VARIATIONS OF CONTAMINANT RETARDATION FACTOR IN THE PRESENCE OF TWO MOBILE COLLOIDS

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Abstract

Contaminant retardation factor is derived from the colloidal and contaminant transport equations for a four-phase porous medium: an aqueous phase, two mobile colloidal phases, and a solid matrix. It is assumed that the contaminant sorption to solid matrix and colloidal particles and the colloidal deposition on solid matrix follow the linear isotherms. The behavior of the contaminant retardation factor in response to the change of model parameters is examined employing the experimental data of Magee et al. (1991) and Jenkins and Lion (1993). In the four-phase system, the contaminant retardation factor is determined by both the contaminant association with solid matrix and colloidal particles and the colloidal deposition on solid matrix. The contaminant mobility is enhanced when the affinity of contaminants to mobile colloids increases. In addition, as the affinity of colloids to solid matrix decreases, the contaminant mobility increases.

key word: retardation factor, contaminant transport, colloid-facilitated transport, linear isotherm

1. INTRODUCTION

A contaminant retardation factor is commonly used to describe the extent of the contaminant transport in groundwater. In a conventional two-phase porous medium, the contaminant retardation factor, R_c, can be expressed as:

$$R_c = \left(1 + \frac{\rho_s K_1}{\theta} \right)$$

(1)

where ρ_s = dry bulk density of solid matrix; K_1 = equilibrium distribution coefficient of contaminants between the aqueous phase and solid matrix; and θ = water content. In groundwater, colloidal particles such as bacteria, inorganic colloids, and dissolved organic matter are widely present. These colloidal particles can play a role of mobile carriers in facilitating the transport of metals, radionuclides, and organic contaminants in soils and groundwater (McCarthy and Zachara 1989; Ryan and Elimelech 1996). The change of the contaminant mobility in groundwater due to the presence of mobile colloids can be quantified by the modified contaminant retardation factor. In the subsurface environments, contaminants will be present together with various colloidal particles,

which have different affinity to them. In addition, those colloids will have different attachment affinity to solid surfaces in the aquifer. When contaminants are present together with two different colloidal particles in saturated porous media, the system can be conceptualized with an aqueous phase, two mobile colloidal phases, and a solid matrix. In this study, the contaminant retardation factor in the four-phase system is derived from the colloidal and contaminant transport equations. The behavior of the contaminant retardation factor due to the change of model parameters is investigated.

2. DERIVATION OF CONTAMINANT RETARDATION FACTOR

2.1. Colloidal Particle Transport

The transport equation for colloidal particle type-a suspended in the aqueous phase can be presented as:

$$\frac{\partial(R_a \theta C_a)}{\partial t} = -\frac{\partial}{\partial x}\left[-D_a \frac{\partial(\theta C_a)}{\partial x} + v_w \theta C_a\right] \tag{2}$$

$$R_a = 1 + \left(\frac{\rho_a K_a}{\theta}\right) \tag{3}$$

where R_a = retardation factor of colloidal particle type-a; C_a = concentration of colloidal particle type-a in the aqueous phase; ρ_a = density of colloidal particle type-a; D_a = hydrodynamic dispersion coefficient of colloidal particle type-a; and v_w = pore-water velocity. K_a = equilibrium distribution coefficient of colloidal particle type-a between the aqueous phase and solid matrix. The transport equation for colloidal particle type-b suspended in the aqueous phase can be expressed as:

$$\frac{\partial(R_b \theta C_b)}{\partial t} = -\frac{\partial}{\partial x}\left[-D_b \frac{\partial(\theta C_b)}{\partial x} + v_w \theta C_b\right] \tag{4}$$

$$R_b = 1 + \left(\frac{\rho_b K_b}{\theta}\right) \tag{5}$$

where R_b = retardation factor of colloidal particle type-b; C_b = concentration of colloidal particle type-b in the aqueous phase; ρ_b = density of colloidal particle type-b; and D_b = hydrodynamic dispersion coefficient of colloidal particle type-b. K_b = equilibrium distribution coefficient of colloidal particle type-b between the aqueous phase and solid matrix.

