Marine and Petroleum Geology 99 (2019) 122–134

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

Research paper

Pore - Throat size distribution indices and their relationships with the petrophysical properties of conventional and unconventional clastic reservoirs

Mohamed S. El Sharawy[a,*], Gamal R. Gaafar[b]

[a] Geophysical Sciences Department, National Research Centre, Cairo, Egypt
[b] PETRONAS Carigali Sdn Bhd, Kuala Lumpur, Malaysia

ARTICLE INFO

Keywords:
Pore size distribution
Porosity
Permeability
Capillary pressure

ABSTRACT

Mercury injection capillary pressure (MICP) curves provide significant information about the pore size distribution (PSD), which controls and defines the main petrophysical properties, namely porosity, and permeability. Due to the importance of the PSD, several indices and parameters were introduced to quantify this property. 140 MICP curves for conventional and unconventional clastic reservoirs, representing different geographic localities, geologic ages, and depositional environments, were used to study these parameters and indices, as well as their relationships with porosity and permeability. This study indicated that the most popular indices, namely Thomeer pore geometrical factor (F_g) and Brooks and Corey pore size distribution index (λ), have poor relationships with both porosity and permeability. On the other hand, displacement pressure and Swanson parameter, and pore-throat radius corresponding to the 25th percentile of mercury saturation give the best relationships with them. Therefore, permeability prediction equations based on Thomeer and Brooks and Corey indices were modified. Additionally, several new equations relating PSD parameters and indices to porosity and permeability were introduced.

1. Introduction

Capillary pressure curves provide information about petrophysical properties such as porosity, permeability, and pore size distribution. Pore throat size distribution (PSD) is a significant property of porous media. It defines and controls porosity, permeability, and capillary pressure curve shape (Archie, 1950). Several parameters and indices have been proposed throughout several decades to quantify the pore size distribution (Archie, 1950; Thomeer, 1960, 1983; Brooks and Corey, 1966; Jennings, 1987; El-Khatib, 1995; Sarwaruddin et al., 2001; Abedini and Torabi, 2015). Among these parameters and indices, Thomeer's F_g (1960, 1983) and Brooks and Corey's λ (1966) are the most popular. The following is a brief account of the most common previous contributions.

Archie (1950) was the first to refer to the role of PSD in controlling the porosity, permeability, and water saturation. He mentioned that a particular family of capillary pressure curves will be produced for a rock type having a certain effective PSD. He also defined the angle (A) that formed as the intersection of the two straight lines. These two lines represent the plateau and steep slopes of the capillary pressure curve. The angle (A) increases as permeability decreases until the plateau disappears. The concept of the angle between the two lines was developed later by Thomeer (1960) and Swanson (1981).

Thomeer (1960) developed a method for the analysis of mercury injection capillary pressure (MICP) data. He observed that log-log of capillary pressure versus the fractional bulk volume occupied by mercury, for simple rock types, could be represented by a hyperbola (Fig. 1). To fit the hyperbola to the data, values of the two asymptotes, $S_{b\infty}$ and P_d, are required. The Thomeer hyperbola can be expressed as follows:

$$\log\left(\frac{Pc}{Pd}\right) * \log\left(\frac{Sb}{Sb\infty}\right) = -C^2 \tag{1}$$

where P_c is the air -mercury capillary pressure, psi.
P_d is the air -mercury displacement pressure, psi.
S_b is the fractional bulk volume occupied by mercury at pressure P_c.
$S_{b\infty}$ is the fractional bulk volume occupied by mercury at infinite pressure or total interconnected pore volume.
C^2 defines the shape of the capillary pressure curve, in

* Corresponding author.
E-mail address: sharawy2001@hotmail.com (M.S. El Sharawy).

https://doi.org/10.1016/j.marpetgeo.2018.10.006
Received 11 June 2018; Received in revised form 18 September 2018; Accepted 5 October 2018
Available online 09 October 2018
0264-8172/ © 2018 Elsevier Ltd. All rights reserved.

