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"Research Note"

OIL CONTAMINATION PROPAGATION PATTERNS IN SOILS AND EFFICIENCY EVALUATION OF PUMPING IN-SITU REMEDIATION METHOD*

M. OLIAEI** AND M. HEIDARPOOR

Dept. of Civil and Environmental Eng., Tarbiat Modares University, Tehran, I. R. of Iran
Email: M.Olyaei@modares.ac.ir
Dept. of Civil and Environmental Eng., Tarbiat Modares University, Tehran, I. R. of Iran

Abstract– In recent decades, attention to contamination propagation into soils and underground water has increased, which has led to a rise in the studies on soil contamination problems and methods of in-situ remediation. In this research, effective parameters on oil contamination propagation in soils and underground water have been investigated using FEM in order to determine propagation patterns. The main parameters are soil permeability, relative density of contamination and ground water table depth. Furthermore, the efficiency of pumping method as an in-situ remediation approach for contaminated soils has been examined. The results show there are different propagation patterns in coarse and fine grain soils and the higher efficiency of dual symmetric pumping approach for in-situ remediation.

Keywords– Oil contamination, propagation pattern, pumping remediation, numerical modeling

1. INTRODUCTION

In recent decades, soil contamination with petroleum compounds has been one of the most challenging issues. In many countries with petroleum industries, mines of oil exploration, refineries, etc, for reasons such as leakage from tanks or pipelines of oil transmission due to corrosion and damage, soil will be contaminated by oil pollution. Hence, contaminant propagation in soils and also remediation of the contaminated soils has been considered as a sensitive, complex and critical environmental issue.

Gitipour et al. [1] in 2002, investigated the contamination of soils around the refineries. In 2001, Lee et al. [2] studied on the effective factors of petroleum contamination propagation in shallow sandy aquifers. Kamon et al. [3] in 2004, by laboratory and numerical models, elaborated the distribution of dense non aqueous phase liquids (DNAPL) in soils. Ehteshami and Ahmadnia [4] in 2006 investigated the leakage process of contamination by means of numerical method. Wilson et al. [5] in 2006 presented an analytical method to simulate the DNAPLs flow and their transmission in porous mediums. In 2008, Sa'adat and Safavi [6] investigated the pollution propagation during remediation of soils by dual discharge pumping method. Also, in 2008, Kartha and Srivastava [7] studied the effect of immobile water content on contaminant advection and dispersion in unsaturated porous media. In 2009, Bandilla et al. [8] introduced a new method for simulating large-scale subsurface contaminant transport to model reactive transport of contamination. Akbari et al. [9], in 2012 and Goodarznia & Esmaeilzadeh [10], in 2006 discussed the distribution of petroleum hydrocarbons contamination in soil within areas of the South Pars Gas Complex, located on the northern shore of the Persian Gulf. Two-dimensional diffusive and advective-diffusive contaminant transport through clay and silt was investigated by Badv and Jafari, in 2013 [11].

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**Corresponding author

Hasheminejad et al. [12], in 2013 studied adsorption of petroleum compounds on four types of sawdust (Walnut, Poplar, Beech and Pine) for synthetic contaminated water with gasoline.

According to the literature, it is clear that further study on petroleum contamination propagation pattern in soils and underground water is needed considering geotechnical aspects.

2. MECHANISMS OF POLLUTION PROPAGATION

Effective factors in the process of contamination release in the soil include two major processes consisting of transport process (sometimes called, advective-dispersive process) and attenuation process. Because of the importance of the transport process, the main parameters of this process have been investigated in this paper.

Two main parameters in pollution transport phenomena are pollution shift between two points (advection) and dissipation of pollution during the transport process (dispersion).

In this research, using the general differential equation of pollution propagation and the finite element method used in CTran package of Geo-studio software [13], numerical modeling was done and the problem of oil pollution has been investigated.

3. NUMERICAL MODELING AND MATERIAL PARAMETERS

In this research, to investigate the efficiency of pumping method for in-situ remediation, a soil medium with depth of 30m and length of 60m consisting of specified factors of permeability, diffusion and dispersivities, which are the most effective advection-dispersion parameters, is modeled. Then, different conditions of remediation by pumping mechanism have been investigated.

