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Project Summary

Laboratory Study on the Use of Hot Water to Recover Light Oily Wastes from Sands

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This laboratory research project investigated the use of hot water to recover oily contaminants that are less dense than water, highly viscous at ambient temperatures, and essentially nonvolatile. Displacement experiments were conducted at constant temperatures in the range from 10 to 50°C, and an increase of approximately 17 to 22 percent in oil recovery was achieved. The major mechanism for the increased recovery appeared to be viscosity reduction. Transient temperature displacement experiments were also performed by placing the oil-saturated column in the incubator at 10°C and using water at 50°C to displace the oil. The oil recovery from these experiments was comparable to that found for a 40°C constant temperature waterflood. Capillary pressure-saturation curves and the displacement experiments showed that the residual water saturation increases with temperature, while the residual oil saturation decreases with temperature. Comparison of the capillary pressure for a given wetting phase saturation for different fluid pairs and for different temperatures show that the ratio of interfacial or surface tensions cannot account for changes in the capillary pressure curves as the fluids and temperatures are changed.

This Project Summary was developed by EPA's Robert S. Kerr Environmental Research Laboratory, Ada, OK 74820, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back)

Introduction

Cases of soil and groundwater contamination by organic liquids that are immiscible with water are numerous and involve many different types of organic liquids. The properties of these fluids, such as density, volatility, viscosity, and water solubility, vary significantly, and therefore different remedial techniques will be required in dealing with these different contaminants. For oils that are viscous and nonvolatile, enhanced recovery using hot water has been demonstrated in the laboratory by researchers in the petroleum industry, and this technique has been used at various field sites.

The purpose of this research project is to investigate the use of moderately hot water for the displacement of oily contaminants from the subsurface. The expectation is that the heat source will be waste heat from an industrial process, which will limit the injection temperature of the water to approximately 50°C. A literature review was conducted into the effects of porous media and fluid properties on the displacement of oil by water and the effects of heat on the displacement process. Laboratory experiments were conducted to study the effects of heat on the capillary pressure-saturation relations and displacement process, and numerical simulations were run in an attempt to model the results.

Experimental Materials and Methods

The oil phase used for these experiments was Inland 15 Vacuum Pump Fluid, and distilled water was used for the displacing fluid. The viscosity of the oil, its density, and its surface and interfacial tension were measured over the range of temperatures of interest. Two different silica sands were used for the porous media. The first sand, referred to as 20/30 sand, has a very uniform grain size distribution with all grains passing the #20 sieve but retained on the #30 sieve, making all grains in the range of 0.85 to 0.60 mm. The second sand was a mixture of three size ranges of sands, giving one third (by weight) of the grains in each of the size ranges of 0.85 to 0.50 mm, 0.50 to 0.25 mm and 0.25 to 0.106 mm. This sand is referred to as the mixed sand.

Three types of experiments were performed. Capillary pressure-saturation curves were determined for each of the sands for water-air and water-oil. The pressure-saturation relations were determined at the constant temperatures of 10 and 30°C. The other two types of experiments were constant temperature displacement experiments in the range of 10 to 50°C and transient temperature displacements where the oil-saturated column was held in an incubator at 10°C and water at 50°C was used to displace the oil. All displacement experiments were performed with one-dimensional stainless steel columns. The soil columns were initially fully saturated with water, which was displaced by oil. The oil was then displaced by water. The column effluent was collected in a fraction collector so that the fraction of oil in the effluent versus the amount of water injected could be determined. The pressure at each end of the column was measured throughout the displacements. The constant temperature displacements provided information on the flow properties of the sands and fluids at each of the temperatures, while the transient temperature experiments more closely modelled the hot water displacement that would occur in the field.

Experimental Results and Discussion

The capillary pressure-saturation curves for the water/air systems show that temperature has a significant effect on the these curves. The increase in temperature from 10 to 30°C caused a decrease of approximately 30 percent in the displacement pressure for these curves and caused an increase in the residual water saturation in the 20/30 sand. The residual saturation of the mixed sand was essentially the same at each temperature. The pressure-saturation curves measured for the water/oil systems essentially did not change over the temperature range of 10 to 30°C, other than changes in the residual water and oil saturations. Comparison of the water/air to water/oil curves for each of the sands showed that the water/oil curves were significantly different from the water/air curves. The Brooks-Corey (1964) and van Genuchten (1980) equations were fit to these curves, and using these equations the relative permeability to each phase as a function of saturation could be predicted.

The constant temperature displacement experiments showed an increase in oil recovery of about 17 to 22 percent as the temperature was increased from 10°C (which was considered ambient temperature) to 50°C. The greatest increases in oil recovery were found at breakthrough, with increases as great as 30 to 50 percent. The mixed sand always showed a greater oil recovery than the 20/30 sand. The oil saturation remaining in the column after the injection of 10 pore volumes of water was about 39 percent for the 20/30 sand at 10°C, and 30 percent at 50°C. For the mixed sand, the oil remaining after the injection of 10 pore volumes of water was 33 percent at 10°C and 23 percent at 50°C. Thus, the increased temperature reduced the oil remaining in the column by 25 to 30 percent.

