Impact of Water Saturation Model on the Reservoir Estimation; A Case Study on Dorado and Barracuda Wells in Mannar Basin, Sri Lanka

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Abstract

Fluid carrying properties of rocks (permeability) and the interaction between fluid and rock that influence the flow of the fluids(porosity and saturation) are required to evaluate the maximum recovery and producibility of any petroleum reservoir. Determination of Water Saturation (S_w) is a critical and complex petro physical calculation, as there are number of independent methods used to calculate the same. The objective of this research was to analyse the impact of water saturation model on the reservoir estimation, using the well-log data of Dorado-1 well and Barracuda well in Mannar Basin, Sri Lanka. First, quick look analysis was done with the well-log data. Then the saturation of water in pay zones were calculated using five water saturation calculation approaches namely Archie's equation, Equivalent Model, Indonesia model, Dual Water Model and Juhasz model. For both wells the highest water saturation values were found with Dual Water Model and Juhanz model, 0.89 for the Dorado well and 0.83 for Barracuda well. While Equivalent model gave the lowest saturation value, 0.46, for Dorado well and the Archie's model estimated the lowest value of 0.60 for Barracuda well. Except the results of Dual Water Model and Juhasz model, all other models estimated different values for water saturation. This leads to a considerable difference in reservoir estimation. Therefore, for a reservoir it is important to establish the most suitable water saturation calculation method to estimate the volume of reservoir correctly.

Keywords: Archie's equation, Dual Water Model, Equivalent model, Indonesia model, Water saturation

1. Introduction

Analysis of petro-physical data of a reservoir is determining the information that facilitate on defining the Stock Tank Oil Initially In Place (STOIIP) or Gas Initially In Place (GIIP) of the reservoir. Calculation of water saturation is considered as the most challenging petro-physical calculation task as it eventually being used to calculate the hydrocarbon saturation which is the quantity of real interest [1].

This analysis mainly focused to calculate water saturation with selected water saturation calculation models and the petro-physical parameters which needed to perform those calculations. Ultimate purpose of calculating water saturation with various models is to observe the impact of those models to the reservoir volume estimation. Since the commercial purpose is to know the actual reservoir volume, selecting the most suitable water saturation calculation model for a reservoir is vital.

In 2011 Dorado, Dorado North and Barracuda wells were drilled by Cairn Lanka Private LTD, in Mannar basin of Sri Lanka [2]. Hydrocarbon columns were found from both Dorado and Barracuda wells while Dorado North well was abandoned as a dry hole [2]. These discoveries of hydrocarbon in Sri Lanka, confirms the existence of active petroleum system in Mannar basin [2].

2. Methodology

2.1 Collection of Data

Well log data ;Gamma ray logs, Density-Porosity logs, Resistivity logs were collected for both Dorado and Barracuda wells.

2.2 Quick Look Analysis

Quick look analysis was carried out to identify the pay zones, fluid type and to determine the condensate - water contact. Then porosity was calculated using density logs and zonic logs.

Zonation was done by using Gamma ray logs and Neutron/Density logs. Sonic log data – sonic travel time data were used to determine fluid type Porosity, and effective porosity were calculated by using the "Slumberger Techlog" software.

2.3 Determination of Water Saturation (S_w)

According to available data and calculated data, water saturation was calculated with following models.

1. Archie model
2. Dual water model
3. Juhasz model
4. Equivalent SWE model
5. Indonesia (Poupon-Leveaux) model

Formulas for manual calculation of saturation values by each model is as presented in equations (1) to (5)

Archie Model[3]

This model is used for field studies in the many sandstone and carbonate reservoirs in which the clay-mineral content is low

$$S_w = \left(\frac{aR_w}{R_t\emptyset^m}\right)^{1/n} \quad \text{.............................(1)}$$

Where,

S_w – Water saturation (fractional)
Φ – Porosity (fractional)
R_w – Formation water resistivity (ohm.m)
R_t – True resistivity (ohm.m)
a – Cementation factor (constant)
m – Cementation exponent (constant)
n – Saturation exponent (constant)

Dual Water Model

This model is based on a large dataset of core electrical mesurements taken by Shell.