The contaminant source is located at the top of the soil surface and central line of the model. The software solves the problem of oil pollution emission, with combination of both packages of CTran and Seep simultaneously. After creating the model, material parameters will be defined. Different material parameters considered in the models are given in Table 1.

Table 1. Material parameters in numerical models

Parameter	Unit	Value
Soil permeability	m/s	1e-2 ~1e-8
Inlet flow of pollutant	m^3/s	1e-5
time	day	1~365
Longitudinal dispersivity [13]	m	4.5
Transversal dispersivity [13]	m	2
Diffusion coefficient [14]	m^2/s	1e-7
Ground water table depth	m	7.5, 15, 22.5
Pollutant relative density	-	0.9,1.2

Soil permeability: 1e-2 ~1e-4 (Coarse soils), 1e-6 ~1e-8 (Fine soils)

4. VERIFICATION

In this section, the DNAPL migration process was numerically investigated compared with an experimental and numerical research that was done by Kamon et al. [3] in a laboratory-scale tank. The results of CTran modeling showed better correlations with the results of experiments in comparison with the presented numerical method by Kamon et al.

5. NUMERICAL RESULTS

In this section, in the first part, oil contamination propagation patterns in soils under different conditions of soil and contaminant are investigated by a comprehensive sensitivity analysis. Then, in the second part, the efficiency of pumping method as an in-situ remediation approach for contaminated soils has been examined.

a) Contamination propagation pattern

For the evaluation of contamination propagation pattern, two main parameters are selected as depth of contaminant penetration in soil (D) and contaminant spreading on the soil surface (L), as shown in Fig. 1.

1. Soil permeability: In the first step, effect of soil permeability on the pattern of contamination release has been evaluated (Figs. 2 to 5).

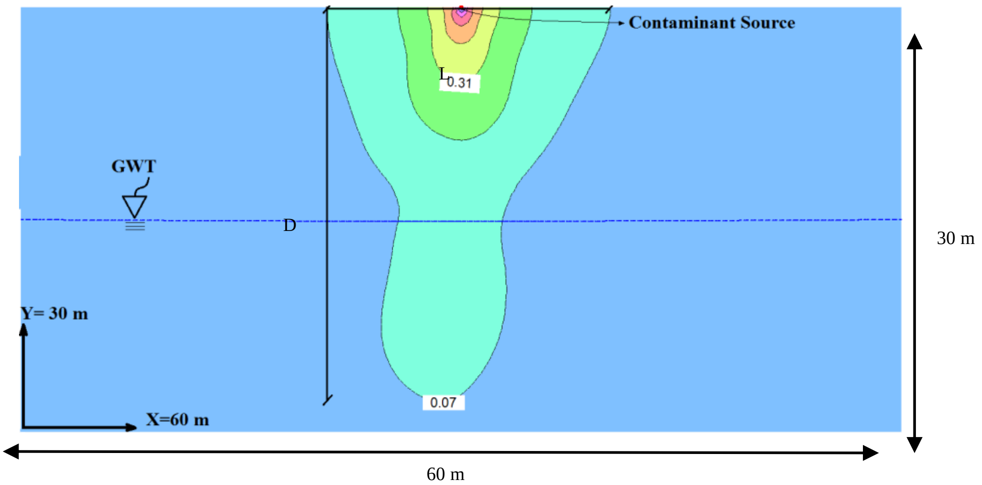

Fig. 1. Oil contamination propagation pattern

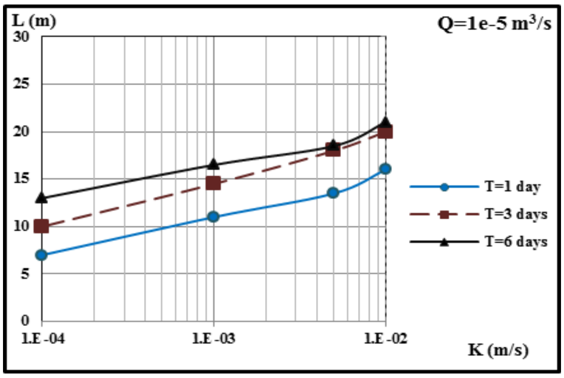

Fig. 2. Variations of contamination extent vs. soil permeability (coarse soil)

