Calculation and Comparison of Water Saturation in Carbonate Formation by Different Methods

Khulud. M. Rahuma
University of Tripoli

Bahia M. Ben Ghawar
University of Tripoli

Abstract—**Water saturation is an important governing quality and quantity of the hydrocarbon evaluation, as reserve estimation. The challenge of the reservoir engineer is to resolve and understand the differences distribution of water saturation content by using different techniques. However, though out this work illustrate variety models to calculate water saturation which is compared with core measured. Therefore, water saturation is calculated using different models; Archie, Simandoux, Indonesia which are compared with Leverett J-Function (capillary pressure measurements). Archie's parameters of the studied reservoir rock; Cementation Factor (m) and Saturation Exponent (n) are derived from the log data used. Error of the water saturation estimation may significantly impose bias in the estimation of both quantities. In spite of, there are various factors affecting potential error in water saturation estimation, such as, average permeability, average porosity and Archie's parameters are used. Consequently, the comparison between results indicates that, Indonesia and Simandoux models are show the smallest average absolute error values, where Archie's model common one used for water saturation in Carbonate rocks. Three wells are selected to present his comparison.**

Index Terms: **Water saturation; Carbonate rock; Capillary pressure; Log data.**

I. INTRODUCTION

In practical terms, petrophysics is used for two types of calculations: determination of original hydrocarbons in place (OOIP and/or OGIP) and their distribution, and reservoir-engineering dynamic flow calculations. For the development geoscientists, petrophysics means developing the detailed stratigraphic, depositional, and diagenetic descriptions of the reservoir, both vertically and laterally. To make accurate calculations of OOIP or OGIP and the various flow calculations, accurate calculations of lithology, net pay, porosity, water saturation, and permeability are necessary. These calculations need to be made not only as overall calculations, but also so that the variation and distribution of these parameters are determined appropriately. Water saturation (S_w) determination is the most challenging of petrophysical calculations and it is used to quantify more important complement. Complexities arise because there are a number of independent approaches that can be used to calculate Sw.

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Most conventional water saturation (S_w) calculations using well logs, which is easier and the logs are available than core samples measurable techniques. The S_w calculations from the resistivity logs and the various Archie parameters can be partially checked in aquifer intervals where S_w is known to be 100%. In the water saturation calculation using resistivity logs, the connate-brine salinity and its resistivity, R_w, can vary within the hydrocarbon column, but the extent of this variation is often not measured. Capillary pressure (Pc) laboratory tests are measurements of fluid volumes associated with cleaned and restored core plugs. These measurements are using to calculate water saturation. Pc laboratory tests do not always achieve the equilibrium water saturation, or the same water distribution within the pore network as is present in the real reservoir, especially this occurred due to sample preparation. Therefore, comparison between two water saturation techniques is the main task in this paper.

II. MATERIAL AND METHODS

Capillary pressure data are obtained from small core samples that represent an extremely small part of the reservoir and, therefore, it is necessary to combine all capillary data to classify a particular reservoir. The Pc depended on the pore-size distribution of the rock and the interfacial properties of the various solid/fluid systems. One Equation technique for all Pc curves is used to convert Pc laboratory data to reservoir condition. Leverett, 1941 (Equation 1), is called as J-function. It was used to normalize capillary pressure data to take into account variations in porosity and permeability. This method is useful for averaging capillary pressure data derived from a given rock type and reservoir and, with caution, can sometimes be extended to different reservoirs with the same lithology. The water saturation and pressure values was converted to a water saturation-versus-height model by replacing the pressure attribute with height above free water level (in true vertical depth), reservoir porosity and permeability. The output was a water saturation curve which will be compared with wire line water saturation evaluation.

Archies, Simandoux and Indonesian Equations (2, 3 and 4) are applied for the same reservoir, to estimate the water saturation. They depend on an available geophysical data. Whereas, Pickett cross-plotting technique in 100% water saturated zones to determine petrophysic properties; Cementation factor (m), saturation exponent (n) and formation water resistivity (Rw) parameters.

The main average reservoir rock properties; porosity (22%), and permeability (535 mD).

$$J(S_w) = 0.2179\left(\frac{P_c}{\sigma}\right)\sqrt{\frac{k}{\phi}} \quad (1)$$

$$S_w = \left(\frac{a \times R_w}{\phi^m \times R_t}\right)^{1/n} \quad (2)$$

$$S_w^n = F \times R_w \left(\frac{1}{R_t} - \frac{V_{cl} \times S_w}{R_{cl}}\right) \quad (3)$$

$$S_w^{n/2} = \left[\frac{\frac{1}{\sqrt{R_t}}}{\frac{V_{sh}^{\left(1 - V_{sh}/2\right)}}{\sqrt{R_{sh}}} + \frac{\phi^{m/2}}{\sqrt{a\,R_w}}}\right] \quad (4)$$

Where: $J(S_w)$= Leverett J-Function, Unitless, Pc =Capillary pressure, Psi, σ =Interfacial tension, Dynes/cm, K =Permeability, mD, Ø =Porosity (fr.), Vsh = Volume of clay (fr.), Rsh = Resistivity of shale (Ω.m), m = Cementation factor, n =Saturation Exponent, Rt = Deep Resistivity of the rock (Ω.m), Rw = formation water resistivity (Ω.m), F = Formation Factor.

