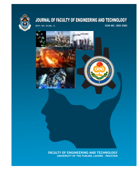
JFET 24(1) (2017) 73-81

Journal of Faculty of Engineering & Technology

journal homepage: www.pu.edu.pk/journals/index.php/jfet/index



Predictive Modelling using Capillary Pressure Models and Fluid Densities and their Effect on Reservoir Fluid Distribution

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Abstract

Capillary pressure has always been a point of concern for reservoir modeling. It describes the initial pressure at which the de-saturation will be initiated and at the other extreme; it defines the irreducible saturation of the displaced fluid. In this study, Brooks & Corey and Van Genuchten models are used to predict maximum displacement pressure data with reference to non-uniformity in pore-size distribution. Both models are compared and a correlation has been developed to predict maximum displacement pressure with reference to variation in pore-size distribution index for Van Genuchten model. Further, the fluid distribution and water-oil contact level with reference to free-water level has been calculated using both models for reservoir modeling. The obtained results show that Van Genuchten model gives higher thickness for transition zones and difference in water-oil contact level with reference to free water level, as compared to Brooks and Corey correlation. Furthermore, on comparative basis, these differences increase with the decrease in uniformity in pore size distribution. Thus, the degree of uncertainty and complexity in developing reservoirs and analyzing fluid dynamics increases, in case of tighter or heterogeneous formations. Moreover, this study also shows that density also plays an important role in fluid dynamics and distribution in the reservoir.

Keywords: Pore-size distribution index, Fluid distribution, static modeling, WOC, de-saturation pressure.

1. Introduction

The De-saturation curve defines the displacement processes occurring or most likely taking place in a reservoir. To generate these de-saturation curves, experimentation is required in which one fluid displaces another, giving information related to behavior of displacement process, irreducible saturation and reservoir characteristics. Based on these experiments, different correlations have been developed, out of which Brooks & Corey[1] as well as Van Genuchten model[2] gained acknowledgeable popularity. These models were primarily used for generating soil water retention curves and were later used to predict capillary pressure curves in petroleum engineering[3-6]. De-saturation or in other words capillary pressure curves are used to analyze the displacement process and are also required to predict the fluid distribution within a reservoir[7]. In oil reservoirs, based on capillary pressure curve, fluid distribution can be categorized in the form of oil zone, transition zone and free-water-level, as shown in **Figure 1**. This information is a pre-requisite for reservoir development

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planning and production forecasting while conducting simulation studies and practically implementing development strategies in a field[8,9].

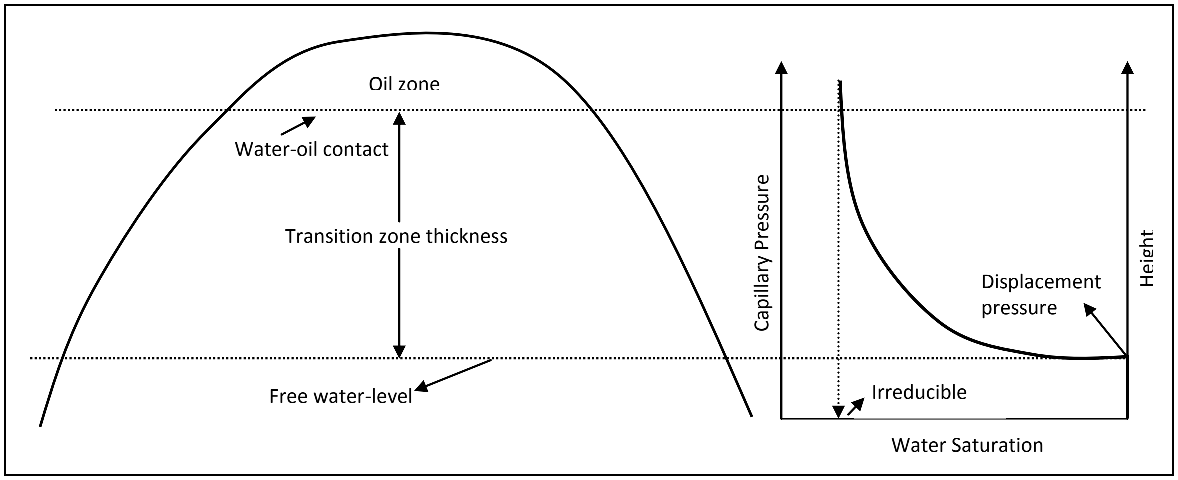

Figure 1. Schematic process of converting capillary pressure curve into fluid distribution system within reservoir

