CAPILLARY PRESSURE-SATURATION RELATIONSHIP IN POROUS MEDIA INCLUDING WATER, LNAPL AND ETHANOL

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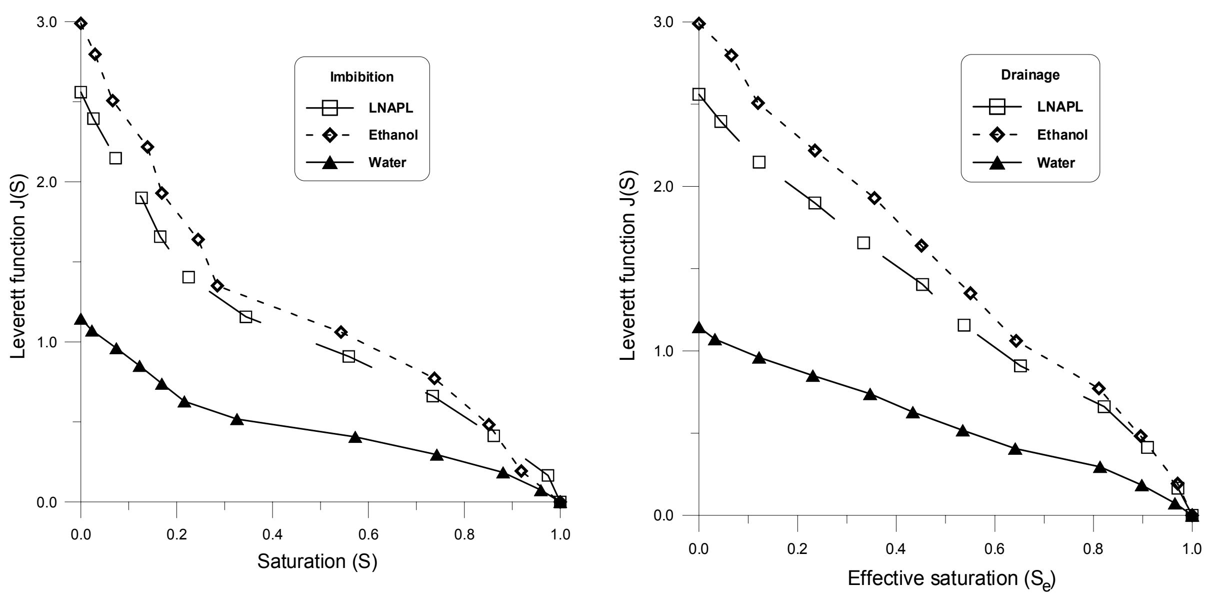
Porous media are encountered literally in every day life, in technology, and in nature. Numerous investigations from a broad range of technical fields have been undertaken to describe and model accurately the phenomena of immiscible, multiphase flow through a porous medium. Capillary pressure is a basic parameter in the study of the behavior of porous media containing two or more immiscible fluid phases. It relates the pressures in the two fluid phases[1]. The capillary pressure in a porous medium is an increasing function of the non-wetting phase saturation or, alternately, a decreasing function of the wetting phase saturation. Two-phase flow models of subsurface transport often require the constitutive relationship of capillary pressure as a function of saturation[2]. Leverett defined a reduced capillary function, which contains the parameters such as permeability, porosity, contact angle, surface tension and used for correlating capillary pressure data[1]. The permeability of the porous medium can be measured or can be calculated by using empirical equations such as Carman-Ergun equation[3].

In this study, a functional relationship (according to the Leverett concept) between capillary pressure and wetting phase saturation is presented. For all sets of experiments, C778 Ottawa sand (20-30 mesh) (US Silica Company, Ottawa, Illinois) was used as a porous medium. The three liquids used in these experiments were distilled water, ethanol (97% purity) and toluene (LNAPL, 99% purity. In the conducted experiments, a 50cm long vertical glass column having an inner diameter of 9.3cm was used for the silica sand. The height of the sand in the column was 46cm from the mesh screen, and it was exceedingly sufficient to allow the saturation profiles fully develop. A polyethylene reservoir providing a constant liquid level was connected to the bottom of the column. This liquid reservoir was lowered and raised to control the capillary pressure and saturation within the sand column during the courses of experiments. A gamma attenuation system was used to determine local saturation and the porosity of the sand. It consists of a NaI(Tl) scintillation detector and gamma source both encased in lead. 1.74×10^{6} Bq ^{60}Co (1332 keV) was used as the gamma source. The radiation source and the detector for gamma attenuation measurements were mounted on vertical plate, which could be moved along the column axis in the vertical direction[4].

