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Evaluation of water saturation models in shaly limestone zone of Asmari formation, Kupal oil field, SW of Iran

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Abstract

Fluid saturation is one of the most important parameters that is used to determine the properties of oil reservoirs. In clean formations, water saturation is calculated by Archie's relation. However, in shaly zones, Archie's formula should change, or a new model should be generated that connect saturation with petrophysical parameters of the reservoirs such as the volume of shale, effective porosity and specific resistance. This practical study has used actual well logging data from the field of South West of Iran to evaluate and compare the most popular fore shaly limestone models for calculating water saturation. In this study, water saturation was calculated by Indonesia, Waxman-Smiths, Simandoux models and CEC on Asmari reservoirs in one of the wells of Kupal oil field. The results show that shale volume models calculate the rate of water saturation more than CEC models. In smaller reservoirs zones, the use of CEC models brings results that are more realistic. Asmari formation is the main hydrocarbon reservoir in the South-West of Iran.

***Keywords**: Petrophysics, Water saturation, CEC model, Asmari formation, Kupal oil field.*

1. Introduction

Porosity and saturation of fluid are important parameters that are used to determine the properties of oil and gas reservoirs [1]. One of the most important goals of the analyst is to determine a fraction of vacancies filled with hydrocarbons. The saturation is equal to the ratio of saturated vacancies volume of the fluid (V_h,V_w) to the total volume of vacancies (V_t). Saturation is used for water (S_w) and hydrocarbon (S_h) (relations 1 and 2).

$$S_w = V_w/V_t \quad (1)$$

$$S_h = V_h/V_t \quad (2)$$

Shale is the most important components of the rocks in the analyzer and have an important effect in the permeability and porosity. They have an important effect on the electrical properties of the rock due to certain electrical properties and influence the saturation.

In the clean formations (without shale), water saturation is calculated by Archie's relation [2]. In shaly formations, the negative ions of clays freely move within the formation and create conductivity. The use of Archie model [2] in determining the saturation in the shaly formation shows the amount of saturation more than the actual amount [3]. The Archie formula relates the specific resistance of the formation and saturation to each other. Assuming that only the electrolyte, which presents in the vacant spaces can have flow conductivity, and other parts of the rock are nonconductive [4], in the presence of the shale, the Archie formula should change, or should be considered under the influence of shale or there should be a new model that provides for saturation and special resistance in shaly formations.

2. Geological setting

The Kupal oil field is located at 66km NE of the Ahwaz City and in the middle of Dezful Embayment. This oil field is asymmetry and between Haftkel in the north, Marun in south and Ahwaz in the west. This anticline is an asymmetrical structure with NE-SW trend, and southern flank dip is higher than northern flank and causes to change the axis to follow the west trend in the northern part and southern trend in the west. The thickness of Asmari reservoir in this field is about 350 m and is divided into 8 zones based on petrophysical data. The most important character of Asmari is the presence of extended natural fracture systems which causes high productivity of wells not withstanding low matrix porosity (8% on average) (Figure 1).

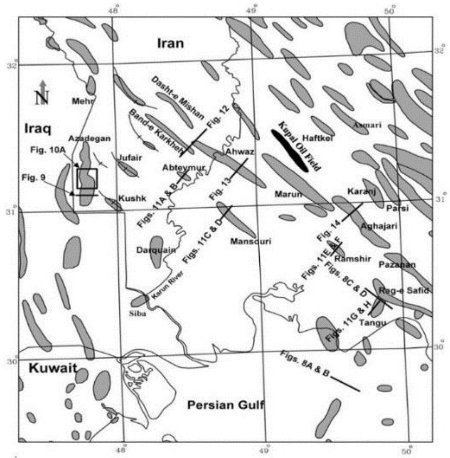

Figure 1. Located of Kupal oil field in Dezful embayment, near the other oil fields, Southwest of Iran

3. Methodology

In this study, the raw data of Asmari formation from well No.54 of Kupal oil field was evaluated via GEOLOG software ver.6.7.1 (made by the Paradigm company) and petrophysical parameter such as shale volume, Clay mineral type, and water saturation were investigated. It is considered an advanced management tool that facilitates maximum production from the reservoir [5].