These remaining oil saturations are significantly greater than the residual oil saturations found in the capillary pressure-saturation curves. Considering the water to oil ratio of the effluent at the end of the displacement experiments, an additional 16 to 20 pore volumes of water would have to be injected to reduce the oil saturation in the columns to the true residual.

Pressure measurements recorded during these displacements showed that the maximum pressure during the displacement occurred at the time of water breakthrough, i.e., as the water reached the effluent end of the column. As the temperature increased, the pressures in the column and the pressure drop along the column decreased significantly.

The transient temperature experiments were run to more closely model the displacement process that would occur in the field. Water at 50°C was used to displace oil at 10°C from the column, while the system was held in a constant temperature incubator. The temperature in the column was monitored at 4 locations along the column during the displacement. The temperature at any location remained at 10°C until the hot water front reached it, then the temperature rose quite rapidly to its equilibrium temperature. At the influent end of the column, the column reached at maximum temperature of about 37 to 39°C, and the equilibrium temperature along the column dropped off linearly along the column to about 30°C close to the effluent. Undoubtedly, the stainless steel column used for these experiments moved heat away from the sand faster than would occur in a field situation because of the significantly higher thermal diffusivity of stainless steel compared to that of silica sand. Attempts to insulate the column to reduce the heat loss increased the temperature along the column by approximately 2°C but did not appear to significantly affect oil recovery.

Despite the fact that the heat essentially did not travel in front of the hot water front, the benefits of the increased temperature were realized in terms of the oil recovery. The percent oil recovery at the time of water breakthrough was not significantly increased, but the oil recovery after water breakthrough was increased. The final oil saturation after the injection of approximately 10 pore volumes of water was similar to that achieved in the 40°C constant temperature waterfloods.

The pressure drop at the time of water breakthrough for the transient temperature displacement experiments was similar to that measured in the 10°C constant temperature displacements. After water breakthrough, the pressure drop along the column decreased quickly to a level comparable to a 40°C waterflood. Thus, the benefits of hot water in terms of the pressure required to drive the displacement process was not realized until after water breakthrough.

From the data of oil recovery versus volume of water injected for the constant temperature displacement experiments, the ratio of oil permeability to water permeability can be calculated for the range of saturations in the column between water breakthrough and the end of the displacement by the method of Welge (1952). These calculations showed that the permeability ratio at low water saturations is shifted to higher values as the temperature is increased. As the water saturation is increased beyond about 0.4 to 0.5, the ratio of permeabilities tend to merge to the same line. The relative permeability to oil and to water was also be calculated by the graphical technique developed by Jones and Roszelle (1978), which is equivalent to the technique developed by Johnson et al. (1959). The relative permeabilities calculated by this method show that the relative permeability to each phase tends to increase as the temperature increases, but the permeability ratios calculated from these individual permeabilities do not change with temperature. The permeability ratios calculated based on the method of Jones and Roszelle (1978) are significantly lower than the ratios calculated based on the method of Welge (1952). It is not possible to tell at this time which technique gives the more accurate ratios.

Simulation of Constant Temperature Experiments

Attempts were made to simulate the constant temperature displacements using the Buckley-Leverett (1941) equation for two-phase flow. Using this equation, the amount of oil recovered from the column as a function of the amount of water injected can be calculated. Input needed for the calculation is the viscosity ratio of the fluids and the relative permeability of each fluid as a function of saturation. The permeability ratios were calculated based on the methods of Welge (1952) and Jones and Roszelle (1978) and on the Brooks-Corey (1964) and van Genuchten (1980) equations fit to the capillary pressure-saturation curves. None of these permeability ratios were able to accurately simulate the oil recovery history found in the displacement experiments. Some qualitative information, however, can still be gained from these simulations. Comparison of the results of the experiments with the simulation results when permeability ratios corresponding to a 10°C displacement are used with the smaller viscosity ratios found at higher temperatures shows that the increased recovery at higher temperatures found in the laboratory displacements are greater than can be accounted for based on the decrease in viscosity ratio alone. Simulations using the permeability ratios determined at higher temperatures shows that this increase in recovery is likely due to shifts in the permeability ratios with temperature.

Conclusions

These experiments have shown that the use of hot water will increase the recovery of oils from sands over that which can be recovered using a waterflood at ambient temperatures. The increase in oil recovery found over the moderate temperature range studied here was approximately 17 to 22 percent. This reduced the residual oil saturation remaining in these sands after 10 pore volumes of water throughput by approximately 25 to 30 percent. However, even the residuals of 23 to 30 percent of the pore space found in 50°C constant temperature displacements would probably require additional treatment.

The wide range of contamination problems facing those involved in subsurface restoration will require a variety of remediation techniques in order to deal with the problems effectively and efficiently. Thermal methods such as hot water displacements of oily contaminants is one technique which should be useful in the recovery of an oily phase that is viscous and essentially nonvolatile. A major advantage of hot water is that it does not require the addition of new, potentially toxic chemicals to the subsurface.

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The complete report, entitled "Laboratory Study on the Use of Hot Water to Recover Light Oily Wastes from Sands," (Order No. PB93-167906; Cost: $19.50; subject to change) will be available only from
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