INSITU DISINFECTION OF CONTAMINATED GROUNDWATER; PARAMETRIC STUDY

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1. ABSTRACT

In this paper, a parametric study of an insitu groundwater disinfection procedure is presented. The developed model is based on injecting disinfection material that helps through chemical reactions to reduce the contaminant concentration. The study region is a hypothetical area of regular shape of dimension L by 0.5L. The two-dimensional unsteady state mathematical modeling includes a simultaneous of the three boundary value problems, namely the groundwater flow, the contaminant transport and the disinfection material transport. A point source of the contamination of 1000 units' concentration is assumed to be existing in the domain and located at the region centroid. The main objective of the mathematical model is to investigate the factors that influence the effectiveness of the remediation process. It was concluded that the location of the source of decontamination with respect to the source of contamination plays a significant role on the remediation process. Moreover, both the heterogeneity and anisotropy of soil enhances to a great extent the remediation processes.

Keywords: Groundwater; Contamination; Disinfection; Mathematical Models.

2. INTRODUCTION

Groundwater contamination is a problem that has serious impacts on the environment, public health, water resources and national economy. Methods of disinfection of contaminated groundwater are numerous. In 1999, Mansour et al. introduced a new technique to achieve a chemical or biological remediation of contaminated groundwater bodies inside the medium where they exist. This can be done by injecting the proper chemical or biological compounds, which can help in the process of groundwater treatment. Moreover, it has the advantage of being suitable to both big size and small size reservoirs and in the mean time allows the users to reduce the contaminant content below any desired value.

In this paper, a parametric study is presented actually the most effective parameters that affect the remediation process.

3. MATHEMATICAL MODELING

The used models are based on a three phase, two-dimensional state condition. The soil can be fully or partially saturated. The three phases are:

- Fluid flow through porous media,
- The contaminant transport through the medium, and
- The disinfecting material transport through the medium.

The flow of compressible fluid through an incompressible porous media can be written in the following general form (Remson et al., 1971):

$$\nabla.[\rho k(\theta)\nabla\varphi]=\partial(\rho\theta)/\partial t \quad (1)$$

In which, ρ is the fluid density; k is the hydraulic conductivity; θ is the fluid water content and φ is the total energy which is the sum of the position energy z and the pressure head h.

The mass transport through the fluid in a porous media is governed by the equation (Sun, 1950):

$$\partial C_i/\partial t=div[C_iV-\rho D_d grad(C_i/\rho)] \quad (2)$$

where C_i is the concentration. The value of i is equal 1 for contaminant and 2 for disinfecting material while v is the velocity vector.

The relation between the disinfection material quantity G that is required to reduce the contaminant concentration C_1 by unit value is assumed to have the following general form

$$G=F(C_1) \quad (3)$$

In the model, the equations 1, 2, and 3 are solved numerically using the method of finite elements by means of two softwares. The first one which is called "SEEP/W Program" deals with the flow of water through porous media. The second one that concerns with solving mass transport through porous media is "CTRAN/W program".

4. DESCRIPTION OF THE PHYSICAL AND MATHEMATICAL MODEL

The factors that influence the effectiveness of the remediation process are studied through a hypothetical study area. To avoid the shape effect, the area is chosen to be rectangular of dimension L X 0.5 L. The region is discretized into 128 square elements. In order to increase the degree of accuracy of the numerical solution, the elements are chosen to be containing 8 boundary nodes.

The boundary conditions of the hydrodynamics model are taken as impervious at the upper and lower boundaries. The total head at the left vertical end zone boundary is assumed to be constant and equals 10 m. Along the right vertical end zone boundary, the total head is equal to zero.

The boundary conditions of the transport model along the upper and lower sides of the study region are taken such that no contaminant is allowed to cross them. The left and right vertical end zone boundaries are assumed to be having zero concentration. In mathematical notations, these boundary conditions can be written in the following forms:

$$\partial C/\partial y = 0 \text{ for } 0 \le x \le L,\ y = 0$$

$$\&\partial C/\partial y = 0 \text{ for } 0 \le x \le L,\ y = 0.5\ L$$

$$C = 0 \text{ for } x = 0,\ 0 \le y \le 0.5\ L$$

$$C = 0 \text{ for } x = L,\ 0 \le y \le 0.5L$$

The hydrodynamics models are treated in the unsteady state while the transport model is handled as transient state.