III. RESULTS AND DISCUSSION

Geological applications and interpretation of capillary pressure in reservoir studies [2], these applications like evaluate reservoir rock quality, expected reservoir fluid saturations and depths of fluid contacts, thickness of transition zone, seal capacity, and pay versus nonpay, and to approximate recovery efficiency. Average capillary pressure of the studied reservoir core samples calculated and plots against water saturation (Fig. 1). Each well 2 and 3 present low transation zone thickness, whereas well 1 has high transition zone and oil zone height. The same result of procedure of average J(Sw) as shown in Figure (2). Therefore, figures 3-5 show comparison between water saturation estimated by models and derived from average capillary pressure. Generally, there is agreement of water saturation values calculated by different techniques cross whole the studied reservoir. Indonesian Equation presents low water saturation values are close to those estimated from capillary pressure. Through these figures it is clarified, the oil – water contact at 6040 feet. Slightly different of water saturation estimated by capillary pressure, may be reveal to laboratory measurements errors during prepared the samples. As affected by the invaded fluid (mud filtrate) on wireline data.

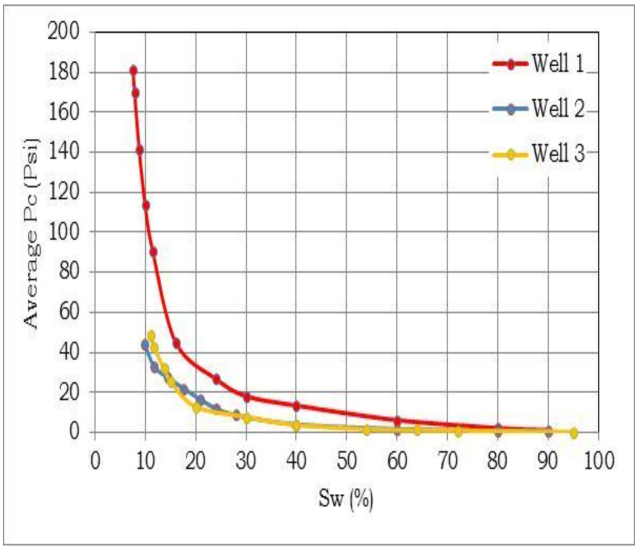

Figure 1. Average Water Saturation Versus Capillary Pressure of Wells.

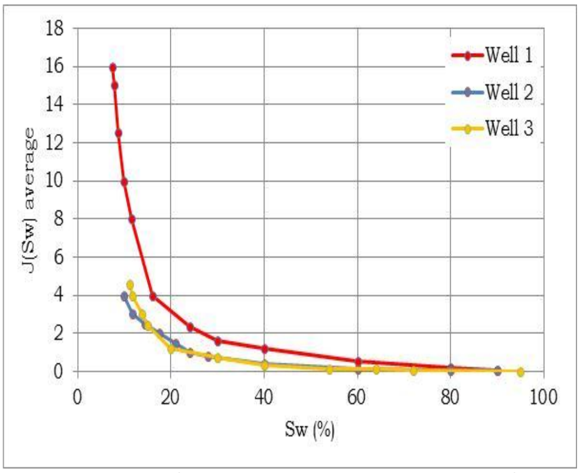

Figure 2. Average of Water Saturation Versus J-Function of Wells.

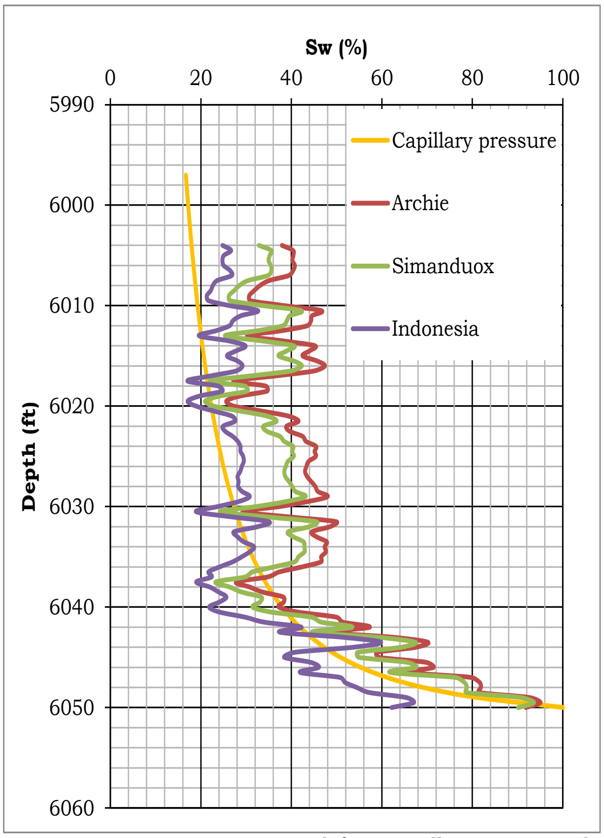

Figure 3. Water Saturation Vs. Depth from Capillary Pressure and Well Log Data, Well 1.

