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Comparison of Log and Empirical High Function Saturation and It's Effect on Volumetric Calculations

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ABSTRACT: This paper discusses the comparison of the Saturation Height Function between the saturation calculation method based on log data using various equations such as Archie, Indonesia and Dual Water with the empirical method which is popularly used in the oil and gas industry, namely the Cuddy method. The advantages and disadvantages of each method will be discussed. Each method of calculating saturation with log data is compared with the Cuddy method to get an idea of which geological conditions are most suitable for the Cuddy method. This study was carried out by modeling the well oil saturation height profile from an Oligocene well from the North West Java Basin of Indonesia. This well was chosen because it did not have complete data, only a series of Electrical logs and no conventional core and SCAL data. Apart from comparing each method on the well, this paper also compares volumetric calculations based on the resulting oil saturation height profile model.By comparing the results of each volumetric calculation, we can find out which method gives better results so that without core data we can still make STOIIP predictions quite validly.

KEYWORDS: Saturation Height Function, Log, Archie, Indonesia, Dual Water, InPlace

I. INTRODUCTION

Size Volumetrics are static measurements based on geological models that use geometry to describe the volume of hydrocarbons in a reservoir. Volumetric estimation is currently the only way available to assess hydrocarbons present prior to drilling. The purpose of calculating volumetric estimates is to evaluate a reservoir and calculate the potential reserves of the reservoir in question. Once drilling begins, pressure and production data are collected providing greater insight into the volumes that need to be evaluated. To perform volumetric estimates, geoscientists must use whatever data they have collected such as core analysis, logs, seismic and other surveys.

One of the important factors used in making geological models or commonly known as static models which will later be used to calculate the volumetric amount of hydrocarbons is the distribution of hydrocarbon saturation which in static modeling is known as the oil and/or gas saturation height profile (Figure 1). This profile, if complete data is available, is usually created using an approach known as the capillary pressure method obtained from Special Core Analysis (SCAL) data. However, as is known, core rock data does not always exist in an oil and gas field, even if there is, the core data is not always analyzed and used as the data needed to create the saturation profile, so other methods are needed. which can be used as a substitute for the saturation profile generated from SCAL data.

The popular method used in the oil and gas industry to create a Saturation Heigh Function profile if Special Core Analysis data is not available is to replace it with Saturation calculations using petrophysical methods from wire logging data and empirical methods, namely the Cuddy method and other empirical methods.

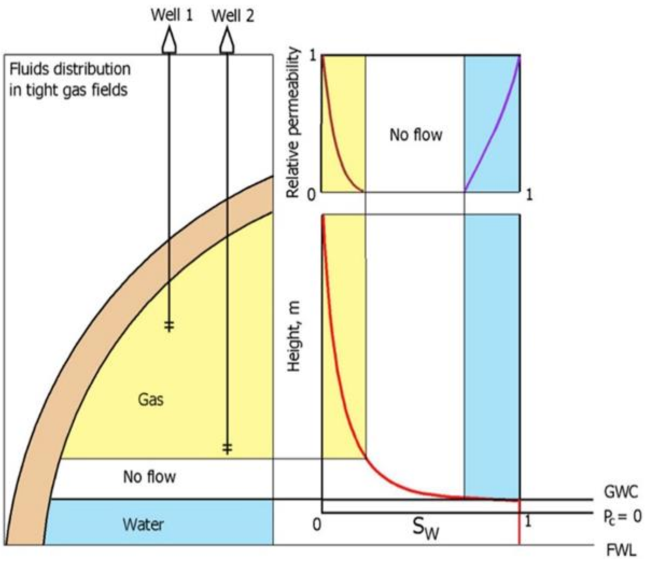

Figure 1: Saturation High Function, (Svetlana et all, 2022)

By comparing the Saturation Heigh Function profiles obtained from the two methods above, we will get which petrophysical calculation method is closer to the empirical method and an explanation of why other petrophysical methods do not approach the empirical method or whether there is a correction for the empirical method so that it can approach the profile resulting from the petrophysics calculation.

II. LITERATURE REVIEW

In a reservoir, the fluid is initially in equilibrium within the porous spaces of the rock. Two immiscible fluids sharing the same pore space tend to occupy different positions depending on their density contrast. Three main forces influence the amount of any fluid in a reservoir: gravitational forces (buoyancy), external forces (flow originating from an aquifer near the reservoir, for example) and interfacial forces. The influence of the latter on the amount of liquid and the interface.