A point source with contamination concentration of 1000 unit is assumed to be existing in the centroid of the study domain and is located at point F and a special case of disinfection location is allocated at point G, Figure (1).

5. PARAMETRIC STUDY

For this simple case, many factors are of great importance as far as the contaminant distribution in the domain before and after injecting the disinfecting compound is concerned.

5.1 Position Parameter

Among the essential factors that influence the contamination concentration distribution is the location of the disinfection source. To study this phenomenon, a purifier source is allowed to move in the domain at different distances from the contamination source and at different angels from the x-axis direction. Eighteen different purifier positions are studied. Locations and Positions of the purifier source are shown in Table (1).

Table (1) Locations and Positions of the purifier source

Location	Angle of Inclination, Ψ	Position		
		1	2	3
1	0	L	2L	4L
2	26.5	$L\sqrt{3}$	$2L\sqrt{3}$	$3L\sqrt{3}$
3	45	$L\sqrt{2}$	$2L\sqrt{2}$	$3L\sqrt{2}$
4	90	L	2L	3L
5	135	$L\sqrt{2}$	$2L\sqrt{2}$	$3L\sqrt{2}$
6	180	2L	4L	6L

Three different purifier concentrations of 200, 1000 and 10,000 unit are studied for each case. It is assumed that the groundwater quality is acceptable if the contaminant concentration is less than 200 units. It is also assumed that the domain is homogeneous and isotropic.

The hydraulic conductivity is equal to 0.1 m/day, the despersivity in both directions equal to 1.0 and the water content is taken to be 0.5.

5.2 Heterogeneity Effect

To study the effect of soil heterogeneity on the remediation process, three cases have been studied. The first case is that of constant hydraulic conductivity which is taken as 0.1 m/day. In the second case, a heterogeneous condition with 8 ascending hydraulic conductivity values is adopted. These values are 0.001, 0.01514, 0.02929, 0.04343, 0.05757, 0.07171, 0.08585 and 0.1 m/day. Each value is assumed to be valid for two rows of elements, taking the higher values in the positive direction of x axes. In the third case, the same 8 values are arranged in descending order starting at 0.1 m/day at x = 0.

5.3 Anisotropy Effect

To find out how far the anisotropy condition may affect the remediation process, an anisotropy case whose longitudinal to transverse disperssivity ratio is taken as 10 to 1.0, has been adopted.

6. RESULTS, ANALYSIS AND DISCUSSION

The result of the previous studied cases are presented in the form of relationship between A* and P*; where A* is the ratio between the contaminated area A_c and the total area of the domain A_T. In the mean time, P* is the ratio between the value of applied purifier's concentrations P_v to the allowable contaminants concentration P_{all}. While r/L determine the distance of the source of disinfection with respect to the source of contamination related to the total length of the domain. On the other hand, ψ is the inclination of the line on which both the source of contamination and source of disinfection are allocated with respect to x axes. All the diagrams are presented in dimensionless form in order to have them applicable for other cases. Figure (2) presents the relation between A* versus P* for an angle of inclination of zero value.

From the study of the results of different cases, it becomes clear that the contamination area decreases with increasing the purifier concentration. However, the increase of purifier concentration becomes practically ineffective after reaching a certain value. This value is mainly dependent on the distance from the injection point to the contamination source.

As an example, for $\psi = 0$, the increase of P* above 80 is of no practical influence in reducing the contamination area as it has approached already a negligible value and the contaminant source has been enclosed around its own location. Actually, the value 80 can be reduced to as low as 10 for $r/L < 0.125$. These arguments can be seen in Figure (2). Similar argument values can be stated for different values of ψ.

The effect of changing the angle of inclination between the disinfection source location and the source of contamination with respect to the x axis on the contaminated area for two different positions ($r/L = 0.1$ and $r/L = 0.2$) at the same concentration ($P^* = 1.0$) is studied and illustrated in Figure (3).

It can be concluded from Figure (3) that the greater the angle of inclination between the two sources, the higher is the contaminated area. The reason behind this is that the fluid flows through the soil from the left end zone boundary to the right one. This means that the advection part is higher for small angles as the angle is measured anti-clockwise for the positive direction of x.

