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IMPLEMENTATION OF BROOKS AND COREY CORRELATION IN EXTREMELY WATER-WET CASE – WITH IMMOBILE WETTING PHASE

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Abstract

Brooks and Corey 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, in most cases. However, there are cases, where 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 in addition to better representation of effective saturation correlation, will result into analyzing and estimating capillary pressure also for the respective scenario, when incorporated into Brooks and Corey Correlation, which will result into better reservoir monitoring and surveillance.

Keywords: Capillary Pressure, Estimation, Prediction, Water-wet, Immobile

1. Introduction

Brooks and Corey [1] 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,

$$P_c\left(S_e\right) = P_d S_e^{-\frac{1}{\lambda}} \qquad (1)$$

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 and wettability of a system, 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 (Se) 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 experimental data

For estimating the capillary pressure using Brooks and Corey correlation from the available capillary pressure vs. non-wetting phase saturation data, when the wetting phase (water) is immobile, the plot generated by B. Pedrera, H. Bertin et al.[2] for W.I = +1, 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 [3] 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.

$$W.I = I_w - I_o \tag{4}$$

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:

$$S_w - S_{wr} = 0 \tag{5}$$

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:

$$S_{em} = \frac{S_{mphase1} - S_{rmphase1}}{1 - S_{mphase2} - S_{mphase1}} \tag{6}$$

That is wetting phase saturation is replaced by mobile phase saturation and mobile phase residual saturation, respectively, so the user can define any mobile phase present in the system as "$S_{mphase1}$".

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

$$P_c\left(S_{em}\right) = P_d S_{em}^{-\frac{1}{\lambda}} \tag{7}$$

or,

$$P_{c.est.} = P_c\left(S_{em}\right) = P_d S_{em}^{-\frac{1}{\lambda}} \tag{8}$$

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,

$$P_c\left(S_{em}\right) = P_d S_{em}^{-\frac{1}{\lambda}} \tag{9}$$

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

$$\log P_c = \log P_d + \log\left(S_{em}^{-\frac{1}{\lambda}}\right) \quad (11)$$

$$\log P_c = \log P_d + \frac{-1}{\lambda}\log\left(S_{em}\right) \quad (12)$$

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

$$y = mx + c \quad (13)$$

we have,

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

$$\Rightarrow \lambda = \frac{-1}{m} \quad (15)$$

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

$$m = \frac{\log(P_{c1}) - \log(P_{c2})}{\log(S_{em1}) - \log(S_{em2})} \quad (16)$$

3. Results

The capillary pressure was estimated using eq.(8) and was plotted to compare with the observed capillary pressure data for very strongly water wet system, i.e, W.I = +1, as shown in figure 1.

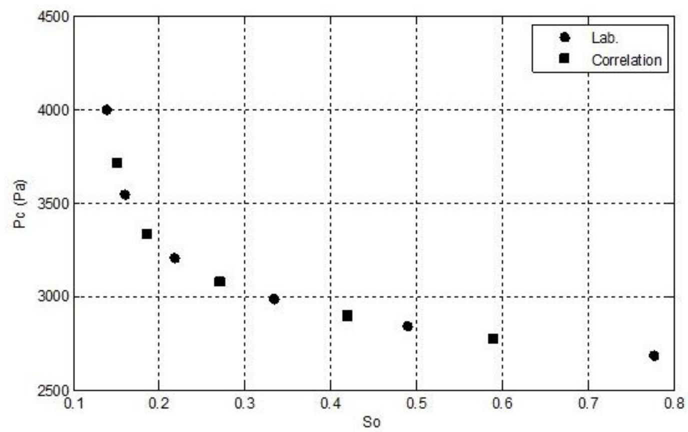

Figure 1 Comparative plot of observed and estimated values of capillary pressure during displacement period.

4. Discussion and conclusions

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

This modification gives the user a convenience in its interpretation and implementation. By modifying the effective saturation correlation, it is possible to utilize variations 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. Once the match has 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 reservoir simulators, for history matching, forecasting, analyzing and selecting optimum enhanced oil recovery method as 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 uses linear interpolation between the data points. By increasing the number of data points, the error generated due to this reason will be minimized.

Nomenclature

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

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