III. CAPILLARY PRESSURE AND WETTABILITY

Capillary pressure can be explained by the interaction between fluid-fluid and fluid-solid causing differences in fluid pressure. Imagine a rock whose pore spaces are filled with two immiscible liquids. Each fluid will interact with the pore surface (solid) and with neighboring fluids that share the same pore space. The interaction effect will depend on the intermolecular forces of attraction (forces): fluid-fluid interactions, will give rise to surface tension; The surface area of a solid occupied by a fluid depends on the affinity of its molecules for the solid. The degree of affinity is determined by the angle formed between the fluid interface and the solid surface, which represents the wettability of the fluid. The smaller the angle, the greater the wettability of the fluid. Drainage occurs when hydrocarbons migrate into reservoirs and displace water. To replace hydrocarbons, water needs to overcome the pressure of rock displacement caused by capillary pressure.

IV. FREE WATER LEVEL (FWL) AND FLUID CONTACTS

The free water height, FWL in water-wet rock, is defined as the point below fluid contact where capillary pressure is zero. It is also used as a reference in many modeling Saturation-Height functions over which height is measured. Above FWL where the capillary pressure is different from zero hydrocarbons can displace water. In logging analysis, formation pressure data plotted against True Vertical Depth is used to predict free water height by examining the points where fluid pressure gradient lines intersect. For fluid contacts, inference is handled differently because the position can vary as a function of pore size: small pore size rocks tend to change having fluid contacts slightly further up from the FWL compared to large pore size rocks. In addition, these layers can also be covered by layers of shale in shale sand sequences, or almost unpredictable thin layers.

V. FLUID SATURATION

The amount of fluid in the pore space of a rock determines the saturation of a reservoir. There can be found three types of fluid in a reservoir: Water, Oil and Gas. The sum of the three fluids will correspond to the total pore volume and the saturation of each fluid will indicate the individual contribution of each fluid to the total.

VI. WATER SATURATION (SW)

Water saturation corresponds to the ratio of water volume to pore volume of a rock sample. The water fraction that cannot be replaced by capillary forces and is usually attached to the rock matrix is often called irreducible water saturation. There are many different approaches to calculating water saturation along the wellbore. The most common, in the field of petrophysics, is the Archie Formula.

VII. SATURATION-HEIGHT FUNCTIONS (SWH)

Several studies on Saturation Height were developed over the years, which resulted in different methods for calculating Sw through SwH modeling. The available literature divides them into two types: those based on the average of the capillary curve and those based on log methods. A third type that integrates both has also been considered. The next few lines will explain some of them.

VIII. CLASSICAL FUNCTION (LEVERETT FUNCTION)

A paper produced by Leverett (1940) described the behavior of capillaries in porous solids, its aim being to consider the application of the principles of thermodynamics and physics to the static and dynamic behavior of fluid mixtures. In contrast to empirical science, it uses the physical properties of rocks to describe dimensionless functions that try to produce universal curves. He relates the definition of interface curvature and its relationship to three important parameters whose shape is a function of the tension between fluids that produce differential pressure across the interface (Figure 2). This first relationship is described by the equation:

$$PC = \gamma \left(\frac{1}{R1} + \frac{1}{R2}\right)$$

Where γ is the interfacial tension, Pc is the capillary pressure$\left(\frac{1}{R1} + \frac{1}{R2}\right)$, corresponding to the principal curvature of the surface and R1 and R2 are the principal radii of curvature.

IX. CUDDY ET AL

A simple function was developed by Cuddy that relates the product of porosity and water saturation to the height above the free water level as expressed by Equation below

$$-\log(\varphi . Sw) = A * \log(h) + B$$

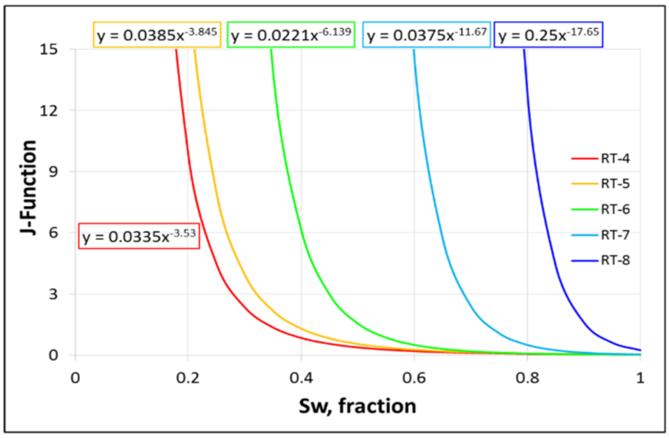

Figure 2: J-function developed for all the rock types (M. N. Ali Akbar et.al, 2016)