Also the influence of changing the angle of inclination on the purifier's concentration at the same value of contaminated area ($A^* = 0.3$) is also studied and presented in Figure (4). It can be concluded from this figure that the required purifier rate increases with the increase of the angle ψ .

In Figure (5), the influence of soil hetrogeneity on the remediation process is illustrated. The figure represents the relation between A* versus P* for three cases of different hydraulic conductivity. These cases are; case of increasing hydraulic conductivity in the direction of increasing x and case of decreasing hydraulic conductivity with increasing x.

It can be concluded from this figure that for the same concentration of purifier, the contaminated area for heterogeneous case is less than that of homogeneous case which proves that the heterogeneity of soil enhances the remediation process. It can also be deduced from the curve that, the k- increasing curve coincide with the k-decreasing curve, which indicates that the form of heterogeneity plays no roll on the remidiation process.

Figure (6) shows A* versus P* diagram for anisotropy condition. The figure illustrates the effectiveness of the anisotropy condition on the enhancement of the remediation process.

7. CONCLUSIONS, APPLICATIONS AND RECOMMENDATIONS

Groundwater contamination is a problem of serious impact on the ecosystem, subsurface structures, water resources, public health, and consequently the national economy.

An insitu groundwater remediation procedure is developed to disinfect contaminated groundwater. The new technique is conducted with the help of a multiphase mathematical modeling process. The models include a simultaneous solution of the groundwater flow through porous media with the contaminant transport and the disinfection compound transport models. In the models, the flow equation through porous media as well as the transport equations of both contaminant and decontaminant are solved numerically by finite element techniques. This process can be achieved by injecting a certain compound that reacts chemically or biologically with the contaminant and hence changing its content into less hazardous compounds.

Parametric study and sensitivity analysis lead to the conclusion that the contaminated area decreases with increasing purifier concentration. However, the increase in purifier concentration becomes practically ineffective after reaching a certain value. This value is mainly dependent on the distance from the injection point to the contaminant source. Also, it can be deduced that the greater the angle of inclination between the source of contamination and that of decontamination, the higher is the contaminated area. Moreover, the required rate of purifier increases with the increase of this angle of inclination. The study deduces a result that the heterogeneity of soil enhances the remediation process while, the form of heterogeneity plays no roll on the treatment process. Meanwhile, it illustrates how far the anisotropy condition enhances to a great extent the remediation process.

Generally, the advantages of the new technique are summarized in the following points:

- It has the advantage of disinfecting the contaminated groundwater body inside the media where they exist, while in the other conventional methods, only the used quantity of water is disinfected leaving the water body without treatment which may expose the ecosystem and the public health to serious impacts.

- It does not need high technology of application since it needs only to recharge the disinfection material with a predetermined rate in existing well or even in a specially constructed new ones.
- The process can be used through interpolation procedure to determine the properties of the soil and the fluid.

The developed procedure in its present form has a wide range of application. Examples of these are:

- Contamination control in the neighborhood of open drains.
- Contamination control inside urban areas that are served with old or improper sewerage network.
- Contamination control of saltwater intrusion in coastal area.
- Contaminant flow under sheet piles and retaining walls.

The following list of recommendations is thought to be of importance in the direction of the procedure improvement:

- It is recommended to supply the suggested model with a list of all popular industrial and domestic waste contaminants with the corresponding decontaminating compounds and the functional or tabular relation between them.
- It is recommended to develop the model to treat three-dimensional problems. This is particularly necessary in case of seepage from contamination bonds, problems of contamination flow from solid waste landfills especially after rainy seasons and hydrocarbon contamination due to leakage from underground petroleum tanks.