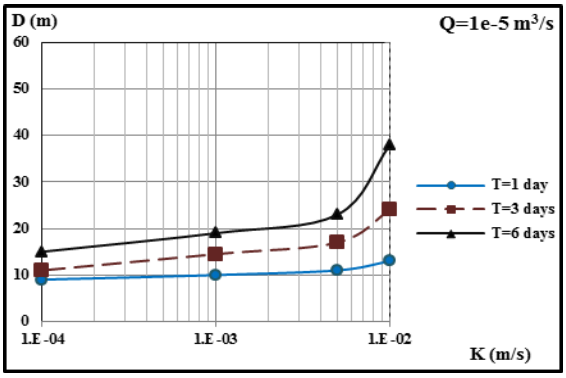

Fig. 3. Variations of contamination depth vs. soil permeability (coarse soil)

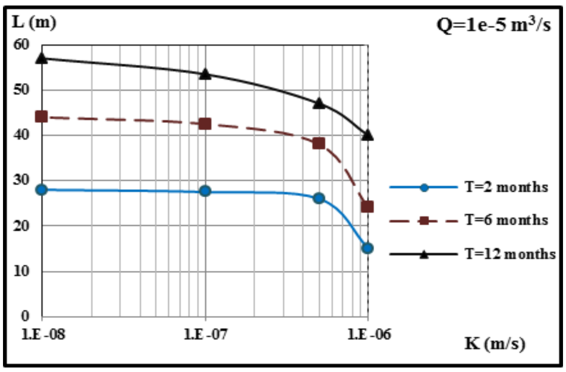

Fig. 4. Variations of contamination extent vs. soil permeability (fine soil)

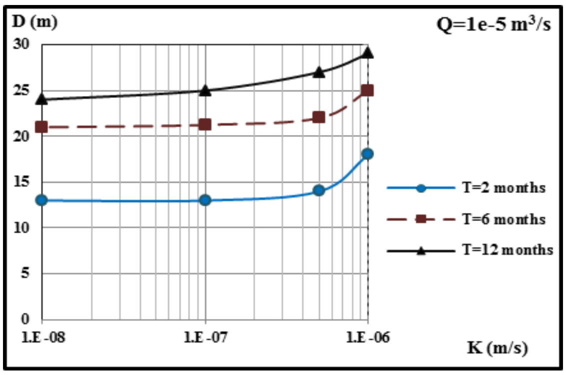

Fig. 5. Variations of contamination depth vs. soil permeability (fine soil)

It is concluded from Figs. 2 and 3, for gravelly soils the effect of gravity acceleration is dominant on the penetration depth and the propagation flow is turbulent. In other words, in gravelly soils, D > L and therefore downward propagation pattern is dominant.

As shown in Figs. 4 and 5, in fine soils, for $K<5*10^{-7}$m/s which corresponds to clays, the variations of L and D versus K is relatively linear which shows the propagation flow is laminar. It also shows L > D. Hence, in clayey soils, lateral propagation pattern is dominant.

However, for $K>5*10^{-7}$m/s and $K<1*10^{-6}$m/s (Figs. 4 and 5), which corresponds to silts, the value of D is increasing in nonlinear form versus increasing K, while the value of L is decreasing. In other words, in silty soils it is shown that the propagation pattern is switching (transferring) to downward propagation pattern which is dominant in coarse soils.

2. Ground water table depth & relative density of contamination: In this part, the results of sensitivity analysis for ground water table depth variations are presented. For this purpose, different ground water table depths of 7.5, 15 and 22.5 meters have been selected considering two different relative densities of 0.9 and 1.2 for contaminant, as LNAPL and DNAPL, respectively.

In this section (5.1.2), L is maximum lateral extension of contamination. Based on the results, it corresponds to contamination extent at the ground water level for LNAPLs and contamination extent underground water level for DNAPLs.