2. Capillary Pressure Models

Brooks and Corey model [1] correlates the capillary pressure with effective saturation in the following manner:

$$P_c = P_d S_e^{-1/\lambda} \tag{1}$$

Where,

$$S_e = \frac{S_w - S_{wir}}{1 - S_{wir}} \tag{2}$$

Using Brooks and Corey model, a correlation between change in maximum de-saturation pressure with reference to characteristic constant "□" has also been proposed, which can be given as[10]:

$$\Delta P_{c,max} = \Delta P_{c,Swir} = -3.93\times10^{-5}\lambda^4 + 0.002\lambda^3 - 0.0399\lambda^2 + 0.3783\lambda - 0.892 \tag{3}$$

While on the other hand Van Genuchten[2] correlated capillary pressure in the form of following equation:

$$P_c(S_e) = \frac{1}{\alpha}\left(S_e^{-\frac{1}{m}} - 1\right)^{\frac{1}{n}} \tag{4}$$

Where, m=1-1/n.

Van Genuchten parameter "n", can be related to pore size distribution, which indicates that as the uniformity increases, "n" decreases [11]. So, here the parameter "n" is made proportional to "□". Further "□" can be calculated by taking the inverse of capillary pressure value on the de-saturation curve at S_e =0.5[11].

3. Models Analysis and Implementation in Porous and Permeable Medium

Maximum de-saturation pressure (P_{md-s}) and height of water-oil contact (WOC) has been calculated by using both models. The stepwise procedure of calculations is explained with the help of flow chart as shown in **Figure 2**.

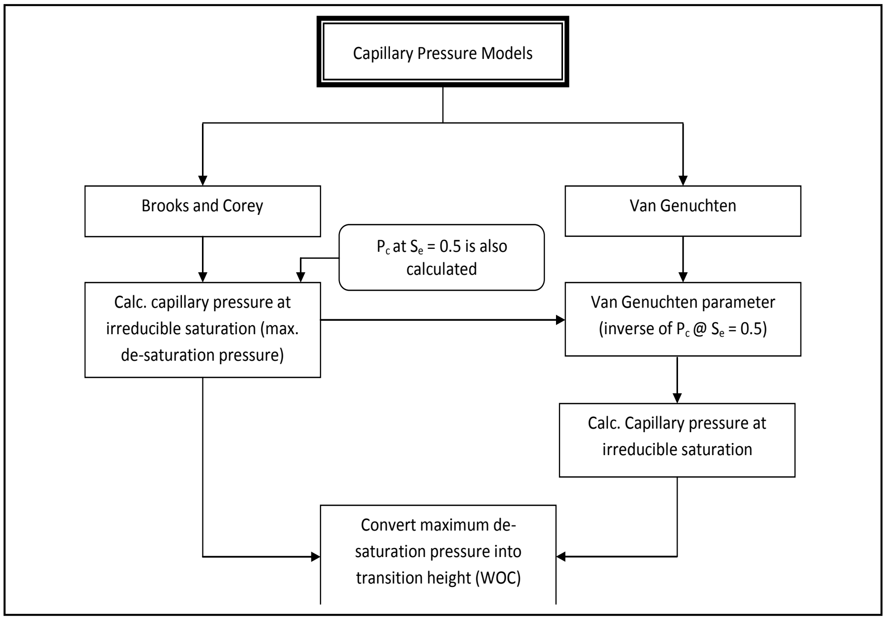

Figure 2. Calculating capillary pressure and water-oil contact height with reference to free-water level

Pore-size distribution index has been varied from a value of "4" to "14", i.e., ranging from higher degree of non-uniformity in pore size distribution (similar high values can also be observed in case of tight formations) towards comparatively higher degree of uniformity. The obtained results using both models for varying pore-size distribution index (characteristic constant) are presented in Table (1). The results show that, the capillary pressure estimated at residual water saturation is higher in case of Van Genuchten model as compared to Brooks and Corey model.

Table1. Maximum de-saturation or capillary pressure based on Brooks & Corey and Van Genuchten models.