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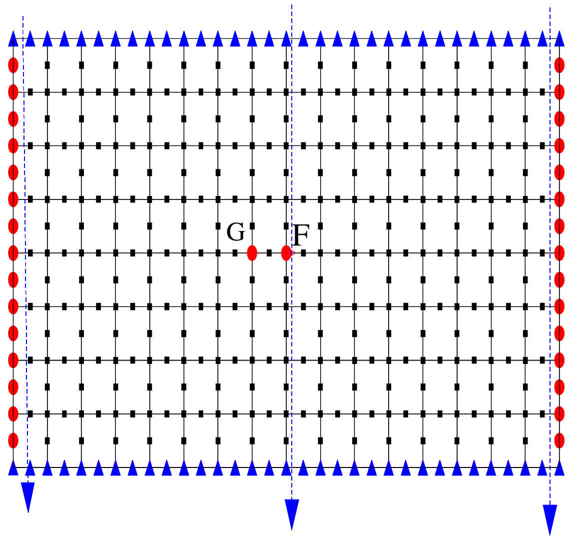

Figure (1) Transport Model

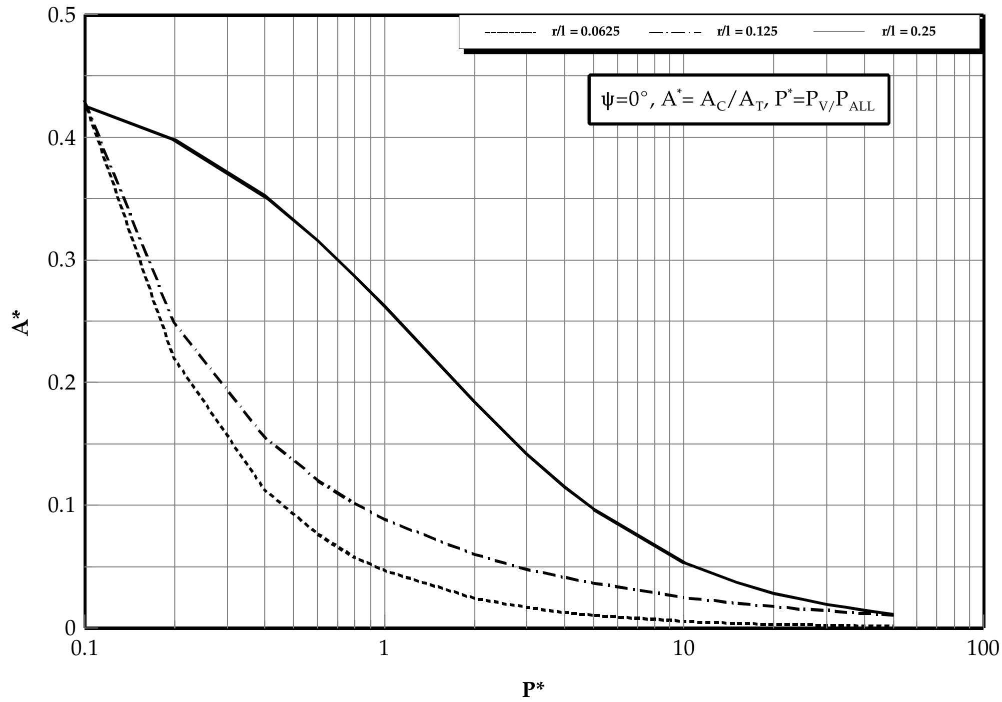