As shown in Figs. 6 and 7, when LNAPL contamination (ρ=0.9) encounters ground water table, because of change in environment properties and filling the porosities with denser liquid (water with ρ=1), LNAPL acts like a liquid which faces a barrier. Hence, in such a case, it propagates on ground water table and by considering decreasing the ground water table depth, the propagation extent will be increased.

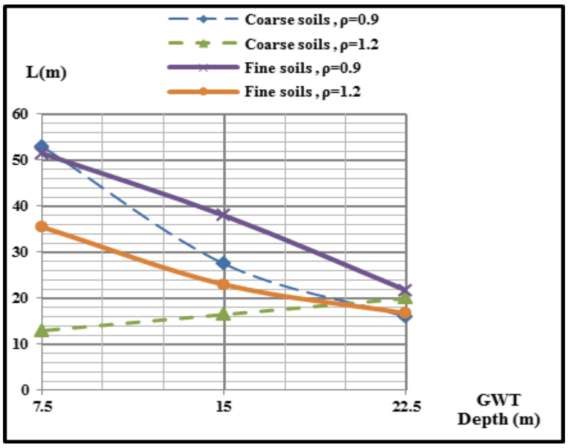

Fig. 6. Variations of contamination extent vs. GWT depth

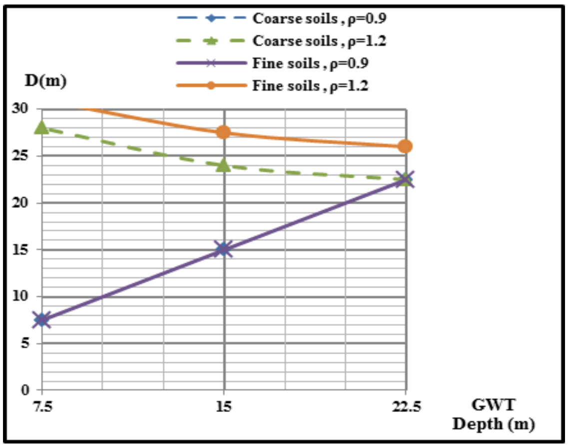

Fig. 7. Variations of contamination depth vs. GWT depth

But for DNAPL contamination (ρ=1.2), contamination will face a lighter liquid (water with ρ=1), and therefore its penetration in soil depth will be increased, especially when the ground water table comes up. In such a case, variations of contamination extent follow the propagation pattern based on the soil type. In other words, the higher ground water level makes a greater extent of contamination in fine grained soils and less in coarse grained soils.

b) Efficiency of in-situ remediation (Pumping method)

The most important point in using the pumps for remediation of hydrocarbon contaminated sites is the efficiency or workability of the pump(s). Therefore, different scenarios of using the pumps with the same total value of suction, but different positions have been considered in this research. The different scenarios are as follow:

- 2 symmetric pumps at GWT (depth=15 m)
- 1 centric pump at GWT (depth=15 m)
- 1 centric pump between GWT and ground surface (Depth=7.5 m)
- 1 eccentric pump at GWT (depth=15 m)

For modeling, the relative density of contamination is selected 0.9 as LNAPL. After modeling, the remediated area is calculated (Fig. 8). Finally, the remediated areas for different approaches are compared and the most effective scenarios for in-situ remediation of the contaminated soil are evaluated (Fig. 9).

