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Evaluation of Oil-Water Relative Permeability Curves at A Contaminated Reservoir Condition

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A leaking oil pipeline in the Karaduvar district of the city of Mersin has caused contamination of valuable groundwater supplies. Quantities of oil have been release into the groundwater reservoir (aquifer), limiting the value of irrigation well fields. The groundwater in 0.2 km^2 (roughly 50 acres) of land is polluted. To solve the problem, first, local geology and hydrogeology of the area were evaluated and GC analysis was made. After the original identification of the problem, existing wells have been monitered and new observation holes have been excavated to further define the problem and several tests have been made. From the results of this work, the source of the pollutants was determined, the leakage was stopped, approximately 500,000 L of oil have been removed and additional contamination of the area was prevented.

Key Words: Oil pollution, Relative permeability, Karaduvar district.

INTRODUCTION

In the Karaduvar district of Mersin city, Turkey the farmers reported smelling a strong gas odour and shortly after oil was discovered in their irrigation wells. The main problem, now facing hydrogeologists and engineers, is how to adequately clean the saturated and unsaturated portions of the aquifer and the removal of the petroleum and other residues. There are six oil, four LPG filling and storage facilities in this area. These companies have several pipelines passing through many different sections of the district. Liquified gas and oil flow from container ships to the companies *via* these pipelines. The area involved is located east of Mersin city near the Mediterranean Sea and between the boundaries of city. The investigation area is situated between latitude 36º49' north and longitude 34º41' east. Mersin province has a great industrial potential for Turkey which has a population of 778,000 and a fast developing harbour city.

The investigation area is a delta plain which is collapsed and sedimented by alluvial material from the Delicay Creek and the area is called Delicay Plain. The morphology of the site is characterized by flatness and altitude are increasing towards north. The altitude of the plain from the sea level is 0-30 m. In the area, there are no significant surface water like streams, lake and springs, wet land which are wet every season. The main surface flow is Delicay Creek and it flows a few months in a year and it has only a small amount of water in winter time.

The investigation area is located in a region with a typical Mediterranean climate with rainy and mild winters, combined with dry and hot summers which is typical for the coastal zone around the Mediterranean Sea. Average annual temperature in the area is 18.6 ºC. The average annual rainfall is about 600-650 mm.

Geologically, sedimantary and metamorphic rocks are located over the region[1]. Miocene and Pliocene, in the area, lie on the Paleozoic aged formation discordantly. Both Pliocene and Miocene sequences dip towards south-southeast. The youngest units are Quaternary aged terrace deposits, alluvium and caliche deposits (Fig. 1).