Figure (2) A*-P* Diagram for ψ=0

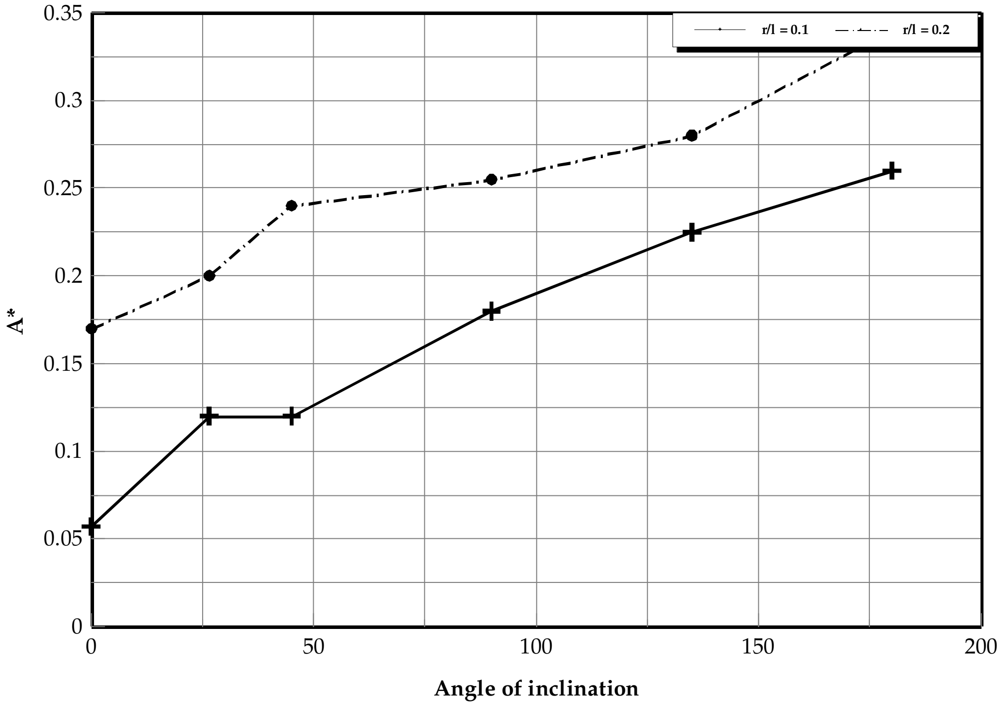

Figure (3) Effect of Changing ψ on A* at P*=1.0

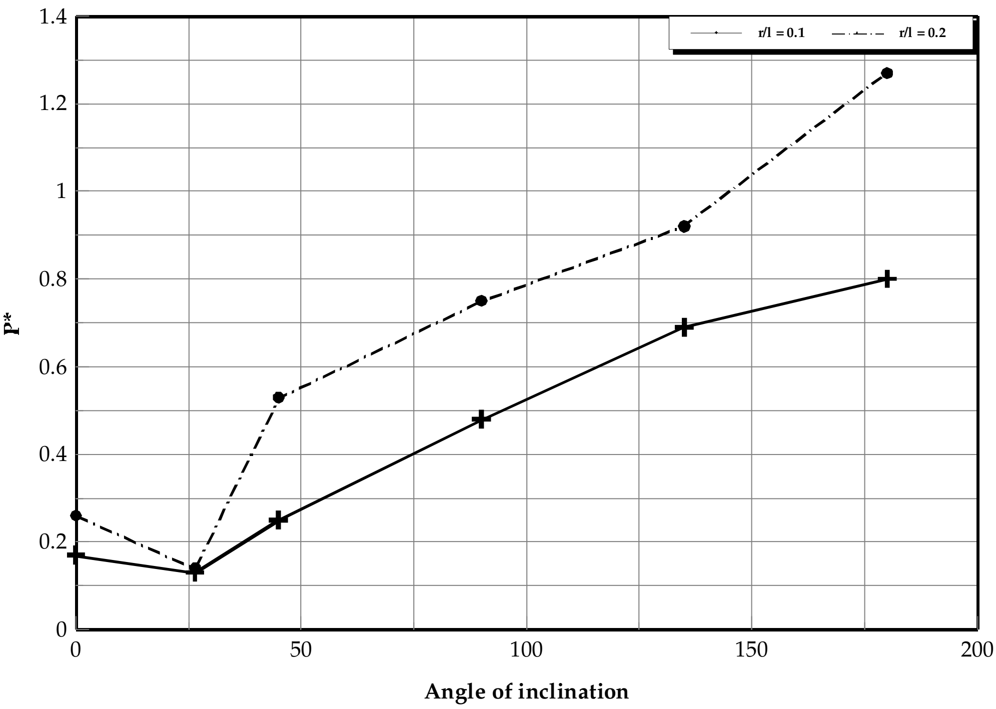

