Measurement of Relative Permeability of Oil and Water and Application to Waterflooding Technique in Petroleum Reservoir

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1. Introduction

In petroleum reservoir engineering, a technique of injecting water into oil reservoir has been used in order to maintain oil production rates during the pumping operation (Fig.1). The method is known as the waterflooding technique, which provides high oil production rates and high degree of petroleum recovery when oil production rates deteriorate. When water is injected into reservoir, oil is displaced toward production well in the situation of two-phase flow. The Buckley and leverett frontal displacement theory[1)] described a method for calculating saturation profiles of oil and water in porous media.

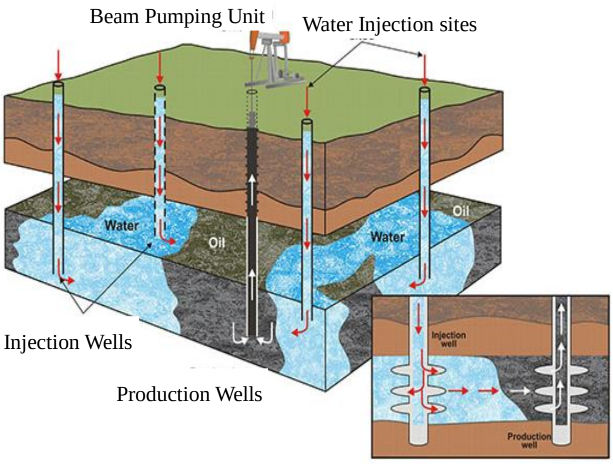

Fig.1 Water-flooding method for oil production[2)].

The relative permeability of oil and water are the most important parameters for performing watreflooding technique. In this paper, using the experimentally determined relative permeability data, the waterflooding is analysed quantitatively based of the Buckley-Leverett analysis.

2. Relative permeability

Relative permeabilities of Kerosene and water for standard and was measured in the laboratory by steady state method[3)]. The sand was packed in a column and initially saturated by Kerosene ($\rho_k = 0.795\ g/cm^3$ $\mu_k = 0.00242\ Pa \cdot s$).Then, water ($\rho_w = 1.00\ g/cm^3$ $\mu_w = 0.001\ Pa \cdot s$) and Kerosene were pumped with different amount of rates from the bottom using tubing pumps. Table1 and Fig.1 show the relative permeabilities obtained from the experiment. The fractional flow rate f_w and its derivatives $f_w^{\prime}$ are computed by,

$$f_w = \left[1 + \frac{k_{ro}}{k_{rw}}\frac{\mu_w}{\mu_o}\right]^{-1} \quad (1) \qquad f_w^{\prime} = \frac{df_w}{dS_w} \quad (2)$$

Table1 Relative Permeability and Fractional Flow.

S_w	k_{rw}	k_{ro}	f_w	$f_w^{\prime}$
0.17	0	1	0	
				0.004
0.2	0.000037	0.8864	0.000102	
				0.213
0.3	0.00465	0.578	0.021436	
				1.760
0.4	0.02713	0.2691	0.197361	
				4.340
0.5	0.08178	0.1163	0.631593	
				2.930
0.6	0.18288	0.0361	0.924995	
				0.006
0.7	0.34473	0.0051	0.993855	
				0.000
0.8	0.58163	0	0.999997	
				0.000
0.815	0.61	0	1	

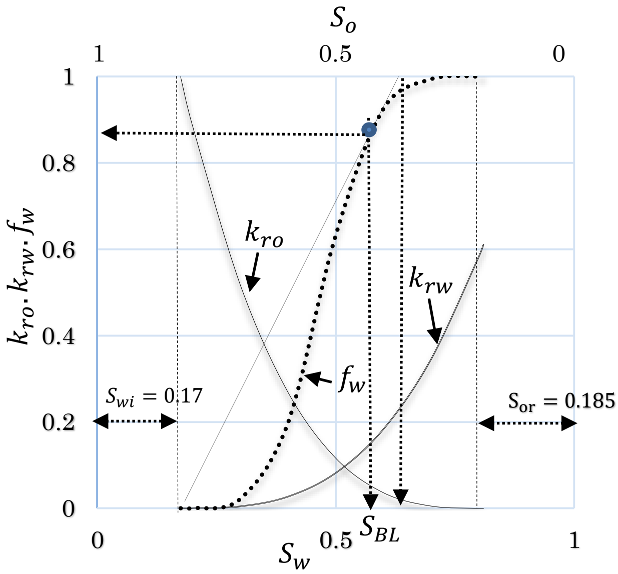

Fig.1 Relative permeability curves.

3. Buckley-Leverett Analysis

In the first, the Buckley-Leverett frontal displacement theory is reviewed, and an example of the analysis is presented. The flow rate of oil and water through completely saturated porous medium in horizontal direction is given by the Darcy's law as follows.

$$Q_o = -\frac{k_x k_{ro} A}{\mu_o}\frac{\partial p_o}{\partial x}, \quad Q_w = -\frac{k_x k_{rw} A}{\mu_w}\frac{\partial p_w}{\partial x} \qquad (3)(4)$$

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

The relative permeability k_{ro} and k_{rw} are given as a function of water saturation S_w as shown in Fig.2.