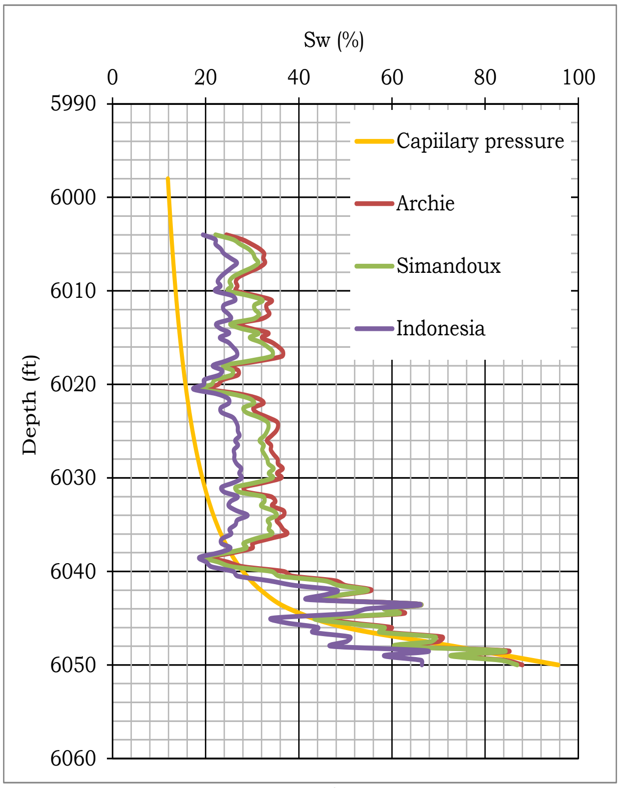

Figure 4. Water Saturation Vs. Depth from Capillary Pressure and Well Log Data, Well 2.

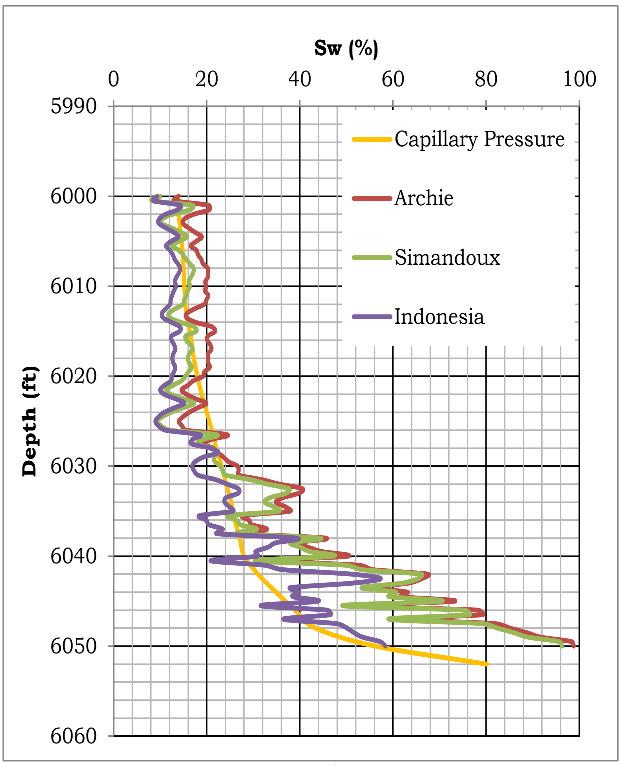

Figure 5. Water Saturation Vs. Depth from Capillary Pressure and Well Log Data, Well 3.

IV. Conclusion

- This study provided the validity of water saturation using log interpretation and special core analysis.
- Good agreement between log and core water saturation evaluation in this studied carbonate reservoir.
- Data collected from logs always affected by the invaded fluid (mud filtrate), and solids such as clay particles and additives.
- Importance of select Water saturation model (Indonesia, Simandoux, Archie), if the core data are not available. Therefore, Indonesia model is best model appropriate with capillary pressure method.
- Average water saturation values range from 21.67% to 25.58%, while the best values of water saturation error obtained by Indonesia equation is 17.09%, and from capillary pressure is 11.66%.
- Petrophysical properties are very important factor for reservoir engineering, and they are vary depending on formation lithology, formation depth and geological age.

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