2.2. Contaminant Transport

The transport equation for the contaminant in the presence of two mobile colloids can be finalized as:

$$\frac{\partial(R_c \theta C_c)}{\partial t} = \frac{\partial(D_c \theta C_c)}{\partial x^2} - \frac{\partial(v_w \theta C_c)}{\partial x} \tag{6}$$

$$R_c = \left[1 + \frac{(\rho_s K_1 + \rho_a K_a K_4 C_a + \rho_b K_b K_5 C_b)}{\theta(1 + K_2 C_a + K_3 C_b)}\right] \tag{7}$$

where C_c = concentration of dissolved contaminants; D_c is the hydrodynamic dispersion coefficient of contaminants; K_2 = equilibrium distribution coefficient of contaminants between the aqueous phase and mobile colloid type-a; K_3 = equilibrium distribution coefficient of contaminants between the aqueous phase and mobile colloid type-b; K_4 = equilibrium distribution coefficient of contaminants between the aqueous phase and immobile colloid type-a; and K_5 = equilibrium distribution coefficient of contaminants between the aqueous phase and immobile colloid type-b. When Eqs. (3) and (5) are substituted into Eq. (7), the contaminant retardation factor in the presence of two mobile colloids can be expressed as:

$$R_c = \left[1 + \frac{(\rho_s K_1/\theta) + (R_a - 1)K_4 C_a + (R_b - 1)K_5 C_b}{1 + K_2 C_a + K_3 C_b}\right] \tag{8}$$

3. VARIATIONS OF CONTAMINANT RETARDATION FACTOR

The contaminant retardation factor can be rewritten in terms of dimensionless variables as:

$$R_c^+ = \left[1 + \frac{(K_1^+/\theta^+) + (R_a^+ - 1)K_4^+ C_a^+ + (R_b^+ - 1)K_5^+ C_b^+}{1 + K_2^+ C_a^+ + K_3^+ C_b^+}\right] \tag{9}$$

When colloidal particle type-b move through the aquifer without deposition onto solid matrix(i.e., R_b^+ = 1.0), Eq. (9) can be modified as:

$$R_c^+ = \left[1 + \frac{(K_1^+/\theta^+) + (R_a^+ - 1)K_4^+ C_a^+}{1 + K_2^+ C_a^+ + K_3^+ C_b^+}\right] \tag{10}$$

Furthermore, if the transport of both colloidal particle type-a and type-b is not retarded in groundwater (i.e., $R_a^+ = R_b^+ = 1.0$), Eq. (9) can be simplified as:

$$R_c^+ = \left[1 + \frac{K_1^+}{\theta^+(1 + K_2^+ C_a^+ + K_3^+ C_b^+)}\right] \tag{11}$$

To examine the behavior of the contaminant retardation factor, the experimental data of Magee et al. (1991) and Jenkins and Lion (1993) are employed. It is considered in this study that bacteria and dissolved organic matter are colloidal particle type-a and type-b, respectively. Fig. 1 shows that as K_1^+ changes four orders of magnitude from

0.01 to 100, the value of Eq. (1) increases from 1.01 to 101 while that of Eq. (9) moves from 1.4 to 55.3. In Fig. 1, the graph of Eq. (9) crosses with that of Eq. (1) at K_1^+ = 0.8. Above this point, the contaminant transport is facilitated due to the presence of mobile colloids. However, below K_1^+ = 0.8, contaminant transport is more retarded even in the presence of colloids than in the absence of them. When the contaminant affinity to solid matrix is very low, most of contaminants are present in the aqueous phase in the absence of colloids, and their transport is not delayed much. In the presence of colloids, when K_1^+ is very low, most of contaminants are either dissolved in the aqueous phase or associated with colloidal particles. In Fig. 2, the value of Eq. (9) is always smaller than that of Eq. (1), indicating that the contaminant mobility is greater in the presence of colloids than in the absence of them between K_2^+ = 0.01 and K_2^+ = 100. Fig. 3 demonstrates the behaviors of R_c^+ due to the change of the retardation factors of colloid type-a and type-b, R_a^+ and R_b^+. The contaminant mobility decreases as the mobility of colloidal particles is reduced. When the mobility of colloidal particles in porous media is low, the presence of colloids does not help to facilitate the contaminant transport.
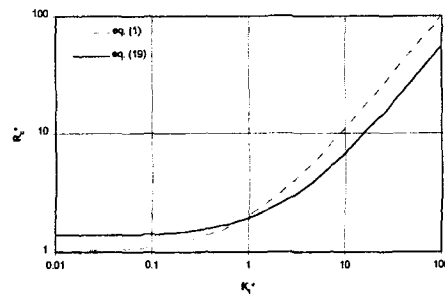