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Subtracting Eq. (3) from Eq. (4) and substituting the relation of $Q_o = Q_T - Q_w$, it becomes

$$Q_T = Q_w\left(1+\frac{k_{ro}}{k_{rw}}\frac{\mu_w}{\mu_o}\right)-\frac{k_x k_{ro} A}{\mu_o}\frac{\partial p_{o/w}}{\partial x} \quad (5)$$

where $p_{o/w} = p_w - p_o$ is the capillary pressure between oil and water. If the effect of capillary pressure is neglected, the fraction of pore water flow, i.e., fractional flow rate f_w, is expressed as

$$f_w = \frac{1}{1+\frac{k_{ro}}{k_{rw}}\frac{\mu_w}{\mu_o}} \quad (6)$$

Next, continuity equation of pore water is expressed as

$$-\frac{\partial Q_w}{\partial x} = A\phi\frac{\partial S_w}{\partial t} \quad (7)$$

where $\emptyset$ is the porosity of the reservoir. Using the relations of $Q_W = f_W Q_T$ and f_W (S_W), Eq. (7) is rewritten as

$$\left(\frac{\partial S_w}{\partial t}\right)_x = -\frac{Q_T}{A\phi}\left(\frac{df_w}{dS_w}\frac{\partial S_w}{\partial x}\right)_t \quad (8)$$

The main and very fruitful idea of Buckley and Leverett is to transform Eq. (8) into the following form:

$$\left(\frac{\partial x}{\partial t}\right)_{S_w} = \frac{Q_T}{A\phi}\left(\frac{df_w}{dS_w}\right)_t \quad (9)$$

Sting that the rate of advance of a plane of fixed saturation S_W is proportional to the rate of change in composition of the flowing stream with saturation. Eq. (9) can be integrated to give the position of a particular saturation as a function of time.

$$x_{S_w} = \frac{Q_T t}{A\phi}\left(\frac{df_w}{dS_w}\right) \quad (10)$$

4. Oil Displacement

As a quantitative demonstration for the Backley-Leverett analysis, relative permeability data shown in Table1, which was obtained in the laboratory experiments, is used.

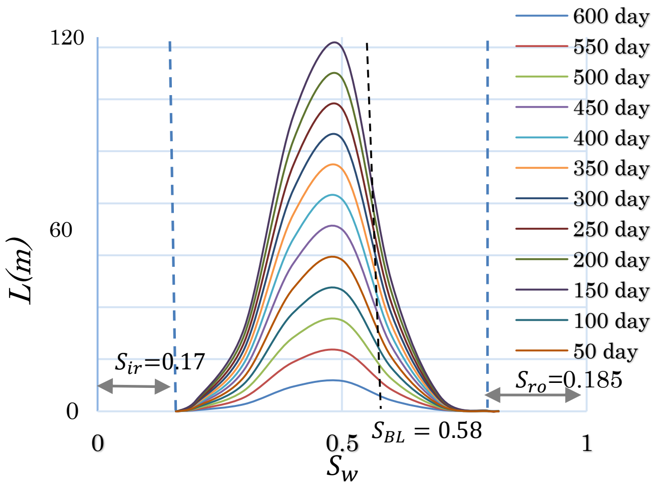

Fig.3 Oil displacement by water until t = 600 days.

For a situation of the reservoir porosity $\emptyset = 0.18$, cross-sectional area for permeation A = 250 m^2, reservoir length L = 120 m, and the amount of water injected into reservoir $Q_T = Q_W = 20$ m^3/day, the calculated results of saturation profile is shown in Fig.4. It is seen from figure four, that the saturation front progress with a constant speed toward outlet, however a considerable amount of oil still remains in the reservoir.

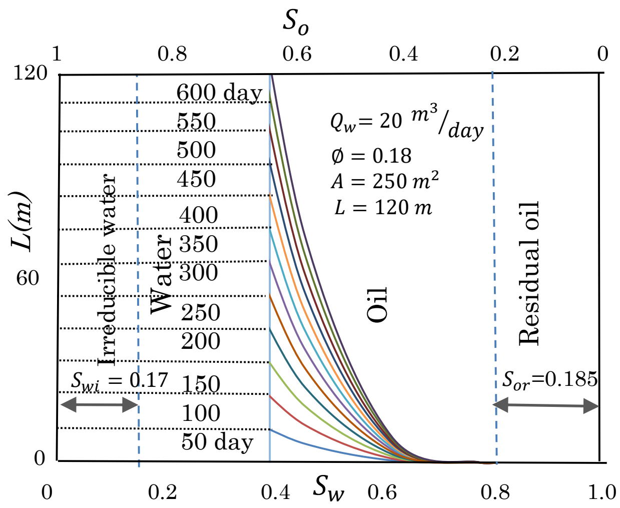

Fig.4. Calculated results of saturation profile by Buckley-Leverett analysis.

The result reveals that as the inject water displaces pore oil toward upward and produce oil from the reservoir. The position of the water front advances, with constant speed because the same amount of water has been injected.

The effect and behavior of relative permeability of oil and water is shown in Fig.2. The water is wetting phase and oil is non-wetting phase. Calculated result by water-flooding technique under the same reservoir condition with the Buckley-Leverett analysis is shown in Fig.4. We can obtain the saturation profile and can provides useful information for the water-flooding operation in petroleum production technology.

References

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