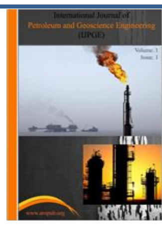
International Journal of Petroleum and Geoscience Engineering
Volume 03, Issue 03, Pages 144-148, 2015



ISSN: 2289-4713

A Comparative Study of Empirical Models for Measuring Capillary Pressure in One of Iranian Oil Reservoirs

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Abstract

Keywords:

Capillary Pressure,
Centrifuge Method,
Drainage process,
Capillary Pressure Curve.

Recently, various experimental and non-experimental methods have been proposed to measure the capillary pressure from core analysis. Due to the high cost of analysis and slow laboratory tests, researchers have had special attention on non-experimental methods which are generally based on mathematics. Theses mathematical formulas are mostly empirical which are derived according to reservoir rock's properties. So, they may provide appropriate response in one region while performing very weak in another region. The purpose of this study is to evaluate the performance of some empirical methods for measuring capillary pressure from thirty-five samples provided from southern Iran. For this, Centrifuge method is selected as the experimental method. Capillary pressures were measured by applying this method using a drainage process and results were compared with the results of empirical models to determine which model best matches the experimental outputs. After all, Brooks and Corey model is recommended by the authors for capillary pressure measurement in the studied region.

Accepted:20 Sep 2015

1. Introduction

Capillary pressure is the pressure difference existing across the interface separating two immiscible fluids. If the wettability of the system is known, then the capillary pressure will always be positive if it is defined as the difference between the pressures in the non-wetting and wetting phases. [1] Moreover Capillary force is the main driving force causing oil to migrate through porous media. In industrial scale, Capillary pressure diagrams are used to get information about initial water saturation and displacement pressure in a porous medium.

Different experimental procedures are developed for determining capillary pressure but due to the high cost of analysis and slow laboratory tests, researchers were always searched for empirical models to replace these slow laboratory procedures. But the fact is that these empirical models are generally developed using local data from a specific region and may not estimate the capillary pressure in another region as accurate as experimental methods. In this paper different capillary pressure correlations were investigated for one of Iranian oil reservoirs in order to determine the best model matching data acquired from experimental analysis.

2. Capillary Pressure Measurement Techniques

Three primary capillary pressure measurement techniques used by the petroleum industry are the porous plate, centrifuge, and high-pressure mercury injection. Although its use is less widespread, the vapor desorption method offers some advantages over the more conventional methods. Each of the measurement techniques is also applicable to very specific testing conditions and is often appropriate for specific types of reservoir rocks. Below is a brief discussion about each method.

2.1. Porous Plate Method

The principal component of the porous plate method is a permeable material having a uniform pore size distribution and containing pores of appropriate size such that the displacing fluid will not penetrate the membrane at some maximum pressure. In addition, the permeable material must have wetting characteristics such that the displaced fluid will completely wet the material surfaces and saturate the pores. Historically, ceramic has been used as the permeable material; however, plastic membranes have replaced ceramic to allow higher displacement pressures. Capillary pressures are computed from the pressure increases required to displace fluid from increasingly smaller pores and pore throats. [2-5]

2.2. Centrifuge Method

As the name implies, the centrifuge method desaturates a core sample by imposing a centrifugal force on the sample, thus forcing the mobile phase out. The centrifugal force is created by rotating or spinning the core at increasingly higher speeds. The principal advantage of the centrifuge is the ability to obtain capillary pressure data very quickly relative to the porous plate method. Furthermore, many high-speed centrifuges can now be operated at reservoir pressure and temperature conditions [6-9].

2.3. High Pressure Mercury Injection Method

High-pressure mercury injection (MICP) involves injecting or forcing mercury into an evacuated core sample. The volume of mercury injected at each pressure step determines the non-wetting (i.e., mercury) saturation. Unlike the porous plate technique, this method is very fast, often requiring only hours rather than days or weeks. Further, MICP is capable of attaining injection pressures as great as 60,000 psi, thus providing coverage of the entire range of water saturation and capillary pressure for both tight gas and high porosity, permeable rocks [10].