4. Results and discussion

4.1. Lithology

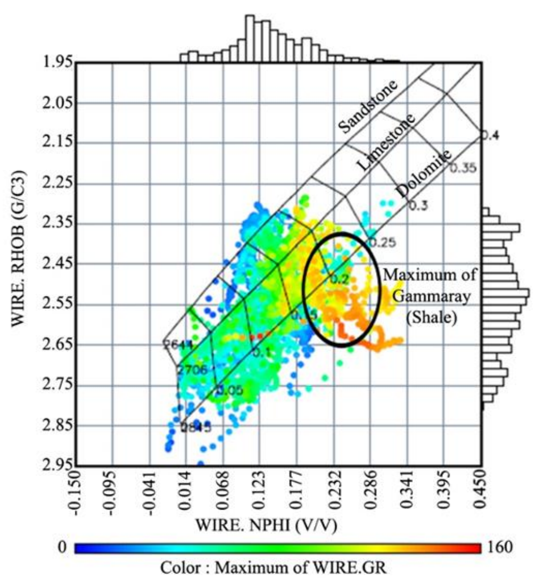

Figure 2. Cross plot of Neutron-Density-GR, Well No.54 in Kupal oil field

One of the main applications of petrophysical data is Lithology detection. Identification of lithological composition is an important step in the evaluation of reservoirs zone from non- reservoir zone. In the Asmari formation, two parts have been identified, including the sandy lime and shale with Oligocene Numolites and the Kalhor lime part that consists of cream to white lime and dolomitic lime [6]. Various graphs are used to determine the lithological composition. It is possible to identify the composition of major minerals in the reservoir such as quartz, calculate, anhydrite and dolomite using these logs. Before using Density-Neutron-Gamma (NPHI-RHOB -GR) crossed plot. First it is necessary to correct the logs in terms of shale and hydrocarbon. The logs can identify up to three different minerals. The neutron log is of NPHI type, and the density log is of RHO type. The location of the plot is a point that indicates the percentage of lithology with respect to the distance of the point from the background lines [7]. Most of the points are in the limestone and dolomite range. Gamma ray point on the dolomite and limestone lines indicate the presence of shale, but the amount of shale has decreased in the sandstone line. This indicates an increase for shale in the lime to dolomite of Asmari formation (Figure 2).

4.2. Volume of shale

Different equations and models of the saturation of shaly formations are divided into two groups. These are models that are based on the percentage of shale volume and note that the effect of shale depends on the amount of shale volume in the reservoir without beings associated with clay minerals. This model is not scientifically accurate because shale's volume is only used to justify the saturation [8]. The advantage of this model is that all of the necessary parameters can be obtained from the data of the graph such as total shale, Juhas, Simandoux, and Indonesia.

4.2.1. Simandoux model

In 1963, Simandoux obtained this model by testing on a dry mixture of the sand and montmorillonite [9].

$$S_w = \sqrt[n]{\left[\frac{aR_w}{\phi^m}\right] \times \left[\left[\frac{1}{R_t}\right] - \left[\frac{V_{sh}}{R_{sh}}\right]\right]} \qquad (3)$$

In relation 3, S_w is water saturation, ϕ is total porosity, R_t is the resistance of formation, V_{sh} is shale resistance, $R_{sh}$is the volume of shale, R_w is specificthe resistance of water, m is saturation power, n is the coefficient of cementing and a is winding factor. The percentage of water saturation frequency is 4-96 present in this model.

4.2.2. Indonesia model

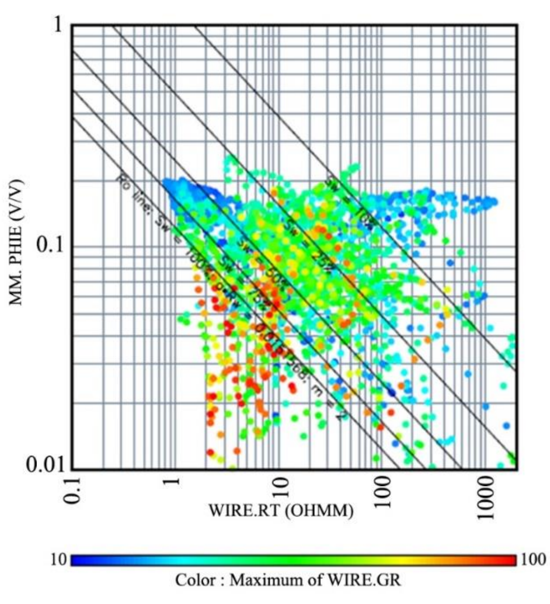

Figure 3. Water saturation (Sw) of Asmari formation for well No.54, based on PHIE to RT

