Relative Permeability for Displacement of Immiscible Two Phase Fluids flow through Porous Media

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1. Introduction

This paper evaluate the results of laboratory measurements of relative permeability at two phase flow of oil and water, through sandstone sample. The relative permeability value is measured through laboratory experiments by steady-state (SS) methods or unsteady-state (USS) methods. The relative permeability is affected by many factors including fluid saturations, saturation history, magnitude of initial-phase saturation S_{wi}, wettability, the effect of rock pore structure and temperature so on.[1)] Thus, relative permeabilites are the result of normalizing effective permeability values by absolute permeability:[2)]

$$k_r = \frac{K_e}{K} \qquad (1)$$

k_r is the relative permeability (dimensionless)

K_e effective permeability (D, mD)

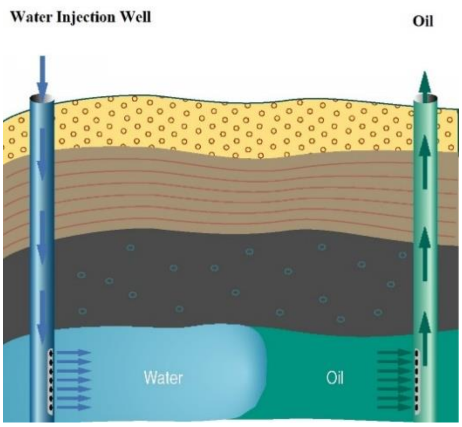

Fig. 1 Displacement of oil by water in petroleum reservoir [5)]

2. Experiments procedure

The apparatus is a very simple piping diagram. The rigs that used in this experiment are acrylic pipe, caps, tubing pump, glass beads and pressure gauge.

The relative permeability tests were conducted in sandstone, which is chosen as a porous medium. Table 1 shows the properties of oil and water used in this experiments. The procedure for the measurement of relative permeability in this experiment is injected immiscible fluids (water and oil) at unsteady-state into the vertical column of sandstone. The acrylic pipe (cell) was filled with a known weight of the selected grain size of sandstone. Injection of a second phase, which was oil, started at a low rate and flow of the first phase was reduced slightly. This procedure maintained the differential pressure across the system at a constant level. After the first reading, the rate of flow of the first phase was decreased slightly and the flow rate of oil was increased simultaneously to maintain the pressure differential across the sample at its previous value. When the system reached a constant level, flow rates and pressure differential were recorded.

Table 1. Physical properties of oils and water

Properties	Kerosene	Water
Density $\rho({}^{g}/_{cm^3})$	0.795	1.00
Viscosity $\mu(Pa \times s)$	0.00242	0.001

3. Result and Discussion

The relative permeability curves are plotted with wetting-fluid saturation, ranging from the irreducible wetting-phase saturation to the residual oil saturation. As the wetting fluid saturation increases, the relative permeability of oil, k_{ro}, gradually decreases with desaturation of oil, and inversely the relative permeability of water gradually increases and reaches to its maximum value k_{rws} (end-point water permeability) at which time k_{ro} is 0 because water is the only phase that is mobile and at its maximum saturation.[4)]

Petroleum reservoir, Two-phase flow, Immiscible displacement, Relative permeability, Porous media
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The flow rate of oil and water through completely saturated porous medium in horizontal is given by Darcy's law as flow:

$$q_o = -\frac{k_z k_{ro} A}{\mu_o}\frac{\partial p_o}{\partial z} \quad , \quad q_w = -\frac{k_z k_{rw} A}{\mu_w}\frac{\partial p_w}{\partial z} \qquad (2\&3)$$

$$q_w = -\frac{k_z k_{rw} A}{\mu_w}\frac{\partial (p_o - p_{o/w})}{\partial z} \qquad (4)$$

Here, k_z is the intrinsic permeability of the medium, A *is* the cross-sectional area for permeation, and are the dynamic viscosity of oil and water, p_o and p_w are the pore pressure of oil and water, and k_{ro} and k_{rw} are the relative permeabilities of oil and water respectively.