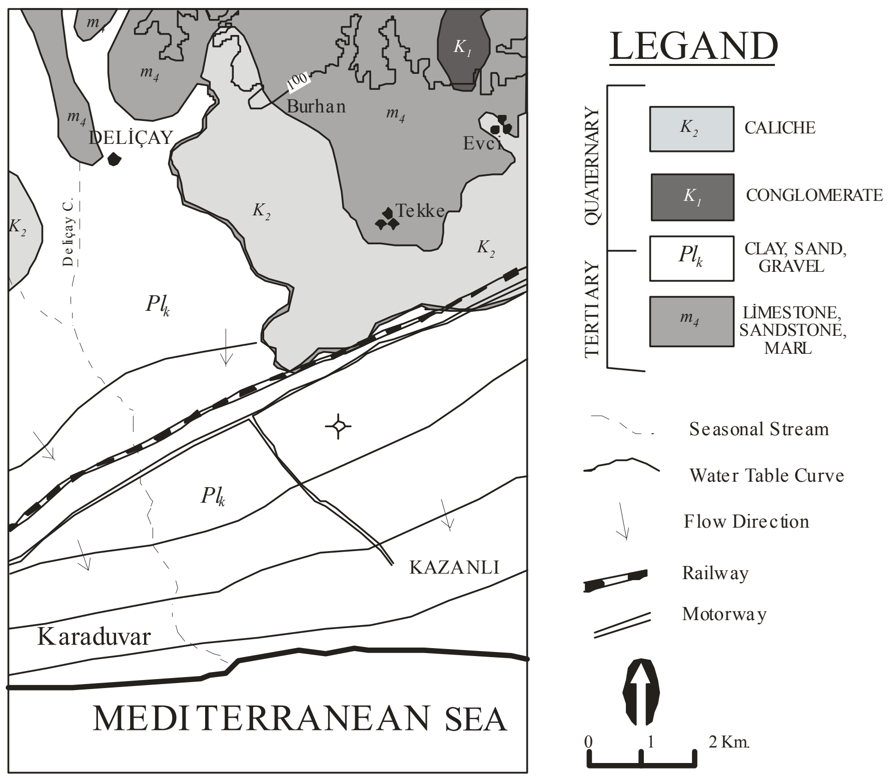

Fig. 1. Geological map of the research area [Ref. 1]

In the region, water bearing formation is Quaternary aged sand-clayey gravelly layers. Also loose structured caliche bears some water but the most productive unit for water is alluvium. Numerous wells and a few caison wells exist in the investigation area, which are used for irrigation purposes. The depth of these wells range between 15-100 m while most of wells are drilled in the alluvium aquifer and some of them penetrate the Handere formation. Static level in the wells, mostly, is in the range of 4-7 m from surface.

EXPERIMENTAL

The pressure test was determined on the buried pipeline located in the contaminated area in hopes was determined the source and quantity of any leaks. It has taken a great effort and time to define the source of contamination and to stop the leak of oil even in such a small area. Although initial tests were negative, but later test results showed possible evidence of a leak and flow from the pipeline was immediately terminated. The pumping of the nearby wells has been stopped to prevent the contamination from migration into the adjacent well sites. After the original identification of the problem, 13 existing wells have been monitered and 9 more observation holes have been excavated to further define the problem and several tests have been made (Fig. 2). Extensive testing continued in the area to further define the problem, and it was decided to concentrate on an intensive pumping program to control the lateral spread of oil. To accomplish this, the contaminated groundwater have been completely pumped out of all existing and newly drilled wells and oil contaminants have been separated from the water.

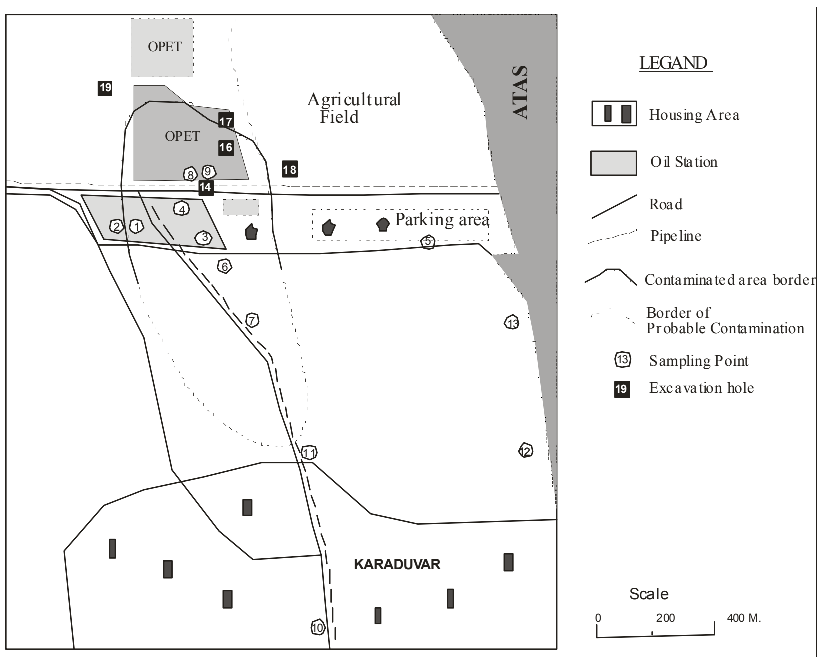

Fig. 2. Map of the contaminated area and sampling points [Ref. 2 and 3]