Maximum de-saturation/displacement pressure [P_{md-s} (Psi)]						
Characteristic Constant (□ or n)	4	6	8	10	12	14
Brooks & Corey Model	3.14	2.14	1.77	1.58	1.46	1.38
Van Genuchten Model	5.47	2.8	2.1	1.78	1.61	1.49

As discussed above, that the correlation has already been presented for Brooks and Corey model, so here the correlation to represent calculated change in maximum displacement pressure with reference to pore size distribution has been established, using data obtained by Van Genuchten model. For this purpose, maximum de-saturation pressure for n = 4, has been taken as base case and change in de-saturation pressure (□P_{md-s}) in absolute terms has been calculated for Van Genuchten model as follows:

$$\Delta P_{md-s} = Abs\left[\frac{P_{cmax,n>4} - P_{cmax,n=4}}{P_{cmax,n=4}}\right] \quad (5)$$

and the resulting values have been plotted as shown in **Figure 3**. The figure represents a 4th degree polynomial and the curve can be regenerated by using the following equation, which has been obtained using curve fitting technique (representing a deviation/error of -0.004 to 0.026).

$$\Delta P_{md-s} = \Delta P_{c,max} = -5.44 \times 10^{5} n^{4} + 0.0028n^{3} - 0.0547n^{2} + 0.4934n - 1.049 \quad (6)$$

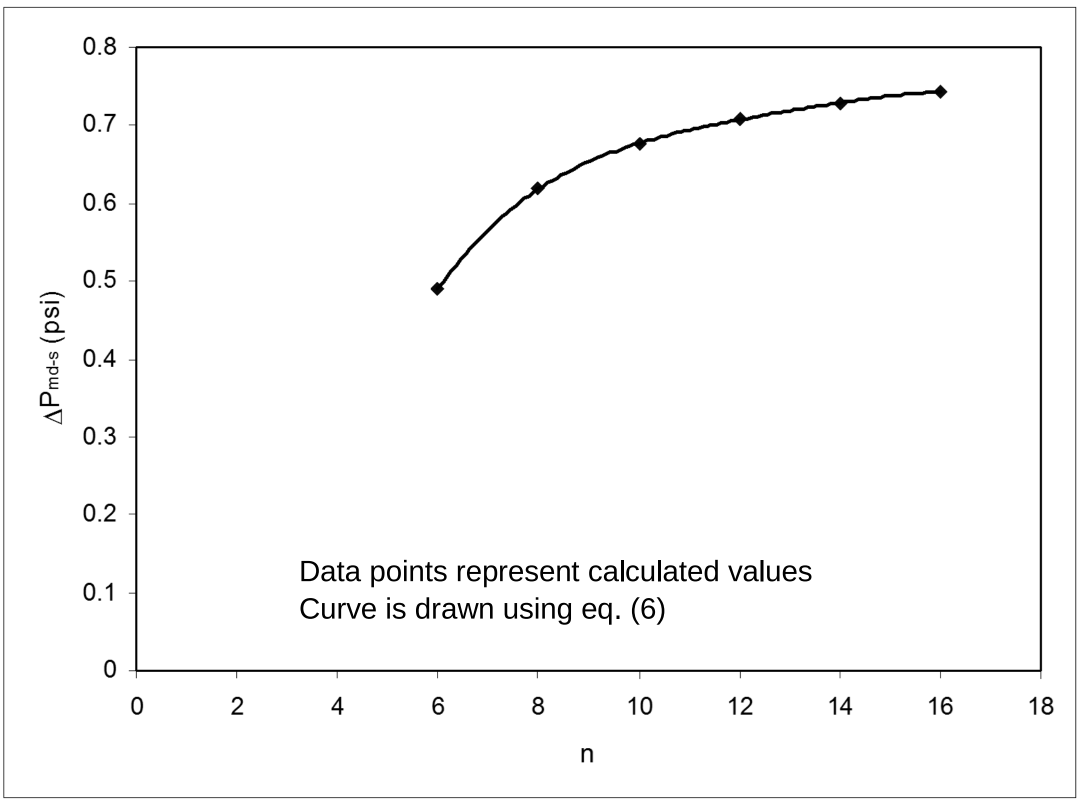

Figure 3. Calculated and correlation predicted P_{md-s} with reference to "n"

Further, these models are also used to estimate water-oil contact level and/or transition zone thickness in the reservoir by transforming the calculated capillary pressure into height by using the following equation[7]:

$$h_{(ft)} = \frac{144\ P_{c(psi)}}{\left(\rho_{w(lb/ft^3)} - \rho_{o(lb/ft^3)}\right)} \quad (7)$$

Taking, □$_w$ as 62.4 lb/ft^3 and □$_o$ as 46.8 lb/ft^3, the length of transition zone or the height of water-oil contact above free-water level can be calculated by using equation (7). The obtained results are shown in **Figure 4.** This figure shows that as the pore-size distribution index increases the height of water-oil contact from free-water level decreases, thus the thickness of oil zone increases, assuming constant reservoir thickness.

