Determination of Water Saturation Based on Well Logging in Mishrif Carbonate Reservoir

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Abstract: Water saturation is calculated by many models that developed over the years based on known physical principles or on empirically derived relationships. The accurate determination of water saturation in complex carbonate reservoirs is the most challenging aspects of well log analysis. The complex formation under study is Mishrif carbonate formation which is one of the deepest hydrocarbons bearing zone in the Nasiriya oilfield in south of Iraq. The available scanned copes of well logs are digitalized by using Neurolog software. Schlumberger charts 2005 had been used for environmental corrections. These correction charts are supplied in the Interactive Petrophysics software. Simple Archie equation, Dual water model, and Indonesia model have been used to calculate water saturation of Mishrif carbonate formations. After making the environmental corrections, the porosity interpretation shows that the logging tools have a good quality of data reading. From Indonesian model, the water saturation for Mishrif formation is ranged from 0.25 to 0.41. This study is provided water saturation values with depth that should use to calculate original oil in place and detect the perforation zones in the pay zone using Interactive Petrophysics software.

Keywords: Porosity, Water Saturation, Carbonate Formation, Mishrif Formation.

1. Introduction

Fluid flow through heterogeneous carbonate reservoirs (limestone and dolomite) is a substantially different process from the flow through the homogeneous sandstone reservoir. This variation is largely cause to the fact that carbonate rocks tend to have a more complex pore system than sandstone [1]. In terms of rock types, carbonate reservoirs are very heterogeneous. Therefore, in order to define average values and trends of petrophysical parameters in the reservoir rocks, the reservoir should be split into layers on the basis of the dominant rock type.

The behaviour of petro physical properties of complex carbonate reservoirs is a highly Nonlinear because these reservoirs are a heterogeneous in nature. In carbonate petroleum reservoirs, many forms of heterogeneity in rock properties are present. Estimation of the volume of hydrocarbons and their flow patterns depend on porosity, permeability and fluid saturation which are the key variables for characterising a reservoir. Porosity can be determined by using different logging devices. For example, if a density logging tool is to be used, the rock matrix density must be known in order to determine the porosity. Likewise, using sonic log for porosity determination, the known parameter must be the matrix travel time and for neutron log, the parameter that must correspond to the

rock type is the matrix setting for the neutron logging tool. Formation density log, sonic log or neutron log all, can determine the values of porosity [2]. The density log is a continuous record of a formation's bulk density. It is used mainly for the determination of porosity, and the differentiation between liquids and gases (when used in combination with neutron log). When organic content is present, density is low. Variation of density indicates porosity changes. For example, low density indicates high porosity [3].The density tool responds to the electron density of the material in the formation. Formation bulk density (RHO_B) is a function of matrix density, porosity, and density of fluids in the pores (salt water, fresh water mud, or hydrocarbons). The formula for calculating density-derived porosity is [4]:

$$\Phi D = \frac{2.71 - \rho_B}{2.71 - \rho_f} \quad \text{.....(1)}$$

Where: RHO_B: is the bulk (matrix) density, [2.71 (gm/cc) for limestone, 2.87 (gm/cc) for dolomite and 2.65 (gm/cc) for sandstone]. RHH_f: is the fluid density (gm/cc) [fresh water mud = 1, for salt water mud 1.1].

Neutron logs are porosity logs that measure the hydrogen concentration in a formation. In clean formations (shale-free), where the pores are filled with water or oil, therefore hydrogen is concentrated in the fluid-filled pores, energy loss can be related to the formation porosity. Whenever shale is part of the formation matrix the reported neutron porosity is greater than the actual formation porosity [5]. The neutron log is used mainly for lithology identification, porosity evaluation, and the differentiation between liquids and gases when used in combination with density log. On cross-plot of neutron and density logs, pure shale can be recognized by the high neutron value relative to the density value which gives a large positive separation to the logs while gas stands out distinctly giving a large negative separation[6].

The sonic log is a porosity log that measures interval transit time (Δt or DT) of a compressional sound wave traveling through the formation, the interval transit time depends upon both lithology and porosity. Wyllie time-average equation may be written as follows [7]:

$$\Phi s = \frac{\Delta t_{\log} - \Delta t_{mat}}{\Delta t_f - \Delta t_{mat}} \quad \text{.....(2)}$$

Where: Φs is sonic-derived porosity, fraction, Δt_{ma}: is the interval transit time in the matrix [Its value is 47.6μsec/ft for limestone and 43.5 μsec/ft, for dolomite], Δt_{log}: is the interval transit time in the formation, μsec/ft., Δt_f: is the interval transit time in the fluid within the formation [For fresh water mud = 189 (μsec/ft); for salt-water mud = 185(μsec/ft)].