The pressure difference at the contact surface between oil and water (i.e., capillary pressure) is denoted by p_o/w, and p_w. The fraction of pore water flow (i.e., fractional flow rate) f_w is expressed as:

$$f_w = \frac{q_w}{q_T} = \frac{1+\dfrac{k_z k_{ro} A}{q_T \mu_o}\dfrac{\partial p_{o/w}}{\partial z}}{1+\dfrac{k_{ro}}{k_{rw}}\dfrac{\mu_w}{\mu_o}} \qquad f_w = \frac{1}{1+\dfrac{k_{ro}}{k_{rw}}\dfrac{\mu_w}{\mu_o}}$$

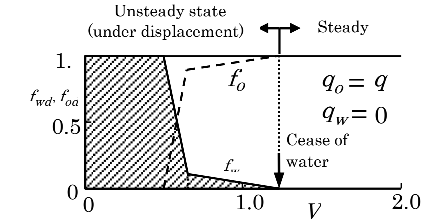

Fig. 2 Discharge of oil at maximum rate.

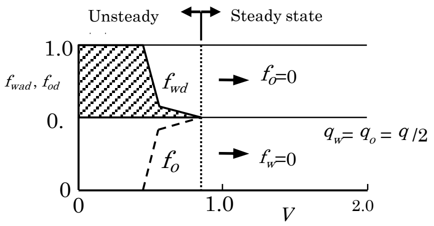

Fig. 3 Discharge of oil and water at 0.5% rate.

As water is injected into the sandstone sample, it displaces the oil increasing the saturation of the former and decreasing the saturation of the latter respectively.[4)]

Fig. 2 shows irreducible water saturation, S_{wi}, the oil discharge is equal to total discharge of fluid and water discharge is equal to zero. In the case of rate 0.5% oil and water, the discharge of oil and water is indicated in fig. 3.

The relative permeability k_{ro} and k_{rw} are generally given as a function of water saturation S_w as shown in Fig. 4, where S_{wi} and S_{or} are the irreducible water saturation and the residual oil saturation in the reservoir.

Table 2. The experimental data used in analysis.

S_w	k_{ro}	k_{rw}	$f_w = [1+\frac{k_{ro}}{k_{rw}}]^{-1}$	$f_w' = df_w/dS_w$
0.16	0.900	0.000	0.000	0.003
0.20	0.742	0.000	0.000	0.036
0.25	0.571	0.001	0.002	0.154
0.30	0.429	0.004	0.010	0.454
0.35	0.313	0.010	0.032	1.104
0.40	0.220	0.021	0.088	2.284
0.45	0.147	0.037	0.202	3.821
0.50	0.093	0.060	0.393	4.701
0.55	0.054	0.091	0.628	3.954
0.60	0.027	0.130	0.826	2.276
0.65	0.012	0.180	0.939	0.948
0.70	0.003	0.240	0.987	0.238
0.75	0.000	0.313	0.999	0.027
0.80	0.000	0.400	1.000	

Irreducible water saturation $S_{wi} = 0.16$
Residual oil saturation $S_{or} = 0.20$

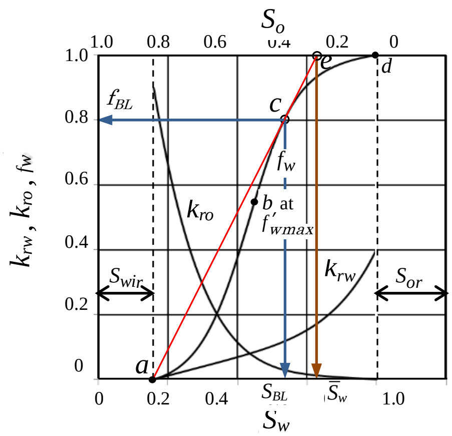

Fig. 2 Relative permeability and fractional flow rate curves[6)].

4. Conclusion

1) Relative permeability has an insignificant effect on the progress of saturation front, as determined by changing the end-point value for water permeability.

2) Relative permeability data are usually plotted as relative permeability-saturation curves. The saturation on the x-axis typically ranges from the irreducible wetting- phase saturation to the residual oil saturation.

References:

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3) CO2-Based Enhanced Oil Recovery, University of North Dakota, 2012, www.egcfe.ewg.apec.org.