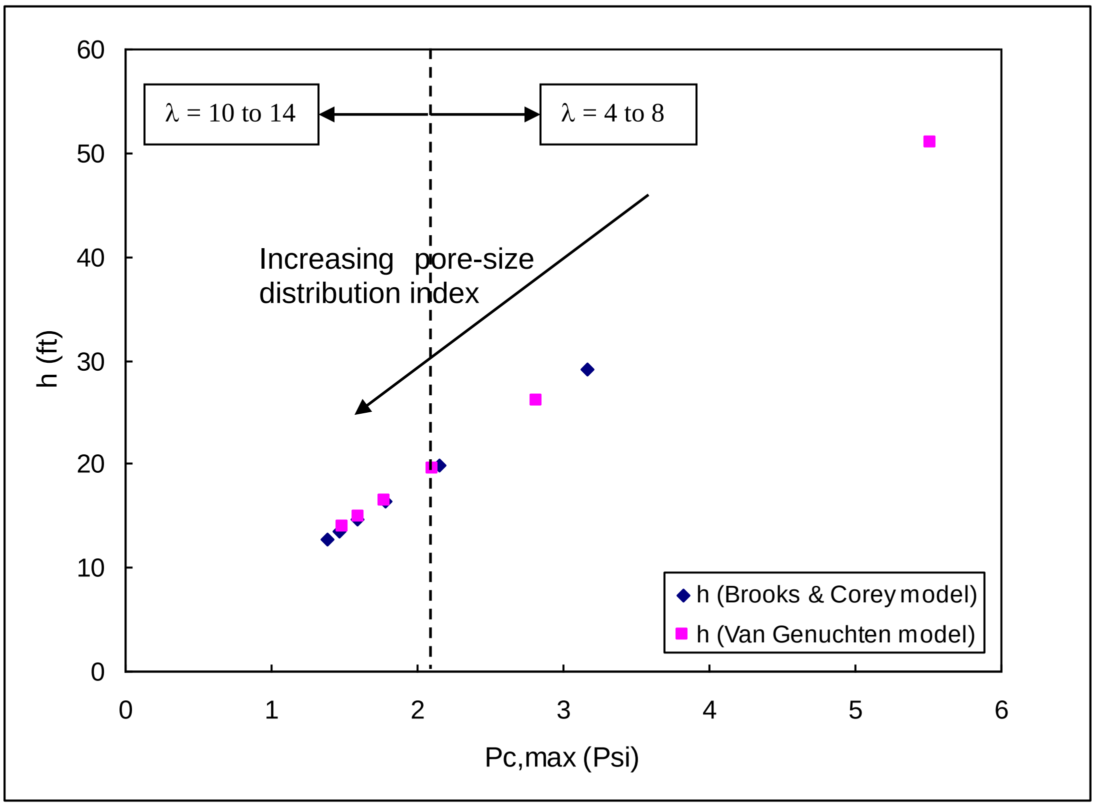

Figure 4. Comparison of height of transition zone thickness and/or water-oil contact calculated by using both models

Further, the difference in estimated height of water-oil contact level by using both models has been calculated by using the following equation and the obtained results are shown in **Figure 5**.

$$\%Difference = \frac{h_{VanGenuechen} - h_{Brooks\&Corey}}{h_{VanGenuechen}} \times 100 \quad (8)$$