One of the most controversial problems in the formation evaluation is the clay effect to reservoir rocks [8]. Shale is usually more radioactive than sand or carbonate, gamma ray log and other logs can be used to calculate volume of shale in porous medium. The volume of shale expressed as a decimal fraction or percentage is called shale volume (V_{shale}) [9]. The volume of clay can be calculated from gamma ray log, the minimum value of clay (V_{clay}) is the closest to the truth [10].

The total natural radioactivity of the formation is provided by the spectral gamma ray (SGr) measurements. The spectral gamma ray tool detects the naturally occurring gamma rays and defines the energy spectrum of the radiations. Because Potassium (K), Thorium (Th) and Uranium (UR) are responsible for the energy spectrum observed by the tool, their respective elemental concentrations can be calculated [11].

$$V_{clay} \le \frac{SGr - SGr_{\min}}{SGr_{\max} - SGr_{\min}} \quad \text{.....(3)}$$

$$(V_{clay})_{UR} \le \frac{UR - UR_{\min}}{UR_{\max} - UR_{\min}} \quad \text{.....(4)}$$

$$(V_{clay})_K \leq \frac{K - K_{\min}}{K_{\max} - K_{\min}} \quad \text{.....(5)}$$

$$(V_{clay})_{Th} \leq \frac{Th - Th_{\min}}{Th_{\max} - Th_{\min}} \quad \text{.....(6)}$$

Since the Uranium is associated with radioactive minerals other than those found in clay (i.e. Organic materials), so it is generally not a reliable clay indicator. By eliminating the uranium contribution from the total gamma ray response and defining the Corrected Gamma Ray GrC (i.e., sum of thorium and potassium only) [12].

$$V_{sh} \leq \left[\frac{GrC - GrC_{\min}}{GrC_{\max} - GrC_{\min}} \right] \quad \text{.....(7)}$$

Where: GrC: Corrected gamma ray logs reading in the zone of interest (API units), GrC_{min}: Corrected gamma ray logs reading in a 100 % clean zone (API units), GrC_{max}: Corrected gamma ray logs reading in 100% shale (API units).

Resistivity logs were used to determine values of water saturation and consequently, hydrocarbon saturation. It is also used in conjunction with lithology logs to identify hydrocarbon bearing intervals and to estimate the net pay thickness. True resistivity (Rt) may be obtained from Deep Induction Log (DIL) or Deep Lateral Log (DLL), so any invasion correction should be applied to obtain the true resistivity which will lead to good interpretation for water saturation.

The standard practice in oil and gas fields for calculating water saturation is by using different saturation models. But these models should be tuned to the area of work which requires the estimation of parameters in the laboratory. There is always more than one fluid phase occupying the pore space in a petroleum and gas reservoirs. The fluid saturation is the petrophysical property that describes the amount of each fluid type in the pore space. It is defined as the fraction of the pore space occupied by a fluid phase. One of the most troublesome aspects of log analysis is the calculation of water saturation (S_w).There are many equations and empirical correlations have been developed over the years to calculate the (S_{wi}). Resistivity and conductivity are common methods to calculate water saturation. In the earliest days of well logging resistivity logs are the most commonly used measurements to determine (S_w). A high resistivity log reading in porous medium can be indicated of the presence of hydrocarbon [13]. While the principle of conductivity method depend on sodium cations concentration, that can be calculated in term of Cation Exchange Capacity (CEC), expressed in mille equivalents per gram of dry clay.

Archie in 1942 was introduced equation, which based on laboratory experiments on clean sands, water wettability and non- vugy carbonates. The earliest research established that for a formation with constant porosity and water salinity, an increase in resistivity indicated the presence of hydrocarbons. Archie qualified this relationship as shown in the following equation; Archie, 1942):

$$Sw^n = \frac{a.Rw}{Rt.\Phi^m} \quad \text{.....(8)}$$

In1971, Poupon and Leveaux introduced Indonesia model. This model was derived based on the fresh waters saturation and clay volume that present in many oil reservoirs in Indonesia. Conductivities of the shale and formation water are affected by the relationship between true resistivity and water saturation in this model. The Indonesia formula can be written as follows [14]:

$$S_w^{0.5} = (R_t)^{-0.5} \left[\frac{V_{cl}^d}{R_{cl}^{0.5}} + \frac{\Phi^{0.5m}}{(aR_w)^{0.5}} \right] \quad \text{.....(9)}$$

Where: d=1-0.5 V_{cl}

Conductivity models are improved the water saturation results by matching well log data with laboratory measurements. The most commonly used cation exchange capacity model is a Dual-Water model. The dual-water model is modified from Waxman-Smits model by calculation the conductivity of free water away from clay surface and relative volume of clay bound water for double-layer. This model is given by two types of formation water as follows [15]:

A- Bound Water Saturation S_{WB}, which defined as the fraction of total porosity occupied by bound water.