Remedial measures include the field work and analytical studies. The field methods involve an elaborate system of skimming pumping hole designed to clean up the groundwater and the pumping hole which has 6 m width and 7.5 m depth have been excavated. The filter materials, which are made up of 5-10 cm grain sized, around 50 cm thickness has been placed at the base of the hole. A T shaped pipe is placed on the filter material and the pipe is covered with same filter material[2]. Hence, a well which has high discharge rate was created. Every day (18,000- 20,000 L) of polluted water are exctracted from the ground and cleaned up from the oil and discharge to the sewage systems during a few months (total 500,000-600,000 L).

It is believed that the most of the oil has been removed, as many wells no longer show any amounts of oil in the test results. On the other hand, the residual petroleum might exist in the aquifer and it can not be flushed out with water. This could be explained by the relative permeability of the oil. In that case, the porous medium can contain more than one fluid and it has an effective permeability. It is important to note the requirement that the flowing fluid must completely saturate the porous medium, but this condition is seldom met under the surface of the earth. In immiscible flow, the permeability of the formation to one of these fluids is dependent on the saturation of the other fluids. The ratio of the effective permeability of the porous medium to absolute permeability of it is called relative permeability. Absolute permeability has the sense of a transport coefficient that appears in Darcy's equation for single phase flow. The effective and corresponding relative permeability functions can also be thought of as important transport coefficients for multiphase flow.

A relative permeability graph shows the relationship between the observed permeability of each fluid for various saturations to that of the observed permeability if the sample were 100 % saturated with that fluid. The relative permeability measurements are not based any actual laboratory work done in the Karaduvar district and cannot be used for quantitative evaluation of the problem. On the other hand, the relative permeability curve shows that the difference between the original oil estimate and the actual amount could be verified.

The relative permabilities for two phase flow, water and oil, have been investigated for heterogeneous sand materials. These test materials have average porosity of 25-30 %. The samples was saturated with water by means of vacuum and then an oil-water emulsion forced through the sample. The amounts of oil discharge was noticable lower during the experiment, even less for heterogeneous sand.

RESULTS AND DISCUSSION

Local geological and hydrogeological features of the investigation area were evaluated. The oldest rock unit which Paleozoic aged methamorphic rocks are composed of crystallized limestone, quartzite and schist which outcrop on the outside of the study area. This crystallized limestone has fissure and fracture and so that the formation carries water in those cracks. This metamorphic units are overlain discordantly by the Tertiary aged sedimentary rocks which are represented by Miocene formations. These are Lower-Middle Miocene aged Gildirli, Karaisali and Guvenc formations and are made up of conglomerate-sandstone, limestone and sandstone-shale. Middle-Upper Miocene aged Kuzgun and Handere formation lie over these sedimentary sequences. Kuzgun formation is formed of an alternating sandstone, conglomerate, limestone, tuff-marl and shale[1]. Miocene aged limestone bears groundwater in great amounts because of having karstic features but there are not any deep wells to drain this water in the investigation area. The white, yellowish and grey colored Handere formation covers large areas in the region. The thickness of the formation ranks between 50 and 500 m. The Handere formation is formed by four different units. These units from bottom to top are claystone-marl-siltstone, limestone, gypsum and sandstone-conglomerate[3]. The uppermost level of Handere formation carry some amounts of water and form an aquifer, but the bottom level which is formed of marl-claystone and siltstone behaviour as an aquitard. These formation are overlain by high terrace units and Early Quaternary aged shore deposits, delta deposits and fan deposits lie over them. Also the caliche depositions are situated in the area as Quaternary depositions. The white and light cream-brownish coloured caliche unit is a continental deposition which is densified at the uppermost and progressively softer towards the lower levels. Generally, the caliches are underlain by pebbles or by masses of conglomerate-like consolidated pebbles. These gravelly layers are cemented by the leakage of water of calcium carbonate concentrations from upper caliche levels. The contact is not distinguished between caliche and gravel layers and they seem to be caliche mixed with gravel. The thickness of caliche is between 3-30 m at the north of the research area. A little amount of water is obtained by the caliche deposits also.