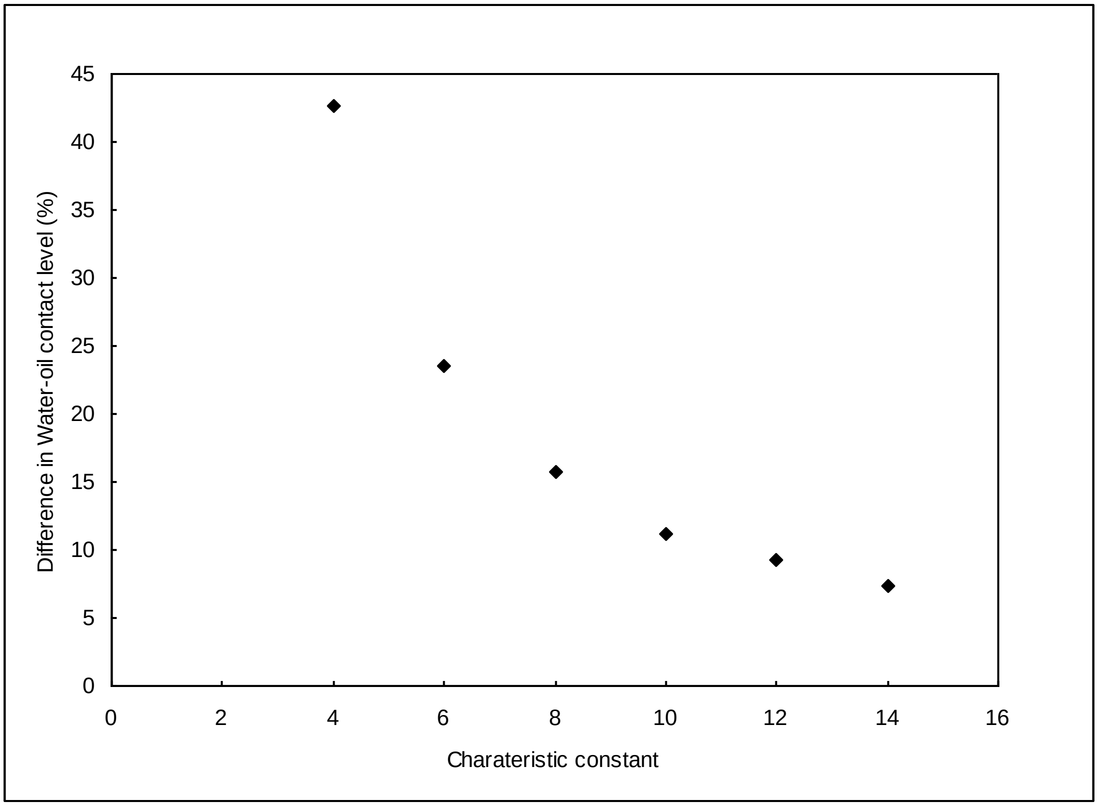

Figure 5. Percentage difference in height calculated by using both models

The above figure shows that the difference in results by using both models decreases as the pore size distribution index increases, thus the significance of model selection is more critical in case of reservoirs having lower pore size distribution index.

4. Effect of Fluid Densities on Fluid Dynamics and Distribution

After estimating the capillary pressure and transition height values, sensitivity analysis has been performed by varying the density of fluids. The data has been generated for capillary pressure values of 5.5 and 2.8 psi. The calculations are performed first, by keeping the constant value of water density and varying oil density **Figure 6** and later for vice versa situation, i.e., oil density is kept constant and water density has been varied **Figure 7**. The obtained results show that as the density of oil increases, transition height increases for both values of capillary pressure.