This correlation has been developed based on the data of gas reservoirs in southern North Sea whereby, above transition zone, one observes an increase in porosity as water saturation decreases and vice versa. Hence, it takes no account of lithology and is biased towards fitting the water saturation data in the better quality sand. In our study we also included the effect of permeability in the above equation in the following form:

$$-\log(\varphi . Sw) = A * log(h) + B + C * log(k)$$

where A, B and C are constants. For the present study, the values of the constants of equations above were obtained as: A=0.2798, B=0.7676, C=0, and A=0.2902, B=0.6113, C=0.0705, respectively.

It should be noted that when using these values h (height), and k (permeability) are in (m) and (mD), respectively, and porosity, water saturation are in fraction of pore volume

X. RESULT AND DISCUSSION

The Upper Cibulakan Formation (CBA) carbonate reservoir, which is the object of this research, is located in the North West Java basin, Indonesia. It is an oil-producing carbonate reservoir, composed of local Packstone and Wackestone - locally found mudstone, cream to light gray in color, brittle, angular sharp, calcite in line with the crossplot results from the log (Figure 4). From the petrographic incision description of the CBA carbonate reservoir: The sample is dolostone, mud to grain-supported containing common bioclasts are including larger [LF], smaller benthic and planktic foraminifera, echinoderm [Ech], molluscs and bryozoans. The original matrix has been almost totally replaced with very fine dolomite crystals (Figure 3). The matrix is composed by lime mud [LM] which is associated with clay material. The lime mud has also been recrystallized to micrite. Carbonaceous organic material occurs as fine particles. Widespread very fine dolomite occurs as replacements of original matrix.

Dolomite sometimes also replaces the plate of echinoderm, and along with calcite [Ca] and pyrite inside the chambers of foraminifera. Locally calcite was overgrowths on echinoderm plates.

Pyrite is also recorded within the matrix at the time of drilling, loss is sometimes found, has a porosity property of 4 to 30%, permeability of 0.31 to 757 mD from core analysis

Log GR ranges from 8 to 63 GAPI, Resistivity 0.1 to 61 Ohmm, Neutron 0.03 to 1 Phiu, density 0.9 to 2.7 G/C3, PEF 0.5 to 17 B/E and dt 47 to 97 µs /Ft. Total porosity from log 0 to 33%, effective porosity 0 to 30%

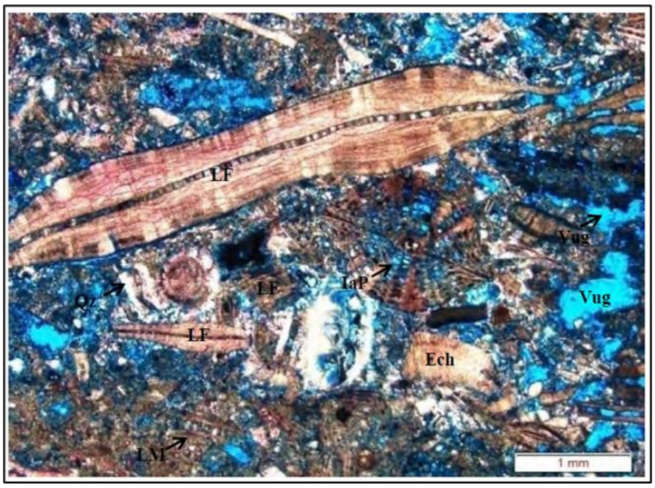

Figure 3: Petrography of the Upper Cibulakan Carbonate Reservoir

The calculation of water saturation uses the respective petrophysical calculation methods, the Archie equation; 5 to 100%, average 56%, the Indonesian equation 5 to 100%, average 74% and the Simandoux method; 16 to 100%, average 72% (Figure 6 a-f). Saturation results calculated using the Cuddy method were 13 to 83%, average 55% (Figure 6 g-i)