Indonesia model was presented by Poupon and Leveaux in 1971 [10] that known as Indonesia. It was presented to use in Indonesia because the presence of sweet formation water and high shale percentage caused the inefficiency of other formulas in the country. This formula states that V_{sh} has a power that is a function of V_{sh} itself.

$$S_w = \sqrt[n]{\frac{1}{R_t\left[\frac{1}{FR_w}+2\sqrt{\frac{V_{sh}^{(2-V_{sh})}}{FR_wR_{sh}}}+\frac{V_{sh}^{(2V_{sh})}}{R_{sh}}\right]}} \qquad (4)$$

In (4) relation, S_w is water saturation, R_t the resistance of formation, V_{sh} shale resistance, R_{sh} shale volume, n the confidant of cementing, R_w specific resistance of water and F is formation resistance factor. The percentage of water saturation frequency has been given as 7-93 percent in Indonesia model.

In figure 3, identified the Sw of Asmari formation for well No.54, based on Indonesia model and data from PHIE, RT, and GR log.

4.3. CEC models

Clay minerals consist of a tetrahedral and octahedral structure of silica and aluminum. Due to the placement of cations with a low positive charge in clay sheets, a negative charge is generated in the clay. In order to neutralize this negative charge, ions with a positive charge (cations or exchange ions) accumulate at the surface of clay minerals [11]. The ability of clay mineral to form a dual electric layer is called Cation exchange capacity (CEC). To measure this property, the sample containing clay is first saturated with salty water, and then the barium solution passes from the sample. Sodium is substituted by Barium, and the amount of substitution is measurable. The amount of positive charge on the clay surface is called Cation exchange capacity (CEC). The CEC value should be measured in the laboratory and using a core. Although the CEC measurement is simple and is considered as a titration, but in the absence of core and not calculating it from the graph the use of CEC based formulation is limited. The effect of clay on the characteristics of the reservoir and Charts depends on the clay mineral in formation. According to this crossover chart and the plotted points in this formation, the type of Asmari clay minerals are mostly Illite and Montmorillonite with different percentages. Figure 4 shows the specification of the type of clay minerals in Asmari formation (Well No.54) using Th/K chart.

The use of two-layer ionic is not simple because QW value shows a different value in different laboratories [12]. Q_v is the amount of ions that interact with shale. Q_V value is calculated according to relation (5).

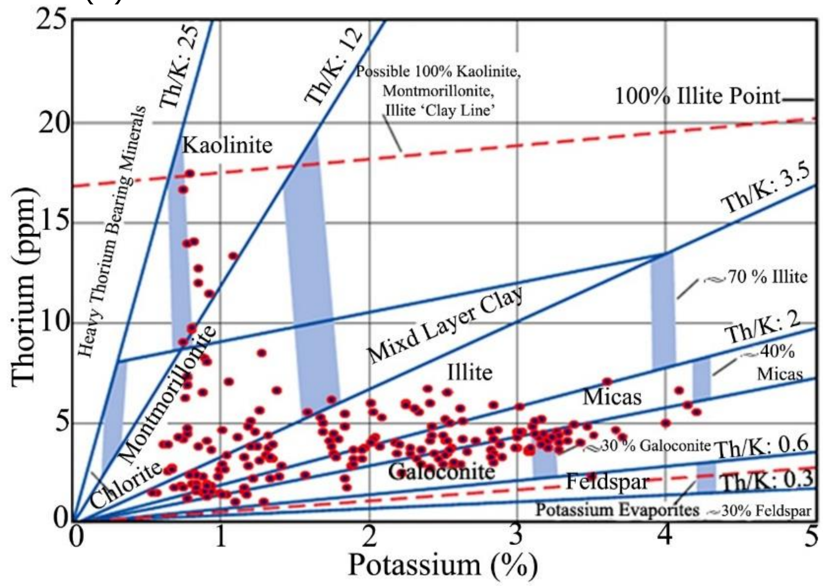

Figure 4. Identify the type of clay minerals for well No.54 in the Kupal oil field

$$Qv = CEC(1-\phi).pma\phi-1 \quad (5)$$

In relation5, CEC is cation exchange capacity, ϕ is porosity and ρ_{ma} is the density of matrix. The values of porosity and density of the matrix are obtained from well logging, but CEC value is calculated based on the core samples, and its value is different in different wells. The result of a well cannot be generalized to other wells of the same field. This relation has many problems. For example, changing the size of the grains and the amount of cementation, the porosity value also changes [13].