Best et al's Dual-water equation is presented bellow as equation 2[4].

$$\frac{1}{R_t} = \emptyset_t^{m_0} S_{wt}^{n_0}\left[\frac{1}{R_{wf}} + \frac{S_{wb}}{S_{wt}}\left(\frac{1}{R_{wb}} - \frac{1}{R_{wf}}\right)\right] \text{...(2)}$$

Where,

S_{wt} -Water saturation of the total porosity (Fractional)

S_{wb} -Saturation of physically bound water in the total PV (fractional)

R_{wb} –Resistivity of clay bound water in the shales (ohm.m)

R_{wf} –Resistivity of free formation water in the shale free water zones (ohm.m)

m_o, n_o – DW exponents (constants)

$\emptyset_t$ – Total porosity (Fractional)

Juhasz Model [5]

This model is also known as Normalised Waxman-Smith model. This uses parameters that can be derived from log measurements.

$$C_t = C_w \emptyset^m S_w^n + (C_{sh}\emptyset_m^{sh} - C_w)(V_{sh}\emptyset_{sh}S_w/\emptyset) \quad (3)$$

Where,

C_t –Formation conductivity from deep resistivity log (S/m)

C_w –Conductivity of formation water (S/m)

C_{sh} – Shale conductivity (S/m)

V_{sh} – Shale volume (m^3)

Equivalent SWE Calculation Model[6]

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$$SW_{eEQ} = 1 - \left[\frac{\emptyset_t}{\emptyset_e} \times (1 - SW_t)\right] \quad (4)$$

Where,

SW_{eEQ} -Equivalent effective water saturation (Fractional)

$\emptyset_e$ -Effective porosity (Fractional)

SW_t -Total saturation (Fractional)

Indonesia (Poupon-Leveaux) Model [7]

This model was developed by field observation. The formula was empirically modeled for water-bearing shaly formmation.

$$S_w = \left\{\left[\left(\frac{V_{sh}^{2-V_{sh}}}{R_{sh}}\right)^{1/2} + \left(\frac{\emptyset_e^m}{R_w}\right)^{1/2}\right]^2 R_t\right\}^{-1/n} \quad (5)$$

Where,

R_{sh} - Shale resistivity (ohm.m)

Then these results were compaired to determine the effect of water saturation model on reservoir estimation.

3. Results and Discussion

3.1 Results of Dorado Well

Fifteen payzone intervels could be found in Dorado well with varing thickness from around 5m to 70m from quick look analysis. Figure 1 presents part of the Quicklook analysis results of Dorado well done with "Slumberger Technlog" software.

Results of water saturation calculation done using five models for Dorado Well show difrent different values (Table 1).

Table 1 – Average water stuaration values of Dorado Well

Model	Avg_SW
Archie	0.64
Equivalent SWE calculation model	0.46
Indonesia(Poupon-Leveaux)	0.79
Dual water	0.89
Juhasz	0.89