In the investigation area, the composition of the groundwater reservoir is mostly alluvium and it is a good aquifer for the district. The nature of the depositional cycles has caused the groundwater flow to be predominantly anisotropic with higher hydraulic conductivities in the direction of alluviation. Interbedded with the sand and gravel deposits are extensive lenses of clayey-silt which forms localized barriers to vertical groundwater flow. This lithologic unit is an unconfined aquifer and static groundwater level is 4-7 m from the surface. Electrical conductivity ranges from 600-1200 μmho/cm. The groundwater flow in the direction of south-southeast, to the Mediterranean Sea. The transmissibility coefficient of the aquifer in Delicay area change between 376-6550 m^3/day/m[1].

Extensive testing and measuring continued in the area and the results of the observations are presented in Table-1. The depth of oil contamination is measured in observation holes and are presented in Table-2. As seen in the tables, most of the wells and observation holes have contamination. Actually, when the depth of contamination is measured under the ground, it includes both the depth of oil which is above the capillary fringe and the depth of oil within the fringe. In that case, the total recovered oil should be less than the estimated amounts and so, some mixture of oil and water occurs in the capillary fringe.

As the groundwater flow direction is from the north to south, the oil pollution has been spreading towards south, Mediterranean Sea. The border of contaminated area is shown in Fig. 2.

TABLE-1
RESULTS OF OBSERVATIONS [Ref. 2]

Sample No.	pH	Oil and grease (mg/L)	Total hydrocarbon (mg/L)
S1	6.68	203.5	106.1
S2	6.38	19.6	5.7
S3	6.74	50.2	43.1
S4	7.17	<10	2.0
S5	6.86	<10	<1.0
S6	6.94	<10	1.7
S7	6.83	<10	<1.0
S8	7.01	14.4	7.3
S9	7.13	28.3	5.9
S10	7.07	<10	1.5
S11	7.05	<10	<1.0
S12	7.14	<10	<1.0
S13	7.13	<10	1.0

TABLE-2
OIL CONTAMINATON LEVELS AT THE OBSERVATION HOLES [Ref. 2]

Sampling hole	Depth (m)	Groundwater depth (m)	Contamination	Contaminated level (m)
H1	3.0	-	Exist	2.80
H2	3.5	-	None	-
H3	5.0	-	Exist	4.00
H4	4.5	-	Exist	3.80
H5	6.0	5.5	Exist	4.50
H6	7.0	6.0	Exist	6.00
H7	7.0	6.0	None	-
H8	7.0	6.0	None	-
H9	5.0	5.0	None	-

The relative permabilities for two phase flow, water and oil, have been investigated to understand of flow characteristic and experimental results have been plotted in graphs (Figs. 3 and 4). As seen in the figures, there are three sections (I, II, III) which represent different flow characteristics resulting from different water saturations. Both relative permeability of water and relative permeability of oil phase curves touched to zero when 15-20 % of the pore space is still occupied by the corresponding phase. It can also be seen that at the same saturation, the relative permeability of water has a smaller value than the relative permeability of oil phase. In region I, there is flow of oil because there is a high saturation of oil. The reason is that flow requires a continuous network of channels throughout the porous system while water is discontinuous. This results in a low relative permeability to water. Since oil is the nonwetting fluid, the smaller capilleries of the aquifer will be filled with water.

