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Experimental Investigation of Contaminant Transport Through Saturated Porous Media Under Groundwater Flow

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ABSTRACT: Contaminant transport in groundwater has been growing concern during the last decades since pollution can leach through the soil and reach the groundwater. The present research has been investigated solute migration through saturated porous media by the physical modeling laboratory, resulting in a practical graph, determining the general pattern of a contaminant plume in both homogeneous and heterogeneous layers. Three types of sand are selected for the experimental model, which include both coarse and fine aggregates. The results indicated that in the coarse aggregate medium, the movement of pollution is 10 times faster than the fine aggregate containing 10% silt and 1.5 times faster than the fine aggregate sand without silt. The ratio of the length to width of the contaminated area in the coarse-grained soil in comparison to the fine-grained soil containing silt, and without silt increase 110 % and 40% respectively. In the heterogeneous fine- coarse model, darcy velocity magnitude in the coarse aggregate medium is much greater than fine aggregate result in more advection. In this case, because of the significant difference in velocity values in the two layers, the pollutant is rapidly transferred to the downstream after reaching the border of the two areas. Also, in the frontier of the coarse- fine medium, pollution is dispersed more for the fine aggregate medium acts as though it were the wall.

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1. INTRODUCTION

Groundwaters are considered the major source of potable and agricultural water supply. In recent years, as contaminants are able to enter extensively from waste oil produced by refineries, leakage, etc. into subsoil layers and groundwater resources, their transport properties have been studied as a critical issue in the related researches [1]. As we know, the vast studies have been carried out to describe contaminant transport in saturated porous media using, numerical ([1] & [2]), analytical ([3]) and experimental methods ([4], [5]&[6]). The previous studies have paid little attention experimentally to the movement and dispersion of contaminants through the saturated layered soils with vertical flow perpendicular to the layer boundaries. Therefore, in the present study, the solute transport was studied experimentally through two homogeneous and heterogeneous saturated media under groundwater flow. Also, the effects that the changed soil properties and layering have on the contaminant transport were studied.

2. METHODOLOGY

In this research, a sandbox was designed and built which consisted of two similar containers to simulate upstream and downstream flows measured as 25.5 × 15 × 10 cm^3. Also, the middle space was measured as 100 × 15 × 110 cm^3 in the sandbox. The sandbox diagram represented different parts and a contaminant injection device in Figure 1. In the present work, three sand types were selected with the average size of soil grains as 1 mm, 0.22 mm and 0.22 mm for 1st (with the uniform grain), 2nd (with the uniform grain) and 3rd (with the spread grain plus 10% silt) sand grades, respectively. In the next sections, they are mentioned as the coarse-, medium-, and fine-grained soils for three sand grades, respectively. Table 1 provides the physical and hydraulic specifications for each studied soil sample. Potassium permanganate was used to treat as the contaminant in the experiment settings. The rectangular cube-liked specimens were constructed with dimensions of 15 cm (in thickness), 110 cm (in length), and 8 cm (in height) for each layer with a relative density of 50% in dry condition. Horizontal layers of soil were created slowly by pouring soils and compacting them in ten layers. This method was adopted for all layers and thus, soil layers were formed at determined equal thicknesses. Upstream and downstream heads were 80 and 40 cm, respectively. The contaminant was injected from the source through the soil specimen after the piezometric water surface remained constant.

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3. RESULTS AND DISCUSSION

3.1. Homogeneous soil

In a homogeneous state, the contaminant motion times from injection source to the down-stream boundary were

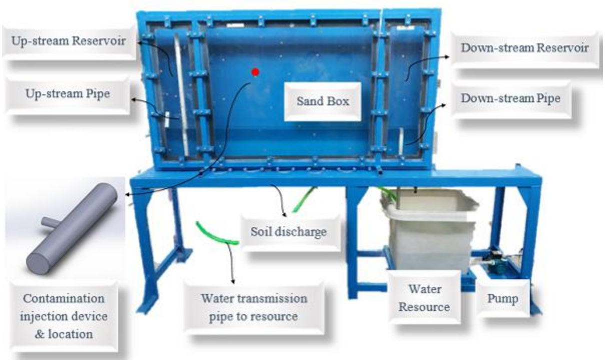

Fig. 1. Sandbox

Table 1. Physical and hydraulic characteristics

Sand type	D_{60} (mm)	D_{30} (mm)	D_{10} (mm)	n	e	K (cm/s)	γ_d min (kN/m^3)	γ_d max (kN/m^3)
Fine-grained	0.25	0.15	0.07	0.41	0.696	0.006	15.44	16.44
Medium-grained	0.25	0.17	0.12	0.42	0.727	0.158	15.18	15.81
Coarse-grained	1.4	0.75	0.55	0.43	0.749	0.225	15.29	16.60

Table 2. Area, perimeter, length, and width values in the time intervals of 5%, 10%, 25%, 50%, 75%, and 100% in the homogenous soil