This model is scientifically more acceptable. To use this model, it is necessary to calibrate the shale- dependent parameters against some petrophysical quantities of the graph such as Waxman- Smiths and dual – water models. The examination of the formation with each of these formulas may lead to a result, which is not similar to other formulas.

4.4. Waxman – Smiths model

Waxman and Smiths [14] proposed an equation for the relationship between saturation and the specific resistance of the shaly formations. In this equation, additional conductivity in the rock is related to the CEC.

$$S_w^2 + BQ_vR_wS_w - \frac{aR_w}{\phi^m R_t} = 0 \tag{6}$$

In equation (6), S_w is water saturation, F is formation factor associated with the related porosity, B is equivalent to the conductivity of clay cations that contain sodium, ϕ is total porosity, m is saturation power, a is winding factor, R_t is the resistance of formation, R_w is the specific resistance of water and Q_v represents CEC per unit volume of vacancies.

Parameter B in Waxman – Smiths formula is the equivalent conductivity of NaCl and is a function of temperature and concentration of the salts.

$$B = \frac{-1.28+0.225T-0.0004059T^2}{1+(0.045T-0.27)R_w^{1.23}} \tag{7}$$

In relation (7), T is the temperature in Celsius degree, and R_w is the specific resistance of water.

Parameter Q_v is related to CEC according to relation (8).

$$Q_v = \frac{CEC \times \rho_b(1-\phi)}{\phi} \tag{8}$$

In relation (8), ρ is total density and ϕ is total porosity that can be obtained from the graphs. One of the main drawbacks of this model is that it does not take into account the absorbing properties of the clays [14]. This model calculated the percentage of water saturation frequency between 18-82 percent.

4.5. Dual Water model

Clavier, Coates, and Dumenaoir presented initial dual water model in 1977, and the latest version was completed in 1984 [15]. This model is based on 3 principles:

1. the conductivity of the clay results from CEC,
2. the CEC value of the pure clay is proportional to the specific surface of the clay mineral,
3. Clay is considered as an agent clinging to the water of crystalline clay.

The mineral clay alone is insulated. The electrical conductivity of the clay minerals is due to the water clinging to them and is not related to the type of clay mineral, and is a function of temperature and salinity of the formation water [15]. According to the above three principles, the relation of dual- water is as follows.

$$S_w = \left[\frac{(S_{wt}-S_{wb})}{(1-S_{wb})}\right] \tag{9}$$

In relation (9), S_w is water saturation S_{wt}, is total saturation and S_{wb} is the saturated water clinging to the clays. The percentage of water saturation frequency has been calculated to be 27 to 73 percent.

4.6. The comparison of water saturation models

The mean water saturation in the models o shale volume is higher than the mean water saturation in CEC models. Therefore, shale volume models show higher water saturation (Figure 5). On the other hand, in reservoir areas with low content of water and oil, the minimum water saturation in CEC models is more than shale volume models because the volume of shale is low in small reservoir areas, water saturation is measured by low shale volume models that these models don't show accurate results in small reservoir areas. In small reservoir areas, CEC models show the amount of actual water saturation because they measure this amount based on the cation exchange capacity of the clays (Figure 6).