B- Free Water Saturation S_{WF}, which defined as the fraction of total porosity occupied by free water.

$$S_{wT} = Y + \left[\frac{R_{wT}}{\Phi_T^2 R_t} + Y^2 \right]^{1/2} \quad \text{.....(10)}$$

Where:

$$Y = \frac{S_{wB}(R_{wB} - R_{wF})}{2R_{wB}} \quad \text{.....(11)}$$

And;

R_{wT} is a resistivity of free Water, S_{wT} is total water saturation, R_{wB} is a resistivity of bound water.

Environmental corrections were made using the current Schlumberger charts (SLB, 2005), which are supplied to (IP) as the environmental correction module. Actual mud properties, calliper log, hydrostatic pressure and

3. Result and Discussion

Using IP software, corrections were achieved per 0.1524 m of depth to avoid erroneous results in water saturation interpretations. The correction charts [20] were supplied to the software as the environmental correction

The field under study is located in the north of Arabian platform in the Middle East between latitudes (34º80`- 34º60` N) and longitudes (57º50`- 60º10` E). It is anticline structure with northwest- southeast general trend. Three reservoir units contain most of the oil within the reservoir; the Yamamma, Nahr Umr, and Mishrif formations[15] which consist mainly of limestone. Mishrif formation is one of the deepest and important reservoir unit due to rudist deposits [16].

In this study, water saturation of Mishrif carbonate formation is determined using corrected well log data and compared with core data which obtained from NS-3 well [17]. The accurate determination the saturation values with depth should improve the oil in place calculation and consequently detected the perforation zones.

2. Methodology

Cross-plot techniques are employed in the analysis of well log data. A set of log data from the NS-3 in the Nasiriya oil field was used as the base data for the research reported in this paper. Neura-Log software [18] was used to digitize the scanned copies of logs in which the results as LAS files were loaded to the Interactive Petrophysics software where the reading measurements were taken as one reading per 0.1524 meters. The log curves are checked to be for depth with each other [19].

Temperature gradient were provided for accurate corrections. Depending on well log data the Interactive Petro physics software had been used to calculate the porosities and determine the lithology cross-plots.

Module. NS-3 is the well under study in the NS oil field. The environmental corrected results for porosity from density, sonic, and neutron logs are shown in Figure (1). Computer Processed Interpretation (CPI) results of effective porosity (PHIE) are closed to the core porosity logging tools have good quality after making the environmental correction.

Porosity logging tools have good quality after making the environmental correction. The relationship between core and CPI porosity is shown in Figure (3). From this figure the corrected equation for effective porosity was produced. This equation was used to correct the CPI value of the effective porosity. The main reason that leads to differences between the porosity value from core and log is the varying between properties of formation water and the mud filtrate [18]**.** The Ferro Chrome Lignite - Chrome Lignite (FCL-CL) was used as drilling mud in the studied well. The (FCL-CL) mud contains barite as a weighting agent and characterized by a high ratio of free phase (water), which lead to a high diameter of invasion zone (more than 50 in) ,that mean the investigation zone for logging tools was invaded by barite [21].

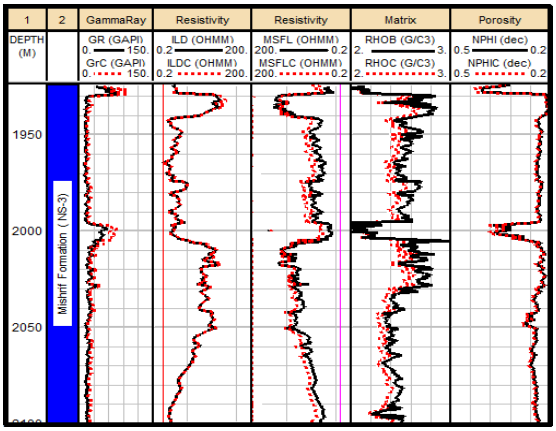

Fig. (1): Environmental correction of porosity

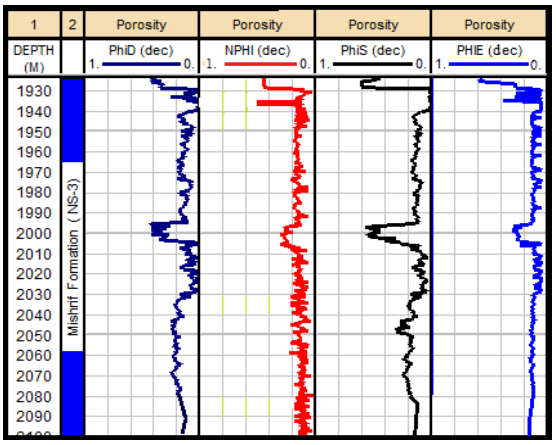

Fig. (2): Porosity results from well logs

Table (1): Comparison results of porosity Between core and CPI

Avg. PHI CORE (INOC, 1985)	**Avg. PHIE CPI**	**% Error**
0.19	0.13	31%
0.19	0.14	26%
0.18	0.15	16%
0.2	0.15	25%
0.2	0.13	35%