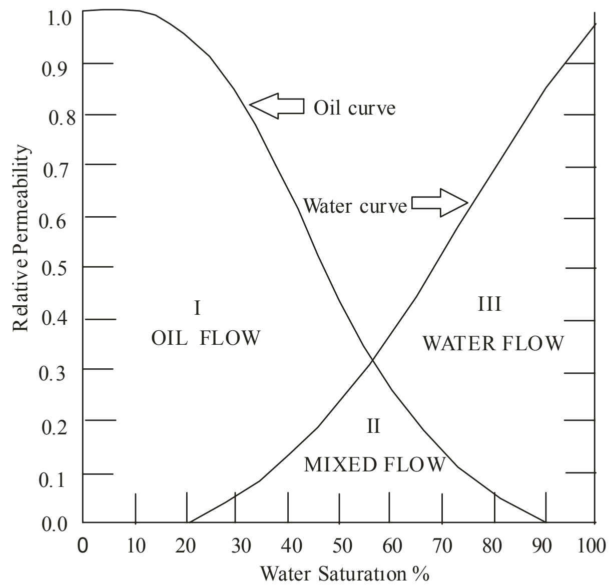

Fig. 3. Relative permeability curve for heterogeneous sand (25 % porosity)

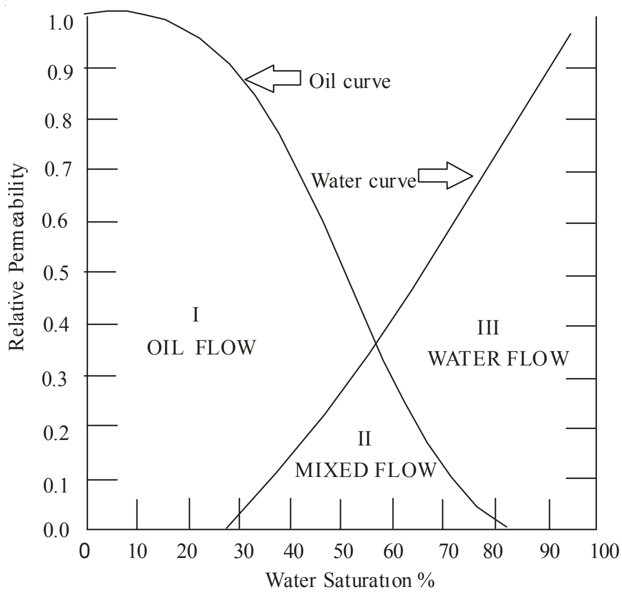

Fig. 4. Relative permeability curve for heterogeneous sand (30 % porosity)

In region II both water and oil flow continuously, even through in the different pores. These pores allow flow of both water and oil. As the saturation of water increases a larger percentage of water also flow and the relative permeability of oil (with respect of water) decreases.

In region III there is a high saturation of water and so that nearly all the fluid flow is composed of water with little or no flow of oil. The smaller capilleries are filled with oil only when the pressure drop overcomes capillary forces.

This relative permeability can be an obstacle to the removal process and to producing clean water. Because there are always be some pores which are bigger than others, it is virtually impossible to remove all the remaining oil. In the research area, if the oil saturation has been reduced to a low level, water which is pumped from the contaminated zone will be clean. Otherwise, the water will tend to flow through unblocked or contiuous water-filled pores rather than through the oil-blocked pores and the water discharge will be low due to this process.

Conclusion

A significant amount of oil spillage occured in the Karaduvar district in Mersin city and it has threatened an important groundwater supply for irrigation. The city municipality tried to terminate seepage from the pipeline and to prevent contamination of water supply. A drilling and measuring program was undertaken to define the limits and contain the spreading the oil.

In the efforts to drain off the 500000-600000 L of oil was removed. At the beginning, the amount of oil seepage was estimated higher than that amount. The difference between the estimate and actual removed could be explained by a reduction in the relative permeability of the oil. After the preventive measures were taken, most of the wells have a faint odor of oil remained. The remedial measures to eliminate the contamination in a problem of this type is very costly, but the preventive maintenance has low costs.

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