Implementation of Brooks and Corey Correlation in Water Wet Case - With Immobile Wetting Phase

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Brooks and Corey[1] developed a correlation to estimate the capillary pressure for drainage processes, which utilizes the concept of effective saturation to generate data. This effective saturation in the correlation is calculated, primarily based on the change in wetting phase saturation and can be used quite effectively for the respective purposes. However, there are cases, in which the wetting phase saturation remains constant throughout the displacement process. For such cases, a modification has been made for better representation and to use Brooks and Corey correlation for capillary pressure estimation under such cases. This modification will result into better analysis, which will result into better reservoir monitoring and surveillance.

Key words: capillary pressure, estimation, prediction, wetting

1. Introduction

Brooks and Corey1 developed an empirical correlation to estimate the capillary pressure for the drainage process, which is based on the concept of utilizing threshold hold pressure and effective wetting phase saturation. Mathematically,

$$P_c(S_e) = p_d S_e^{\frac{1}{\lambda}} \qquad (1)$$

where, threshold pressure P_d, is the pressure at which the displacement of one fluid by another will start. In addition to the type of fluid involved, it depends on the largest pore open to flow for initiating a displacement process. Mathematically:

$$p_d = P_c = \frac{2\sigma\cos\theta}{r} \qquad (2)$$

Effective wetting phase saturation S_e in eq. (1), can be given as:

$$S_e = \frac{S_w - S_{wr}}{1 - S_{wr} - S_{nr}} \qquad (3)$$

Where S_w and S_{wr} represents the wetting phase saturation and wetting phase residual saturation, respectively.

In eq. (1), characteristic constant λ, defines the uniformity of the grain size distribution. The greater the value, the greater will be the uniformity and vice versa.

2. Methodology

2.1 Estimating Capillary Pressure from Capillary pressure vs. Non-Wetting Phase Saturation Data using Brooks and Corey Correlation

For estimating/ regenerating the capillary pressure curve using Brooks and Corey correlation from the available capillary pressure vs. non-wetting phase saturation data, when the wetting phase is immobile, the plot generated by B. Pedrera, H. Bertin et al.[3], is selected. The respective plot was generated as a result of drainage process, i.e, displacing oil by gas injection. During their experiments, core wettability was measured by using Amott-IFP tests[2] that evaluates the core wettability to each phase through the ratios of liquid volumes produced during spontaneous and forced displacements. This test produces two phase indexes, I_w and I_o, ranging from 0 to +1, corresponding respectively to water and oil wettability and expressing the affinity of the considered phase to the porous medium. Then a global index, *W.I.*, called wettability index, which is defined as follows, can be calculated.

$$W.I. = I_w - I_o \qquad (4)$$

and varies from +1 for a strongly water wet medium to -1 for a strongly oil wet medium.

In this case, effective wetting phase saturation calculated by using eq. (3), will be zero, as:

$$S_w - S_{wr} = 0 \qquad (5)$$

Because wetting phase (water) saturation is immobile.

2.2 Re-defining Effective Saturation Definition

The effective wetting phase saturation is hereby re-defined for better representation of the correlation and to calculate capillary pressure using Brooks and Corey correlation for such cases. This was done by defining the effective saturation based on mobile phase saturation as follows, resulting into:

$$S_{em} = \frac{S_{mphase1} - S_{rmphase1}}{1 - S_{mphase2} - S_{mphase1}} \qquad (6)$$

This is wetting phase saturation is replaced by mobile phase saturation and mobile phase residual saturation, respectively.

Replacing S_e by S_{em}, in eq. (1), we get:

$$P_c(S_{em}) = p_d S_{em}^{-\frac{1}{\lambda}} \quad (7)$$

or,

$$P_{c.est.} = P_c(S_{em}) = p_d S_{em}^{-\frac{1}{\lambda}} \quad (8)$$

So, the capillary pressure can be estimated by using the above equation even for the case when the wetting phase is immobile.