Plume characteristics	Sand type	T_0	T_1	T_2	T_3	T_4	T_5
Area (cm^2)	Fine-grained	49.82	121.61	309.62	666.66	1103.48	1333.95
	Medium-grained	73.75	176.35	412.83	607.01	737.08	785.34
	Coarse-grained	84.27	247.73	697.59	1327.91	1772.30	1949.41
Perimeter (cm)	Fine-grained	27.54	49.63	83.88	120.73	167.99	195.43
	Medium-grained	31.66	50.72	114.41	151.01	176.06	184.45
	Coarse-grained	35.92	59.07	108.33	164.79	185.22	198.38
Length (cm)	Fine-grained	9.36	15.72	26.67	41.99	51.95	58.57
	Medium-grained	10.50	18.35	30.62	43.57	53.66	60.46
	Coarse-grained	10.63	19.64	39.74	55.92	69.71	73.26
Width (cm)	Fine-grained	7.06	9.66	12.74	16.08	18.25	19.06
	Medium-grained	8.95	13.80	18.47	20.15	22.77	24.98
	Coarse-grained	9.77	16.85	26.82	33.87	36.60	38.10

obtained as 560 s, 3180 s, and 5400 s in the coarse-, medium, and fine-grained sand specimens, respectively. Table 2 represents area, perimeter, length, and width values in the time intervals of 5%, 10%, 25%, 50%, 75%, and 100% in the homogeneous soil specimens. Figure 2 shows the contaminant spread shapes approximately in the studied homogeneous soil specimens after 500 s from the start of the experiments. According to Figure 2, the transverse contaminant spread was more in the fine-grained sand specimen compared to the other two specimens, and the observed contaminant longitudinal motion was more in the coarse-grained sand specimen compared to the medium-grained specimen and it is more in the medium-grained specimen compared to the fine-grained sand specimen. The transverse spread and longitudinal motion of contaminants occur based on the dispersion and advection phenomena, respectively.

3.2. Heterogeneous soil

In this condition, soil specimens contain two coarse- and fine-grained layers. In the first model, the upstream fine-grained and downstream coarse-grained soil specimens were set with the contaminant flow perpendicular to the layer boundaries. The layers are lengthened equally with layer boundaries located in the middle of the model. In the second model, two layers were displacing. Figures 3 and 4 indicated the contaminant mass area in different time intervals in the

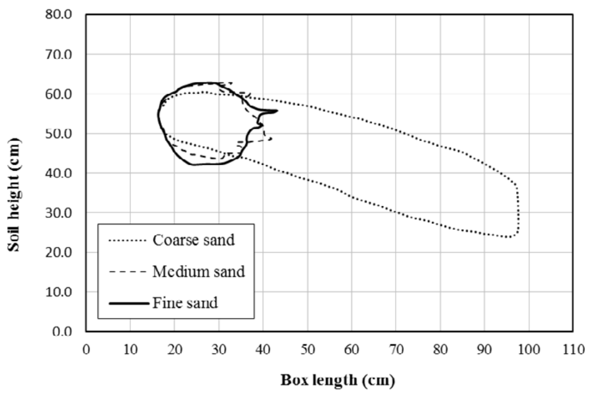

Fig. 2. The contaminant spread shapes approximately in the studied homogeneous soil specimens after 500 s

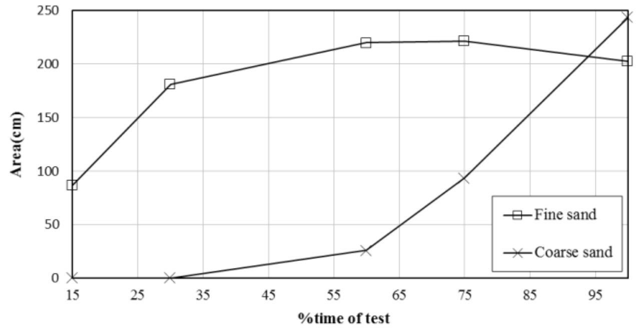

Fig. 3. The contaminant mass area at different time intervals in the first model

first and second models, respectively. The ascending trend of spreading the contaminant area can be observed in the fine-grained soil specimens as shown in Figure 3. More than 80% of the final contaminated area occurred in the fine-grained soil specimen before it entered into the coarse-grained medium. In Figure 4, only 10% of the total experimental time period was taken for the contaminants to pass through the coarse-grained medium and reach to the two-layer boundary. The remained time was assigned to the contaminant transport through the fine-grained medium over the experimental period.

4. CONCLUSIONS

The obtained results were summarized about contaminant transport in the next section.

- The contaminant was transported through the coarse-grained sand at a rate being 9.6 and 1.7 times faster than those in the fine- and medium-grained soil specimens, respectively due to high seepage velocity and subsequent advection rates. This result suggested a superior role for the advection phenomenon compared to the dispersion in this soil type.
- During the experiment, the longitudinal motion to transverse spread ratio of contaminant mass was increased over time in all three homogeneous soil specimens. This ratio is 2.1 and 1.4 times higher in the coarse-grain sandy soil specimen compared to the fine- and medium-grained sandy soil specimens.
- Advection and dispersion phenomena influence each other in two-layered media. In other words, they are influenced under the upstream and downstream boundary conditions. For instance, the downstream fine-grained layer functions as a wall resulted in a slow contaminant advection and high dispersion in an upstream coarse-grained medium. In turn, the downstream coarse-grained layer functions as a drain resulted in the high contaminant advection in an upstream fine-grained layer.

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