3. Capillary Pressure Empirical Models

Due to high cost of analysis and slow laboratory tests, researchers were always searched for some empirical models to estimate the capillary pressure with the aim of obtaining data which are close to experimental results. Some of these models are as follows: [12]

Leverett Models (1941)
Burdine Model (1953)
Brooks and Corey Model (1964)
Kwon and Pickett Model (1975)
Bentsen et al (1976)
Golaz et al (1980)
Donaldson et al (1991)
Al-Fosail (2003)

Frode Lomeland (2008)

4. Experimental procedures

Centrifuge method is used to measure the capillary pressure in this study. Capillary pressures were measured on thirty-five core samples taken from wells completed in one of Iranian oil reservoirs. All capillary pressures were measured using a drainage process (i.e., water saturations decreasing). Before measuring any capillary pressure, we first saturated the cores with synthetic brine having an NaCl concentration of 5,000 ppm. The test sequence began by desaturating the cores and measuring capillary pressures using a high-speed centrifuge apparatus set to minimum speed. By increasing the speed and consequently the pressure, more water are expelled from core samples, thus, capillary pressure versus water saturation curve was possible to be plotted for each sample. Also residual water saturation and minimum displacement pressure could be measured. However, water saturation obtained from centrifuge method must be corrected. In order to correct water saturations, Hassler and brunner correction method is applied on saturation data. [11] Then capillary pressure versus corrected water saturation is then plotted.

5. Results and discussion

As mentioned earlier, the purpose of this study is to determine the best empirical model to obtain the capillary pressure and water saturation by comparing the centrifuge data with data obtained from these models. In order to compare, two methods were used: RQI (Reservoir Quality Index) method and mean deviation factor method.

5.1. Models Comparison by Mean Deviation Factor Method

Deviation factor for each sample was calculated using statistical analysis which is stated by a number between 0 and 1000. Zero deviation factors is the worst scenario and deviation factor of 1000 shows complete matching. Table 1 shows the deviation factor parameters calculated for the samples. According to Table 1, Brooks and Corey Model best matches the experimental results obtained from centrifuge method.

Table 1: Models Comparison Based on Mean Deviation Factor.

Model	Mean Deviation Factor
Brooks and Corey	900.8
Bentsen et al	766.2
Al-Fosail	701.2
Donaldson et al	667.7
Kwon and Pickett	650.5
Golaz et al	472.7
Burdine	459.7
Frode Lomeland	398

5.2. Models Comparison by RQI Factor

Amaefule et al. first introduced the RQI factor which is defined based on rock porosity and permeability as follows: [13]

$$RQI = 0.0314\sqrt{\frac{k}{\phi}}$$

RQI factor was calculated in this study for each sample. Then, samples were categorized to three main groups according to this calculated RQI.

Category 1: Samples with RQI factor less than 0.2 including samples No. 1, 14, 15, 19, 22, 23, 24, 25, 26, 27, 28, 29, 30 and 33.

Category 2: Samples with RQI factor more than 0.6 including samples No. 5, 7, 17, 35.

Category 3: Samples with RQI factor between 0.2 and 0.6 including the remaining samples.

Tables 2, 3 and 4 show the deviation factor calculated for categories 1, 2 and 3 respectively. Results show that for each category, Brooks and Corey Model best matches the experimental results obtained from centrifuge method.

Table 2: Model Comparison for Low RQI Samples.

Model	Mean Deviation Factor
Brooks and Corey	910.6
Bentsen et al	774.2
Al-Fosail	767
Kwon and Pickett	700.5
Donaldson et al	688.5
Frode Lomeland	544
Golaz et al	471.7
Burdine	419.1

Table 3: Model Comparison for High RQI Samples.

Model	Mean Deviation Factor
Brooks and Corey	920.75
Bentsen et al	780.5
Al-Fosail	731.25
Donaldson et al	625
Burdine	536.5
Golaz et al	459
Kwon and Pickett	335
Frode Lomeland	259

Table 4: Model Comparison for Moderate RQI Samples.

Model	Mean Deviation Factor
Brooks and Corey	888
Bentsen et al	756.4
Kwon and Pickett	683.5
Donaldson et al	660.5
Al-Fosail	639.6
Golaz et al	476.6
Burdine	475.1
Frode Lomeland	310.5

6. Conclusions

In this paper different capillary pressure correlations were investigated for one of Iranian oil reservoirs to determine the best model matching data acquired from experimental analysis. According to the results obtained, Brooks and Corey Model is recommended by the authors for capillary pressure measurement in the studied region. This model best matches the data obtained from laboratory tests based on both RQI (Reservoir Quality Index) and mean deviation factor method. According to RQI classification, Brooks and Corey model having the biggest amount of deviation factor is the best model for the specific reservoir studied in Iran. Therefore, when time and cost are the limitations for reservoir fluid study in this reservoir, authors recommend applying Brooks and Corey model to obtain the capillary pressure and water saturation measurements.

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