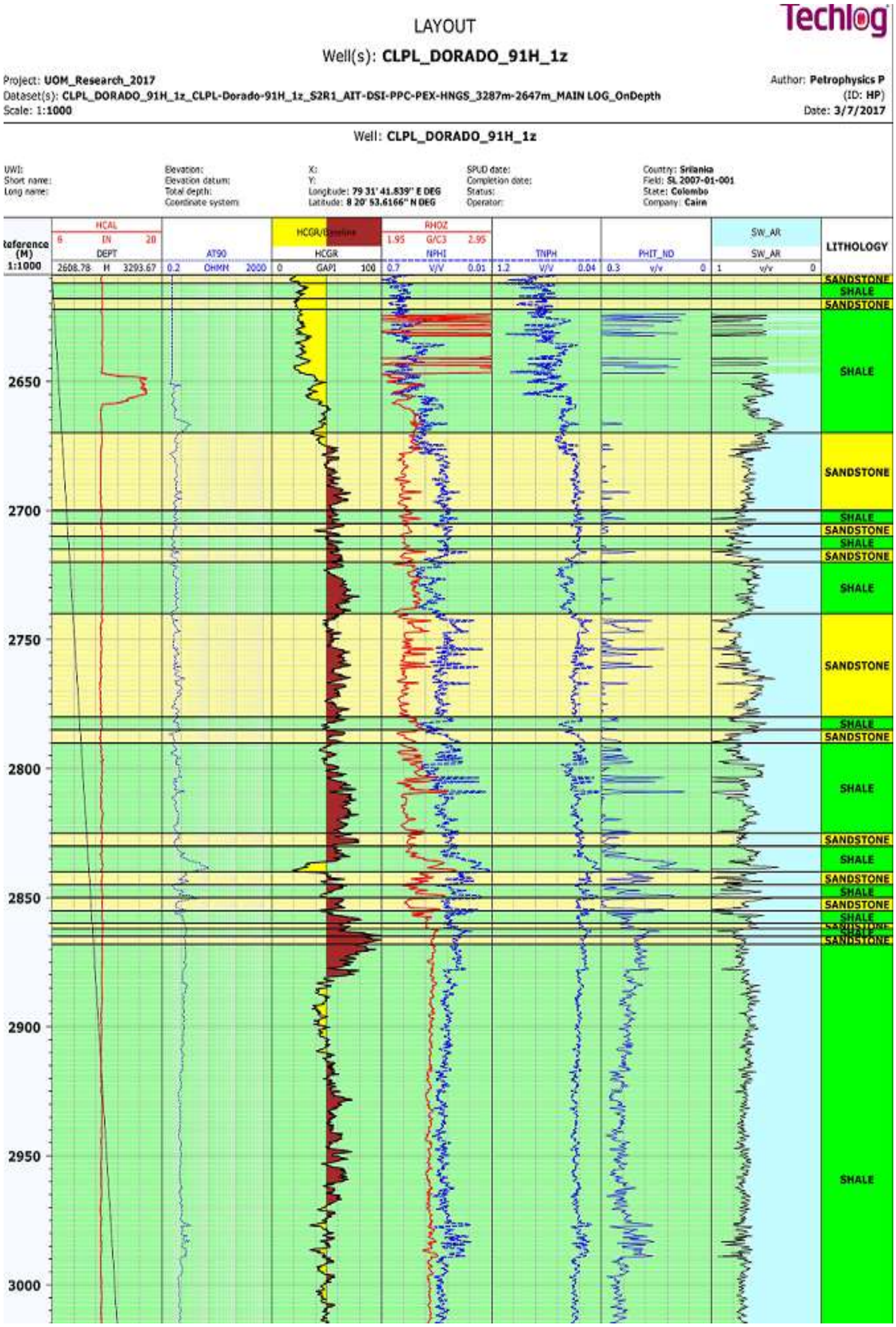

Figure 1– Part of the results of Quick look Analysis of Dorado

Both Juhasz Model and Dual Water Model gave same results of 0.89 for water saturation in the Dorado well. It was the heighst value calculated, while Equivalent SWE calculation model derived the lowest value of 0.46 for water saturation.

3.2 Results of Barracuda Well

From the Quick Look analysis of Barracuda well, seven payzone intervels could be found with varing thickness of around 10m to 20m. Part of the Quicklook analysis results of Barracuda well done with Slumberger Technlog software is presented in Figure 2.

Results of water saturation calculation done using five models for Barracuda Well also showed different values (Table 2).

Table 2 – Average water stuaration values of Barracuda Well

Model	Avg_SW
Archie	0.60
Equivalent SWE calculation model	0.65
Indonesia(Poupon-Leveaux)	0.85
Dual water	0.84
Juhasz	0.83

Both Juhasz Model and Dual Water Model gave same results of around 0.84 for water saturation in the Barracuda well. It was the highest value calculated while Archie's model derived the lowest value of 0.60 for water saturation.

The results of water saturation calculation of both wells show that the value deived from one model is differ than other, except in Johansz Model and Dual Water Model. Both of these models were related to Waxman-Smmith-Thomas Model. Dual water model is based on the same Shell dataset. The Normmalised Waxman-Smith Model or the Johansz Model uses parammeters that can be determmined from logs and converts the Waxmman-Smith-Thommas model into a form that can be used without SCAL measurements. This is the main reason for deriving similar values from these two models.

Compare to other two methos ,Archie and Equivalent SWE Calculation Model, Indonesia Models gave a closer water saturation value to value derived from Dual Water Model and Juhasz Model for both wells.

When using the Archie's Model, values for cementation factor (a), cementation exponent (m) and saturation exponent (n) had to be determined with Special Core Analysis Data. In the case of Dorado and Barracuda wells, no SCAL data were obtained from the well-logging programme. Therefore, calulations were done by assuming that a =1, n=m=2 which are used in general cases. The same assumptions were used in Dual Water Model and Johasz Model.

The lowest value calculated for water was recorded as 0.46 for Doardio well and the height value was 0.89. For the Baracuda well, the lowest value was 0.60 and the heighest was 0.84. This shows the variation of value of water saturation which depends on the model that is used.