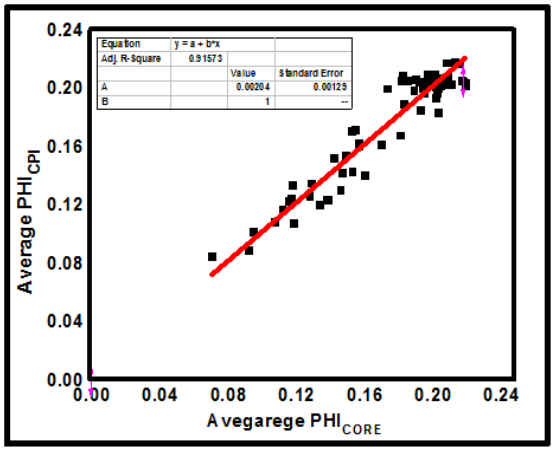

Fig. (3): ΦCPI and ΦCORE relationship

Figure (4) shows the results of apparent water resistivity (R_{wa}), true resistivity (R_t), and clay volume from gamma ray (V_{CL-Gr}). Water saturation results from dual water, Archie and Indonesian models are shown in Figure 5 as well the comparison of these models results with core saturation are listed in Table (2). From this table the water saturation results from Indonesian model are more regular in

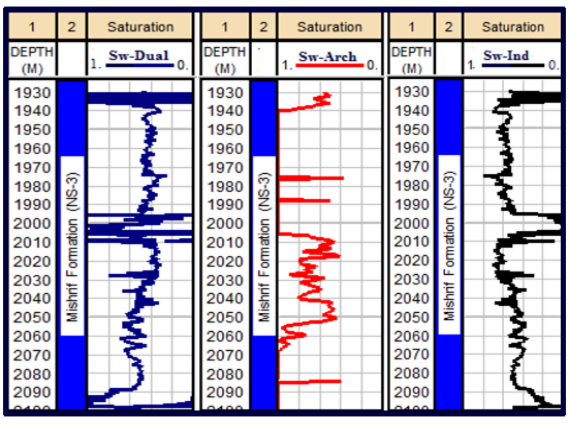

Fig. (4): Resistivity and clay volume results

Comparison with Archie and dual water models. Moreover, Indonesian model results are closed to core saturation which means this model gives the results of water saturation.

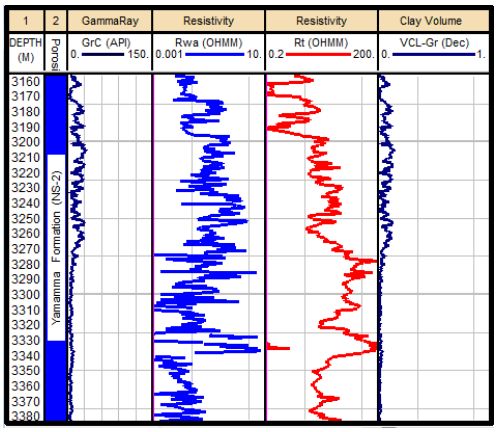

Fig. (5): Water saturation results from Dual water, Archie and Indonesian models for Mishrif formation

Table (2): Comparison of water saturation models and core saturation results

Sw Dual	Sw Arch.	Sw Ind.	Sw core
0.57	0.58	0.47	0.51
0.53	0.57	0.43	0.46
0.58	0.66	0.54	0.50
0.51	0.58	0.46	0.40
0.52	0.55	0.45	0.40

Archie formula gives a misleading result that ranged from 0.38 to 0.78 because it assumes that the formation water is the only electrically conductive material in the formation, which is not true for the case of shaly formation. The shale effect on various log responses depends on the type, the amount, and the way is distributed in formation [22].

In shaly formations, it is generally accepted that the Dual water conductivity model which using total porosity gives water saturation results that are more consistent than Archie's equation [23]. However, the conductivity models have inherent problem which is the total porosity cannot be measured without calibration with core analysis since the dry clay matrix points does not exist in nature and is therefore not seen by the logs.

4. Conclusion

The accurate determination of water saturation results gives reliable of hydrocarbon reserve calculations as well as accurate detection of perforation zones. The environmental correction for sonic, density and neutron logs gives accurate values of porosity and the average effective porosity for Mishrif formation is almost between 0.05 and 0.15. The Indonesian model gives water saturation results that are more consistent than other type equations and closet to the core saturation. The average water saturation value of this model for studied formation is located between 0.25 and 0.41.

5. References

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