Figure (4) Effect of Changing ψ on P*

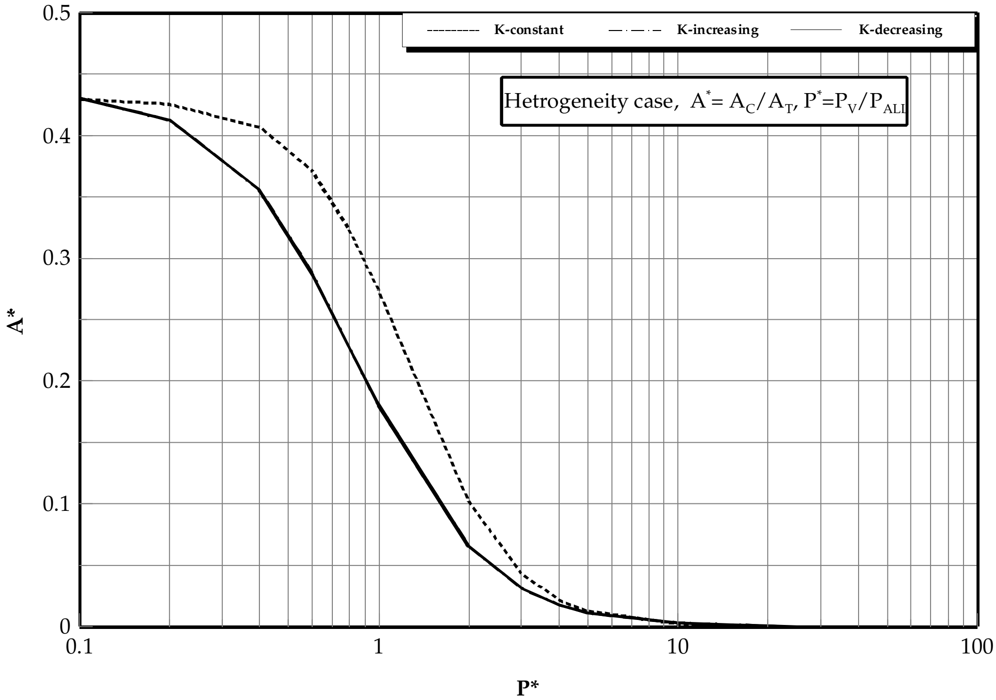

Figure (5) Effect of Heterogeneity Effect

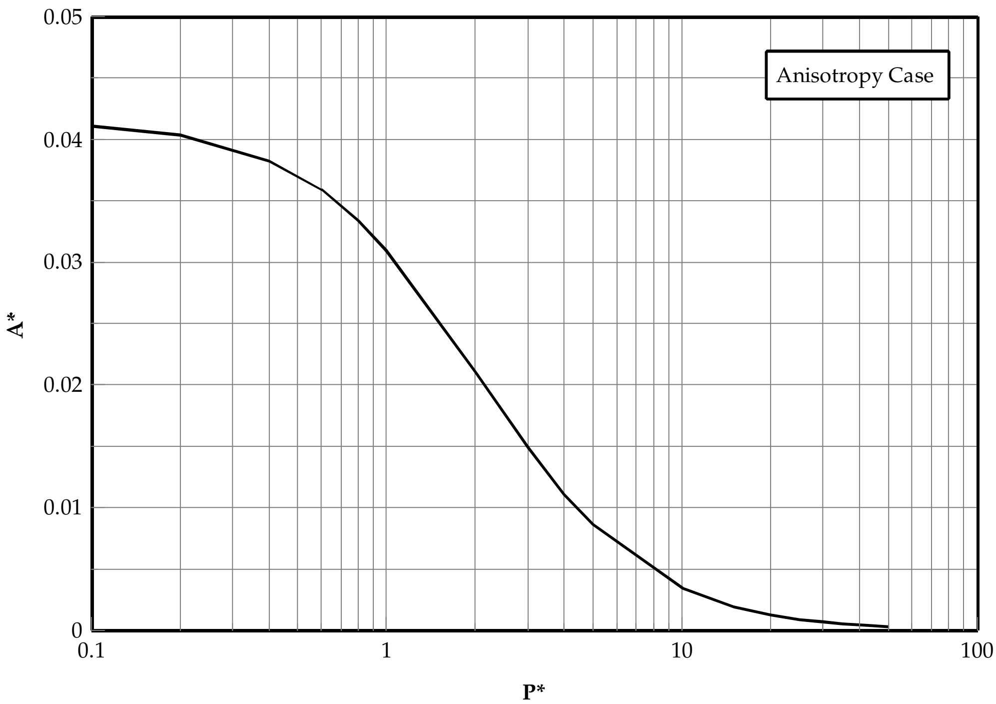

Figure (6) Anisotropy Effect