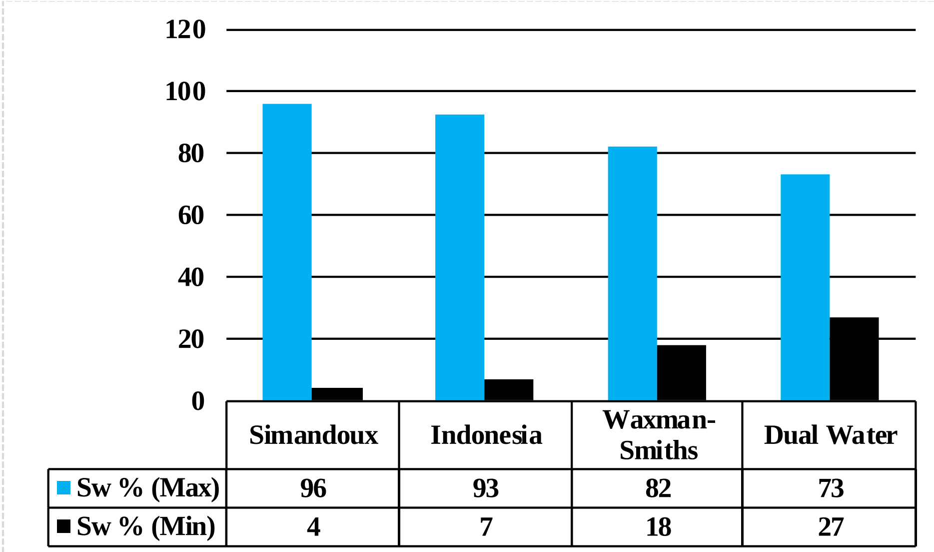

Figure 5. Water saturation percentage in fore models of water saturation

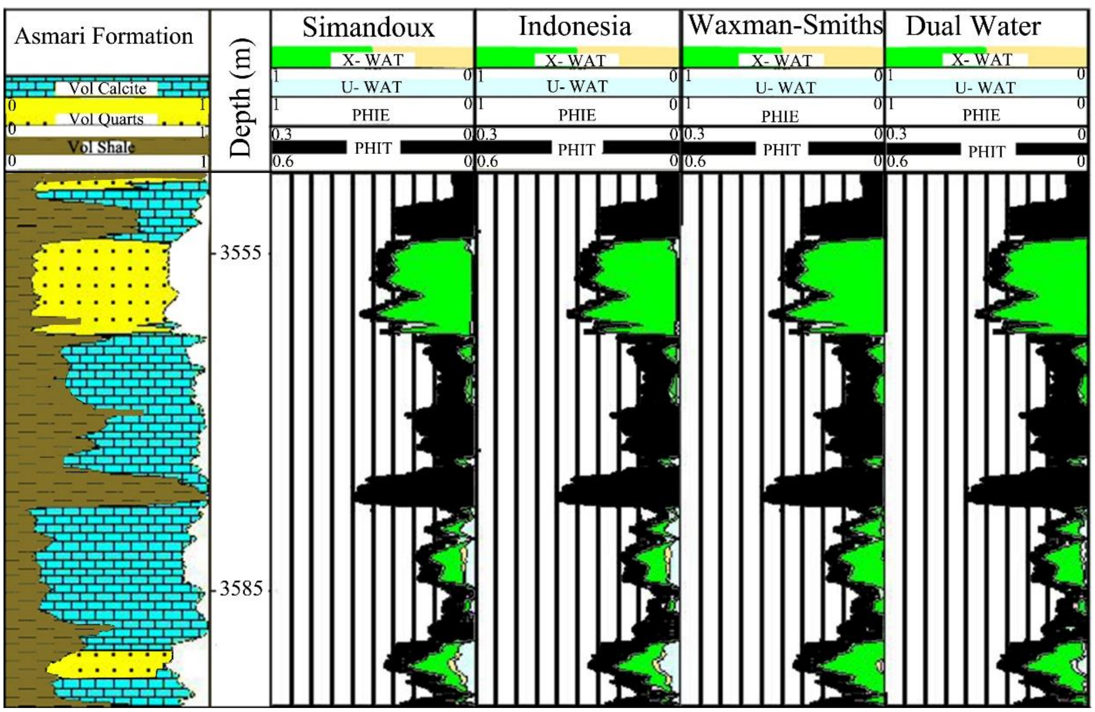

Figure 6. The mixed graph of water saturation models in Kupal oil field, well No.54.

5. Conclusions

The minimum and maximum percentage of water saturation frequency in Simandoux, Indonesia, Waxman-Smiths and dual- water is measured as 4-96, 7-93, 18-82 and 27-73 respectively. The mean of water saturation in shale volume models is higher than the mean of water saturation in CEC models. In reservoirs areas with low content of water and oil, shale volume models calculate the amount of water saturation higher than CEC models. In smaller reservoir areas, the results of water saturation of CEC models are closer to reality.

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