of the system is challenging because the study location continue to experience increase in pollution from the microbes under the influences of the stated parameters, such expression define the development of the system that produced the governing equation, it is imperative to express this conditions mathematically to generate solution, the derived solution applied different mathematical; methods considering several condition in the system that could be derived with such mathematical methods, the derived solution express it in different application to generate the fine model that will monitor the deposition of the microbe with those condition in the formation.

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