Fig. 1. Behavior of Contaminant Retardation Factor, R_c^+ due to the Change of Equilibrium Distribution Coefficient of the Contaminants between the Aqueous Phase and the Solid Matrix, K_1^+ .
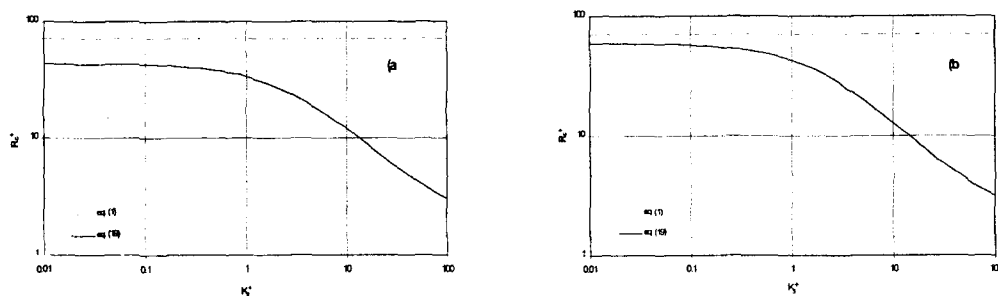

Fig. 2. Behavior of Contaminant Retardation Factor, R_c^+ due to the Change of (a) Equilibrium Distribution Coefficient of the Contaminants between the Aqueous Phase and Mobile Colloid Type-a, K_2^+; (b) Equilibrium Distribution Coefficient of the Contaminants between the Aqueous Phase and Mobile Colloid Type-b, K_3^+.
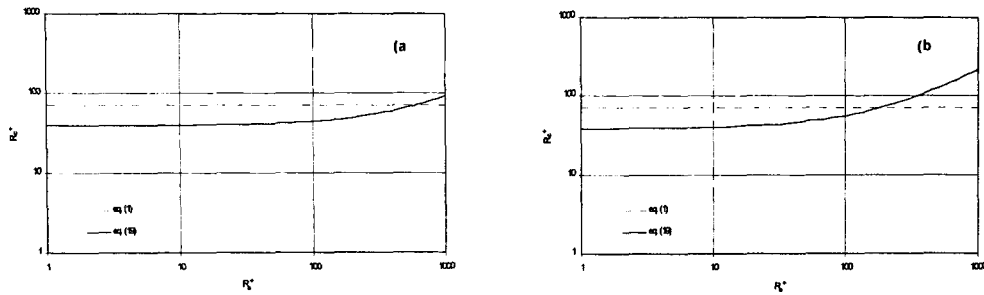
Fig. 3. Behavior of Contaminant Retardation Factor, R_c^+ due to the Change of (a) Retardation Factor of Colloids Type-a, R_a^+;(b) Retardation Factor of Colloid Type-b,R_b^+.

4. CONCLUSIONS

The contaminant retardation factor for the four-phase system is derived, and its behavior in response to the change of model parameters is investigated. The analysis shows that in the presence of colloidal particles, the contaminant mobility is closely related to the contaminant affinity to mobile colloids and the mobility of colloidal particles. In groundwater the contaminant transport can be facilitated due to its association with mobile colloids, and the contaminant mobility can be enhanced further as the mobility of colloidal particles increases.

5. REFERENCES

Jenkins, M. B. and Lion, L. W. (1993). Mobile bacteria and transport of polynuclear aromatic hydrocarbons in porous media. *Appl. Environ. Microbiol.*, 59, 3306-3313.

Magee, B. R., Lion, L. W., and Lemley, A. T. (1991). Transport of dissolved organic macromolecules and their effect on the transport of phenanthrene in porous media. *Environ. Sci. Technol.*, 25, 324-331.

McCarthy, J. F., and Zachara, J. M. (1989). Subsurface transport of contaminants. *Environ. Sci. Technol.*, 23, 496-502.

Ryan, J. N. and Elimelech, M. (1996). Colloid mobilization and transport in groundwater. *Colloids Surf. A*, 107, 1-56.