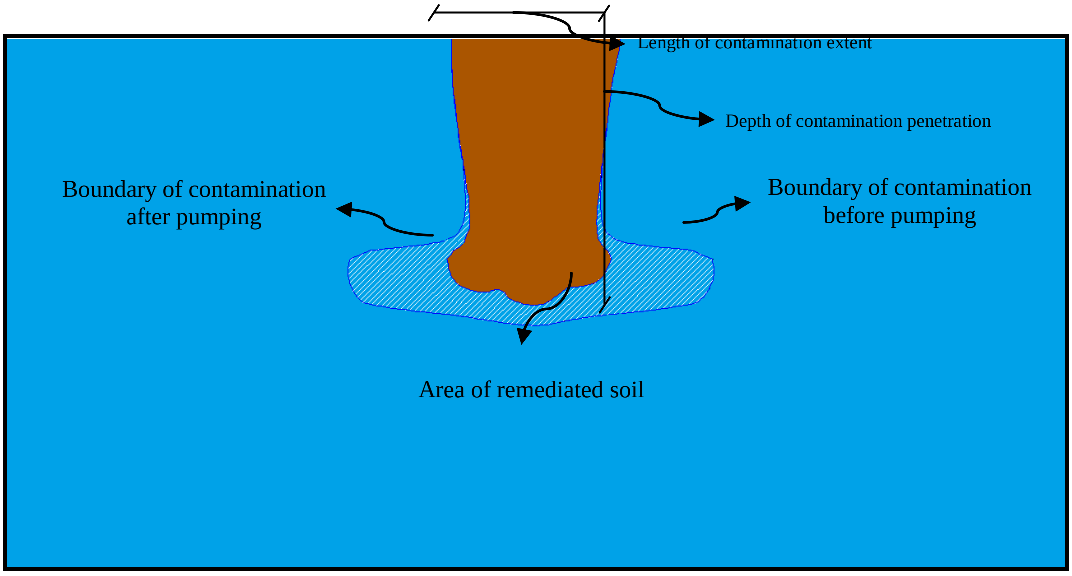

Fig. 8. Propagation pattern of oil pollution before and after in-situ remediation by pump

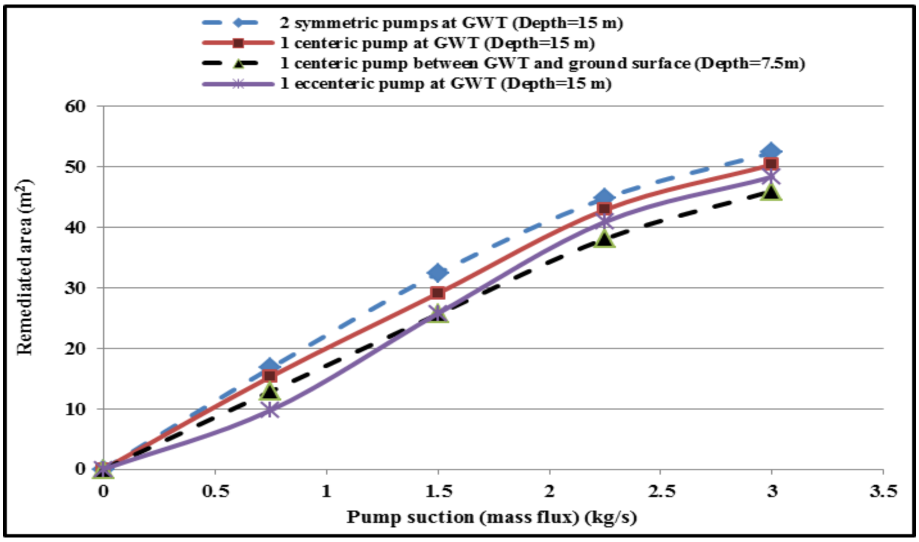

Fig. 9. Performance of different pumping scenarios

It is shown from Fig. 9, the 2 symmetric pumps have the best efficiency of in-situ remediation. It is related to uniform suction pattern of 2 pumps scenario and lower velocities of contaminant flows around 2 pumps suction points rather than to other approaches.

6. CONCLUSION

The most important conclusions are as follow:

- In coarse grain soils, downward propagation pattern and in fine grain soils lateral propagation pattern are dominant.
- When LNAPL contamination encounters ground water table, LNAPL acts like a liquid which faces a barrier. Hence, it propagates on ground water table and by considering decreasing the ground water table depth, the propagation extent will be increased.
- For DNAPL contamination, contamination will face a lighter liquid, and therefore its penetration in soil depth will be increased, especially when the ground water table comes up. In such a case, variations of contamination extent follow the propagation pattern based on the soil type.
- Comparison of different pumping remediation scenarios shows that dual symmetric pumping approach has the best efficiency of in-situ remediation.

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