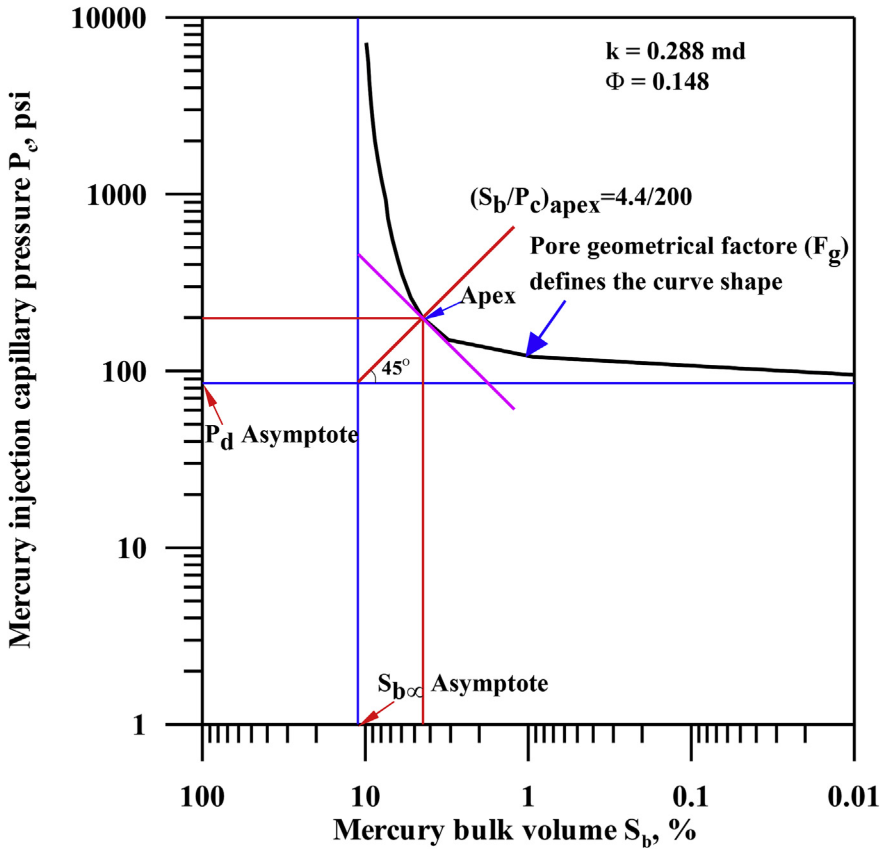

Fig. 1. A log – log hyperbolic plot of bulk volume of saturated mercury (%) versus capillary pressure to define the Swanson's parameter and the Thomeer two asymptotes.

which$C = \sqrt{\frac{Fg}{2.303}}$.

For simplicity,

$$\frac{Sb}{Sb\infty} = e^{\frac{-Fg}{\log\left(\frac{Pc}{Pd}\right)}} \quad (2)$$

where F_g is the pore geometrical factor, which determines the shape of the hyperbola. It depends on the interconnection of pores and the sorting of the pore throats. Well – sorted pore –throats tend to have small F_g values, meanwhile, poorly sorted pore throats tend to have large F_g values.

Later, Thomeer (1983) developed an equation for predicting permeability as a function of three F_g, P_d, and $S_b\infty$:

$$k = 3.8068Fg^{-1.3334}\left(\frac{Sb\infty}{Pd}\right)^2 \quad (3)$$

Assuming $S_b\infty = \Phi$, therefore

$$k = 3.8068Fg^{-1.3334}\left(\frac{100\Phi}{Pd}\right)^2 \quad (4)$$

where k is the permeability in md and Φ is the porosity (fraction). This assumption is valid for permeability higher than 10 md, as the model was based on oil reservoir samples as well as not all samples give hyperbolic curves (Wu, 2004). For very low-permeability, errors can be obtained.

Based on the capillary pressure curves, Brooks and Corey (1966) modified the Corey (1954) model by introducing a new parameter called pore size distribution index (λ). This index controls the slope of a capillary pressure curve, in which larger λ values usually have well –sorted pore-throats, while smaller λ values usually have poorly-sorted pore-throats. This parameter can be determined by the following relationship:

$$Se = \left(\frac{Pc}{Pd}\right)^{\frac{-1}{\lambda}} \text{ for Pc > Pd} \quad (5)$$

where S_e is the normalized water saturation, which equals:

$$Se = \frac{(Sw - Swir)}{(1 - Swir)} \quad (6)$$

where S_w is the water saturation and S_{wir} is the irreducible water saturation. Log–log plot of P_c/P_d versus S_e yields a straight line with a negative slope equal to λ.

Kolodzie (1980), based on the Winland multiple regression analysis, published the following equation:

$$\text{Log } r_{35} = 0.732 + 0.588 \log k - 0.864 \log \Phi \quad (7)$$

where r_{35} is the pore-throat radius corresponding to the 35th percentile of mercury saturation in micron, k is permeability in md, and Φ is porosity in %. The 35th percentile is assumed to approximate the modal class of pore throat size at which the pore network becomes interconnected forming a continuous fluid path through the sample (Spearing et al., 2001). The Winland r_{35} can be used to classify the reservoir into flow units (Martin et al., 1997; Boada et al., 2001). In 1992, Pittman carried out several analyses and found that the mean apex for 196 sandstones samples had a mercury saturation of 36%, which is very close to the 35% that introduced by Winland to delineate hydrocarbon accumulations in stratigraphic traps.

Swanson (1981) developed an equation for permeability as a function of capillary pressure curve characteristics. The general form of the equation is:

Download English Version:

https://daneshyari.com/en/article/11262854

Download Persian Version:

https://daneshyari.com/article/11262854

Daneshyari.com