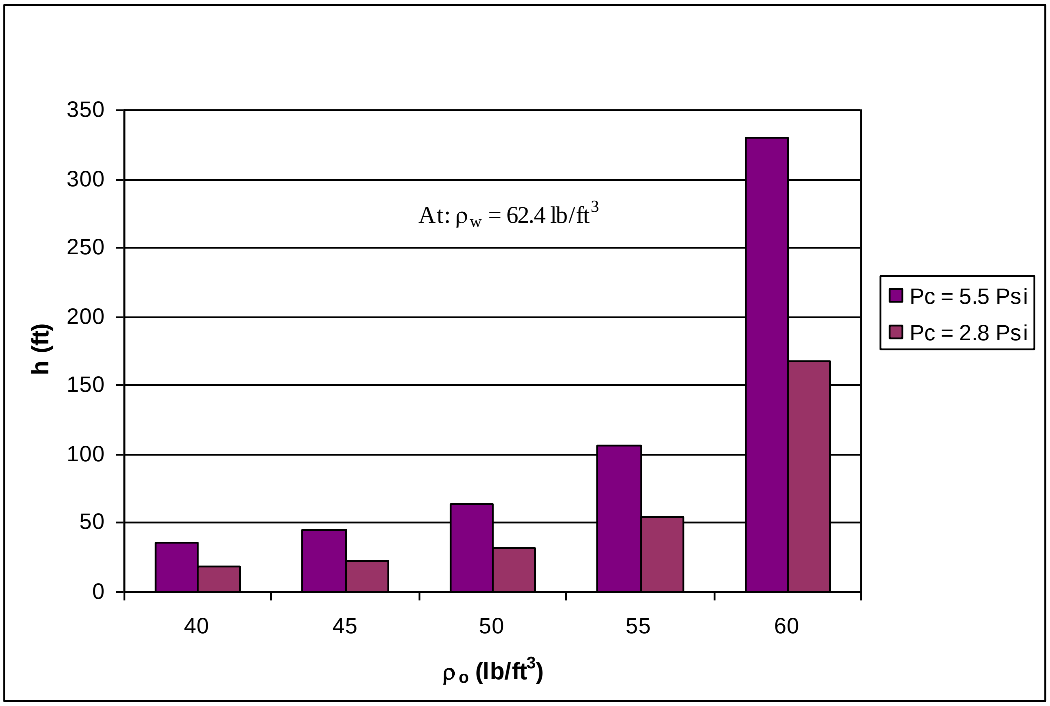

Figure 6. Effect of oil density on transition height

While on the other hand as the water density increases height of transition zone decreases as shown in **Figure 7**. This may be due to the fact of segregation (movement of fluid or fluid dynamics resulting from density or gravity effects), which is particularly occurring in the later case.

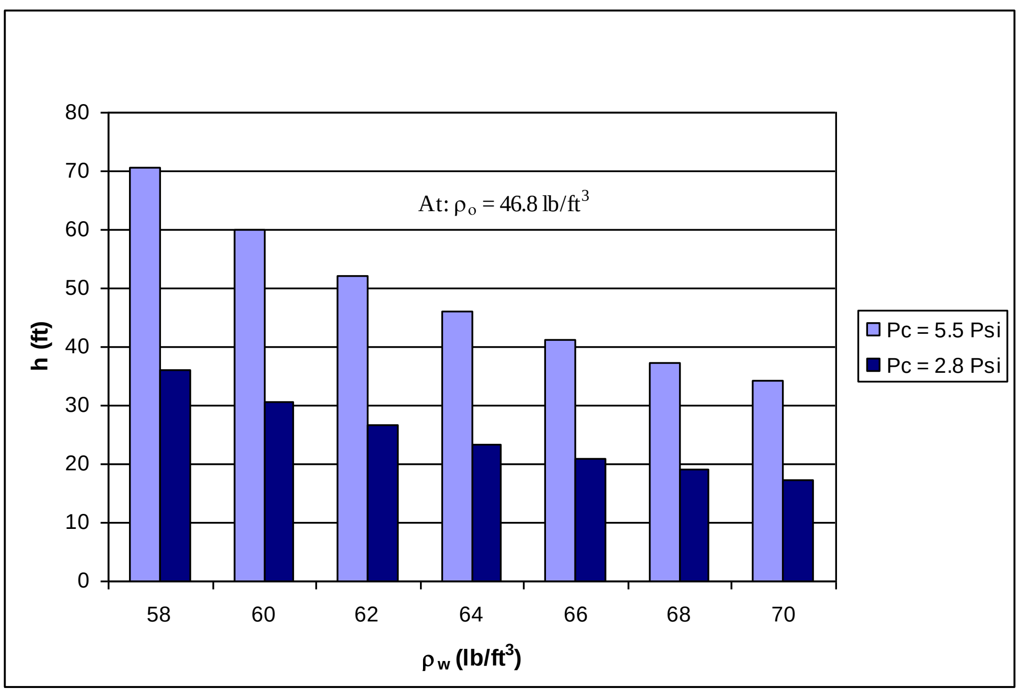

Figure 7. Variation in height w.r.t. water density variations

5. Conclusions

Correlation for representing Van Genuchten model directly in terms of maximum displacement pressure change with reference to characteristic constant has been developed. Both models, i.e., Brooks & Corey model and Van Genuchten models give different values for maximum displacement pressure. Similarly, it generates difference in transition zone thickness estimations and calculated WOC height from free-water level. However, the difference in obtained results decreases with the increase in pore size distribution index. So, in case of reservoirs having higher degree of non-uniformity in pore size distribution or tighter formations, both models need to be analyzed during reservoir modeling and fluid distribution predictions for better surveillance.
This study also shows that fluid density also effects the movement of fluid and height of transition zones in relation with pore size distribution and capillary pressure.

Nomenclature

Abs	- absolute
h	- height (ft)
P_c	- capillary pressure (psi)
P_d	- displacement pressure (psi)
$\Delta P_{c,max}, \Delta P_{md-s}$	- change in maximum capillary pressure or de-saturation pressure (psi)
S_e	- effective saturation (fraction)
S_w	- water saturation (fraction)
S_{wir}	- irreducible water saturation (fraction)
□,n,m	- Van Genuchten parameters (constants)
□o	- oil density (lb/ft^3)
□w	- water density (lb/ft^3)
□	- pore-size distribution index or characteristic constant

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