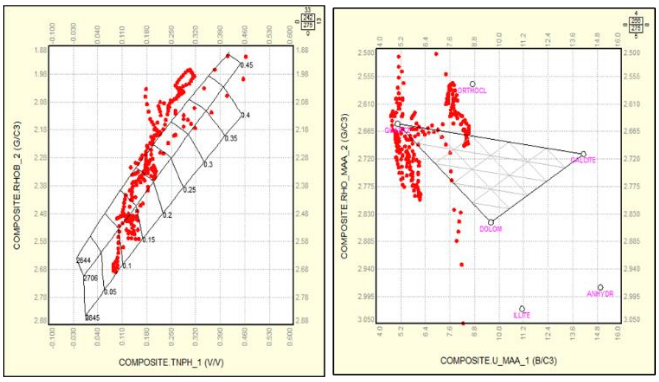

Figure 4: Crossplot Logging showing Calcite lithology

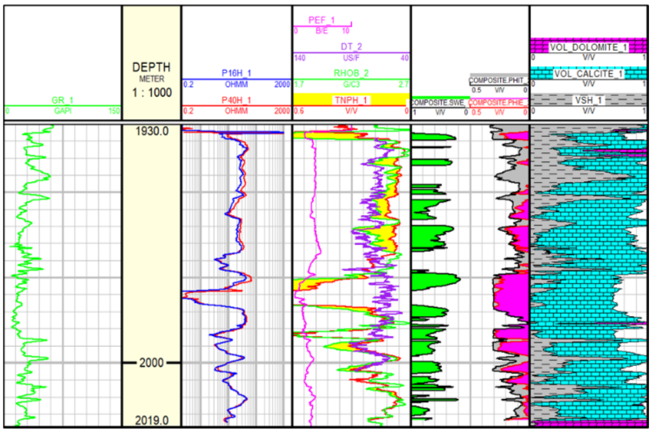

Figure 5: Petrophysical analysis of the CBA carbonate reservoir

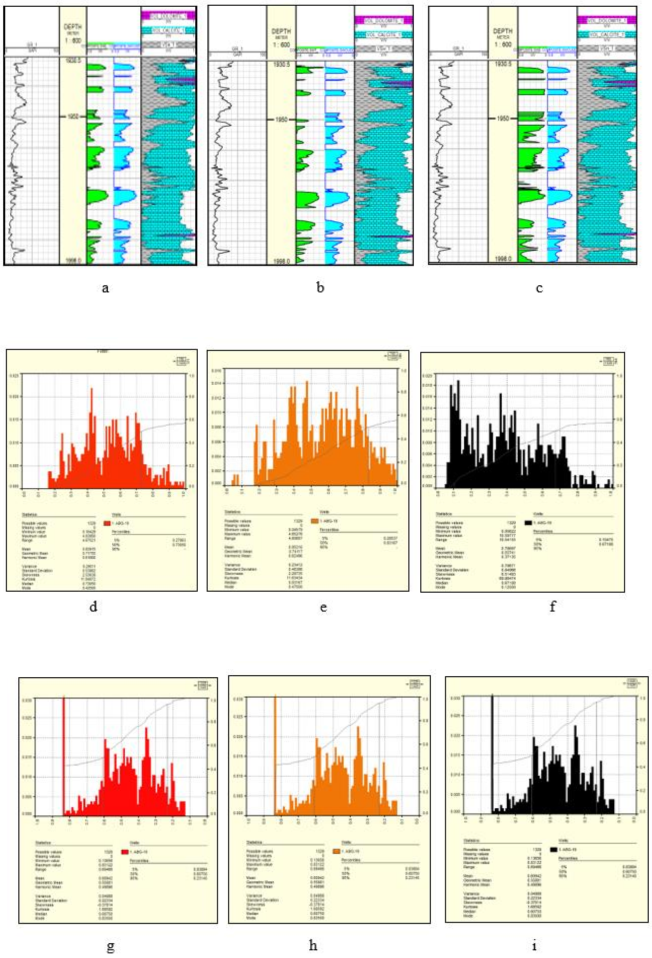

Figure 6: Comparison of saturation between the Indonesian, Archie, Dual Water and Cuddy methods

XI. COMPARATIVE ANALYSIS OF SATURATION HEIGHT METHODS

Each of the saturation height methods was used to predict saturation trends in our two example wells. Apart from comparing the average saturation predicted in the well, the distribution of each is also made in cube form. Figure 7a is the Saturation Height Function Distribution Using the Archie Method, while Figure 7b is the Distribution of the Saturation Height Function Using the Cuddy Method.