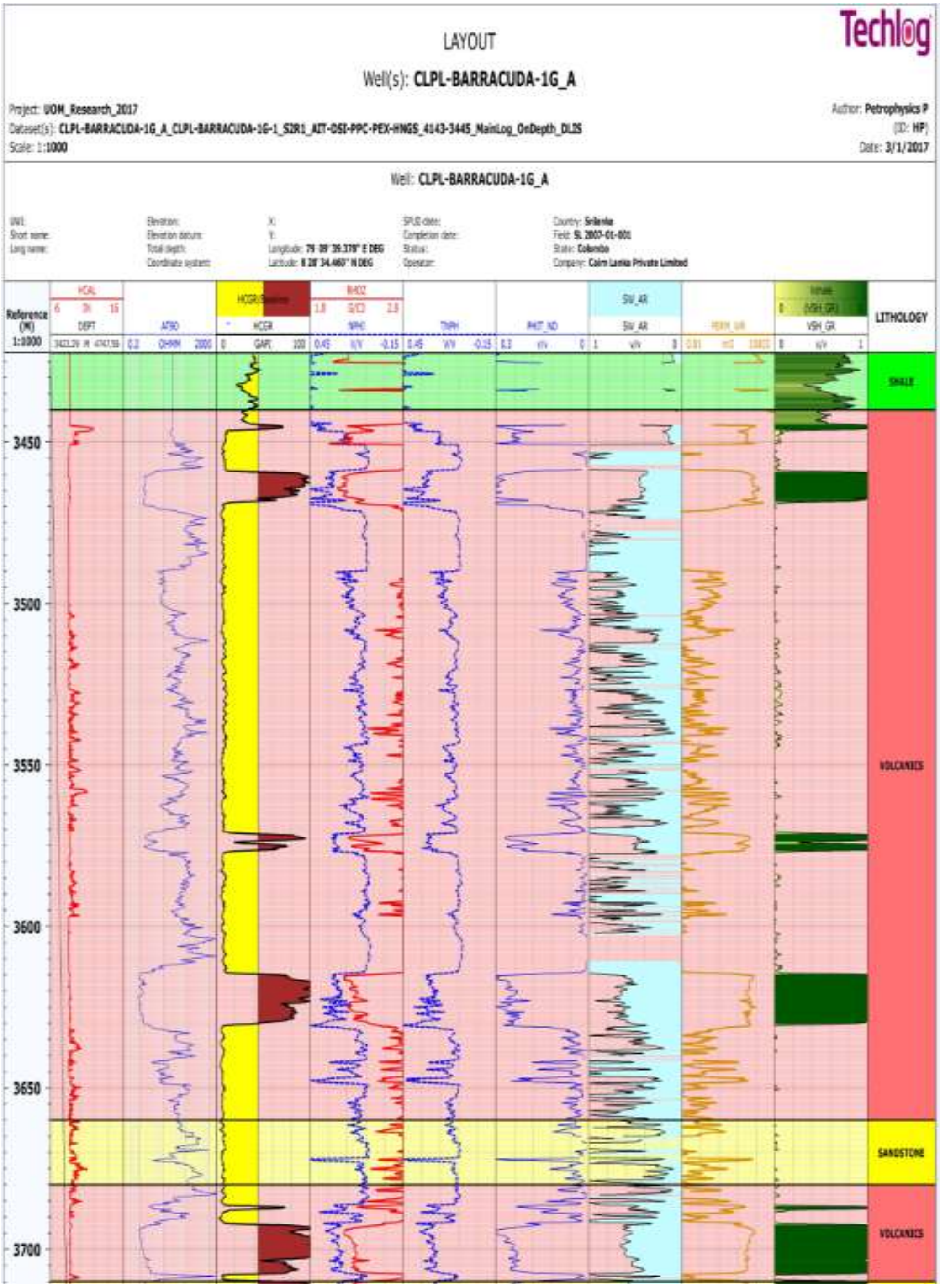

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Figure 2 – Part of the results of Quick look Analysis of Baracuda

As water satutaion is a key parameter in calculating the reservoir estimate, variation of value even in the second decimel place makes a significant diference in the reservoir volume.

4. Conclusions

Dual Water Model and Juhasz Model derived the heighest saturation value for both Doardo and Baracuda wells

Archie Model gave the lowest water saturation value for Baracuda well while Equivalent SWE calculation model gave the lowest value for Dorado well.

Water saturation value calculated from Dual Water Model and Juhasz Model are comparatively similar in both wells.

For Dorado well, calculated value for water saturation varied between 0.46 and 0.89 for the used models. For the Baracuda well, variation was between 0.60 to 0.84. Therefore, it is viatal to select the suitable water saturation calculation model for the reservoir as it directly affects the reservoir volume.

5. Recommendations

Since there was no special core analysis data for both wells, reservoir specific parameters like Archie Constant, Cementaion Factor could not be derived and general values were assumed for those paramentes. Therfore, it is recommended to do special core analysis to determine these parameters to get an accurate estimation.

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