Experiments were performed to develop capillary pressure-saturation profiles for all the primary imbibition of a liquid into a dry porous medium, the primary drainage of a liquid from an initially saturated porous medium. For all the primary imbibition experiments, the saturation profile was achieved by starting with an initially dry packed column. After packing the column as uniformly as possible with sand, the gamma ray transmission measurements were taken for dry sand at 20 locations spaced 1.5cm. The free liquid level within the reservoir was set to be 15cm above the mesh screen. The height of this level was used as the zero reference (at which the capillary pressure is defined to be zero), and no measurements were taken below this level. Then reservoir valve was opened, allowing the liquid to enter the column form the screen and be imbibed upward into the packed column. The liquid level in the column is immediately the same as in the reservoir. The liquid reservoir was the slowly raised from h=15cm at a rate of 4cm/h until the liquid was ponded on top of the sand. Thus the liquid reservoir was used to control the capillary pressure in the sand column. When, during each step, static equilibrium had been reached after a change in liquid level, liquid saturations were measured periodically with gamma transmission system. For the primary drainage experiments, the saturation profile was achieved by starting with fully saturated sand packed column with liquid. Therefore, the column was prepared so that a few centimeters of liquid rested on top of the saturated sand. Then, the liquid reservoir was slowly lowered at a rate of 4cm/h in all experiments (or for all liquids) to lower the liquid saturation in column. The liquid level in the reservoir was lowered until it was 15cm above the mesh screen. This allowed the bottom of the sand column to remain liquid-saturated throughout the entire experiments. During this period, the liquid saturation measurements were obtained with the gamma transmission system at the same locations as used during the primary imbibition.

CONCLUSION

The primary imbibition and effective (drainage) saturation data against the Leverett function for all the three liquids are presented in Figure 1. In Figure 1, when each of the three liquids are considered separately, Leverett function works very well in describing the relationship between capillary pressure and saturation.



(a) (b)

Figure 1. Capillary pressure function-saturation relations for three liquids (a) imbibition, (b) drainage.

However, when the Leverett function for all the three liquids are compared, a considerable difference is obviously noticed as seen in Figure 1. It has been postulated here that this difference is a result of the differences in contact angles of the three liquids. In this study, a contact angle dependence term into the Leverett function has also been used for reducing the data in Figure 1 to a common curve. The contact angle is not definite and may have any value between two extremes, depending on whether the liquid is tending to advance over a dry surface or recede from a previously wetted one. A rather serious problem in conjunction with the concept of contact angle is the fact that the advancing contact angle is often found to be significantly larger than the receding one[1]. In this study, both the dry surface (Advancing) and the wetted surface (Receding) contact angles were determined by experimentally for the three liquids.

The Leverett function have been modified for the imbibition and drainage saturation data of the three liquids as follows:

$$MJ(S) = \frac{J(S)}{(\cos^a \varphi\ )^b} \qquad 0 \leq S \leq 1$$

where φ is the advancing contact angle for imbibition and receding contact angle for drainage, a and b are the best-fit parameters; a=2.67 and b=1 for imbibition and a=2.67 and b=4.42 for drainage. Modified capillary pressure function for imbibition and effective (drainage) saturation for three liquids is given in Figure 2. This figure clearly illustrates that the correlation provides a very accurate relationship between capillary pressure and saturation for various liquids.

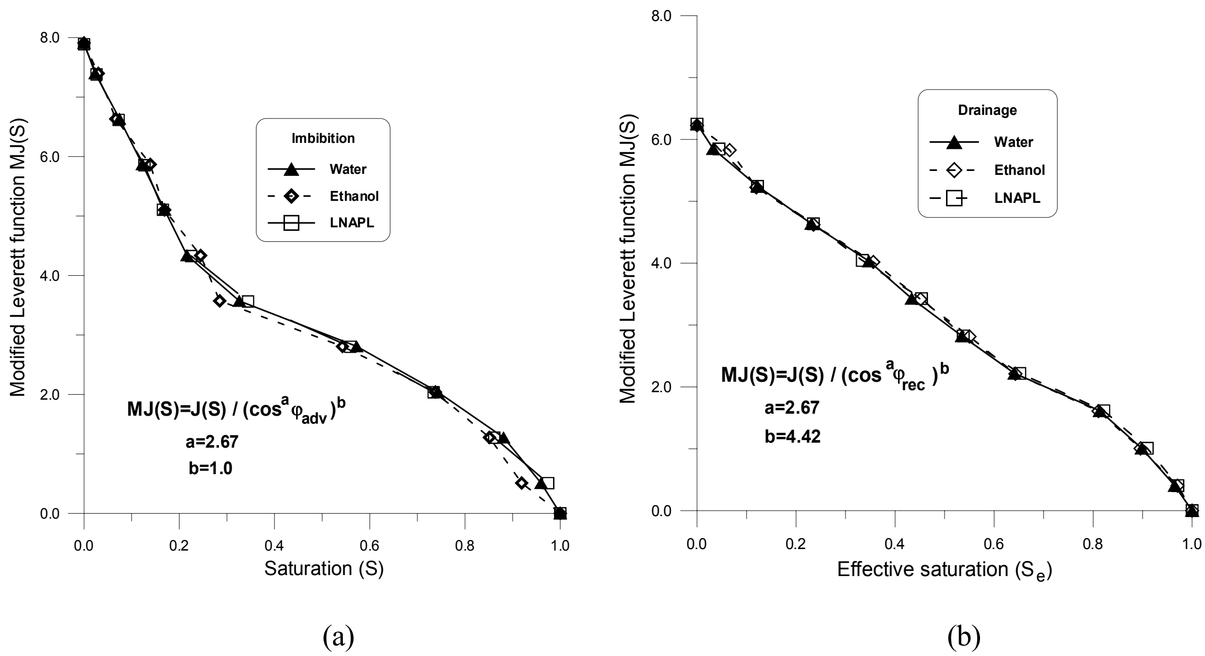


Figure 2. Modified capillary pressure function-saturation relations for three liquids (a) imbibition, (b) drainage.

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