The saturation trend is then integrated with the gross rock area (GRA) vs. The height curve to calculate the volumetric estimate of the existing hydrocarbons, from SNI is then used to measure how close the estimated saturation height function is using the empirical method, in this case the Cuddy method, to the value derived from the log.

From the values obtained from calculations using each method, although Cuddy's results are still too optimistic, the smoothing results can be close to the calculation results using the Archie method for calculations from logs, namely 55 and 56%.

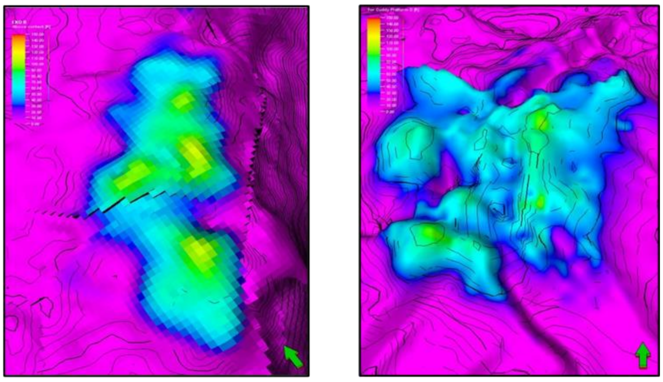

Figure 7: Distribution of Saturation Height Function Using Method Cuddy (a) and Archie (b)

XII. DIFFERENCES INPLACE CALCULATION RESULTS

After distributing each Saturation Height Function and multiplying it by Gross Rock Volume, the Inplace value can be calculated from each method as can be seen in table 1.

From the values we see in table 1, the Inplace value calculated using the Cuddy method has the highest value, higher than the InPlace value calculated using the 3 method calculation using log

Table 1: Inplace calculations using various Saturation Height Function methods

Formatio.	*INPLACE (MMSTB)*			
CBA Carbonate	INDONESIA	ARCHIE	DUAL WATER	CUDDY
	43.47	47.39	38.11	52.6

From this we can conclude that correctly modeling the transition zone with the saturation height function is very important, especially in the case of oil reservoirs. The three saturations derived from the log give smaller values with a difference of 10 to 27%, the highest difference is Cuddy with Dual Water and the lowest is Cuddy with Archie. The difference in the average Sw value of only 1% gives a difference in the Inplace value of 5.21 MMSTB or almost 10% due to the difference in the transition zone.

These values serve as a guide to how the saturation height function can be used to estimate the Inplace of a valid saturation height function and can be used to choose which empirical method has close to valid results if core data is not available.

A volumetric value with a very good estimate does not mean that it gives a value that is in accordance with the original, thus we must be careful in Inplace calculations, especially in selecting the average saturation height method which tends to predict
the average saturation in a hydrocarbon column and not the actual value at a given depth. It has been mentioned above that the Cuddy method outperforms oil saturation predictions compared to other methods derived from log calculations because there are many assumptions in the saturation calculation which causes the STOIIP estimate from the Cuddy function to be much higher than the others
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CONCLUSIONS

1. The four saturation height function methods that are popularly used have been calculated and compared, namely calculations using logs with various methods, namely Archie, Indonesia and Dual Water with calculations using the empirical Cuddy method
2. This method is used to predict the saturation level in carbonate reservoir oil wells in North West Java. The resulting saturation height function is then integrated with the GRA-height transformation of the reservoir structure to estimate the volumetric hydrocarbons in place.
3. The Cuddy log-based method is the simplest and easiest to carry out and then the results are compared with other commonly used saturation calculation methods, namely Archie, Indonesia and Dual Water. All tested methods perform quite well. Hydrocarbon saturation is estimated to be in the range of 56-74%
4. All methods for estimating OOIP that are different from the Cuddy method have a difference between 5.21 – 14.5 MMSTB
5. There is quite a large difference in the STOIIP estimate between the calculation method using saturation which is commonly used compared to the Cuddy method, possibly because the transition zone is different and the estimated data used in the calculation using the Cuddy method is less valid
6. SCAL data is needed for subsequent research to produce more accurate calculation figures

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