2.3 Estimating Characteristic Constant

Taking logarithm on both sides of eq. (8), we have,

$$P_c(S_{em}) = p_d S_{em}^{-\frac{1}{\lambda}}$$

$$\log P_c = \log\left(p_d S_{em}^{-\frac{1}{\lambda}}\right) \quad (9)$$

$$\log P_c = \log p_d + \log\left(S_{em}^{-\frac{1}{\lambda}}\right) \quad (10)$$

$$\log P_c = \log p_d + \frac{-1}{\lambda}\log(S_{em}) \quad (11)$$

Comparing the above equation with the straight line equation, i.e,

$$y = mx + c \quad (12)$$

we have,

$$\text{slope } m = \frac{-1}{\lambda} \quad (13)$$

$$\Rightarrow \lambda = \frac{-1}{m} \quad (14)$$

So, characteristic constant can be estimated by using wither the log-log plot of observed capillary pressure (experimental data) vs. S_{em}, and/ or by using the following equation for slope:

$$m = \frac{\log(P_{c1}) - \log(P_{c2})}{\log(S_{em1}) - \log(S_{em2})} \quad (15)$$

3. Results

The capillary pressure was estimated using eq. (8) and was plotted to compare with the selected capillary pressure laboratory data for a water-wet system, as shown in figure 1.

4. Discussion and Conclusion

From the comparative plot (fig.1), it can be seen that there is a good match between the observed capillary pressure and estimated capillary pressure using Brooks and Corey correlation, when the modified effective saturation is incorporated in it.

By modifying the effective saturation correlation, it is possible to utilize variation in saturation of the mobile phase (non-wetting) in Brooks and Corey correlation, resulting into the estimation of the capillary pressure even for the displacement processes in which the wetting phase is immobile. This modification also gives the user a convenience in its interpretation and implementation.

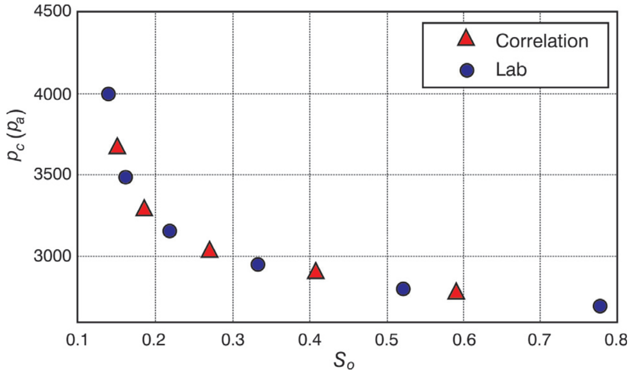

Fig. 1. Comparative plot of observed and estimated values of capillary pressure during displacement period

Sl. 1. Komparativni prikaz opaženih i procijenjenih vrijednosti kapilarnog tlaka za vrijeme istiskivanja

Once the match have been obtained, any number of data points (Pc.est. for any particular saturation) can be generated, which might have not been recorded during experiment(s).

This technique will provide even better input to different available commercial simulators, for history matching, forecasting, analyzing and selecting optimum enhanced oil recovery method, because the behavior of capillary pressure plot is not linear. So number of data points can be generated, to be used for simulation and analysis purposes, as most of the simulators use linear interpolation between the data points. By increasing the number of data points, the error generated due to this reason can be minimized.

Nomenclature

P_c	Capillary Pressure
$P_{c.est}$	Estimated capillary pressure
p_d	Displacement pressure
R	Radius of largest pore open for injected fluid to initiate displacement process
S_e	Effective saturation
S_{em}	Effective mobile phase saturation
S_w	Wetting phase saturation
S_{wr}	Residual wetting phase saturation
S_{nr}	Residual non-wetting phase saturation
$S_{mphase1}$	Mobile phase saturation of fluid 1
$S_{rmphase1}$	Residual saturation of fluid 1
$S_{rmphase2}$	Residual saturation of fluid 2
I_w	Wettability index to water
I_o	Wettability index to oil
$W.I.$	Wettability Index
σ	Interfacial tension
θ	Angle of contact
λ	Characteristic constant

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