Journal of Mineral Resources Engineering, 7(2): 47-66, (2022)

Imam Khomeini International University
Vol. 7, No. 2, Summer 2022

نشریه مهندسی منابع معدنی
Journal of Mineral Resources Engineering
(JMRE)

Research Paper

Comparison of Core Water Saturation with Electric Models in Kangan and Dalan Formations in the Central Part of the Persian Gulf

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Received: 29 Sep. 2020 **Accepted: 09 Jun. 2021**

Abstract: Reliable and accurate determination of water saturation above the oil-water contact of the hydrocarbon-bearing formations is essential for calculating hydrocarbon in place. In this study, water saturations were measured directly from 160 core samples by Dean-stark test in one well and thin sections have been used to identify geological properties. Archie coefficients were also determined on plug samples. The water saturation values obtained from the electrical models including Archie, Waxman-Smith, and dual water were measured in Geolog7 software and applied in Kangan and Dalan formations in one of the fields in the Central Persian Gulf. In this study, four methods have been used to determine the rock types, including Winland, reservoir quality index, pore type, and depositional texture to identify the parameters affecting the distribution of water saturation. Results showed that pore throat radius is a parameter that affects water saturation and this parameter is directly related to the increased permeability and reduction of the difference between the water saturation values of Archie with the Dean-stark test. Determination of rock types based on depositional texture and pore type revealed that the cement type and texture and the pore types, control the permeability and distribution of water saturation in the reservoir. It was also found that depositional texture, unlike pore throat radius, well separates sedimentary environments. The results of water saturation calculations showed that if the Archie coefficients are calculated in each flow unit, the water saturation resulting from it would be very close to the water saturation values in the core (Dean-Stark). The electrical model of water saturation, with different coefficients in samples with different reservoir quality index or pore types, yields the most accurate water saturation values compared to Dean-Stark.

Keywords: Dean-Stark, Electrical Model, Rock types, Reservoir quality index, Kangan and Dalan Formations.

How to cite this article
Gholami, R., and Tavakoli, V. (2022). *"Comparison of core water saturation with electric models in Kangan and Dalan formations in the central part of the Persian Gulf"*. Journal of Mineral Resources Engineering, 7(2): 47-66.
DOI: 10.30479/JMRE.2021.14244.1450

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INTRODUCTION

Calculating water saturation is one of the most important steps for determining the volume of oil and gas in place. Accurate calculation of this parameter in carbonate reservoirs due to their heterogeneity has always been one of the main challenges in the oil industry. Distribution of petrophysical properties in these reservoirs is diverse due to facies changes as well as diagenetic processes[1]. Kangan and Dalan carbonate-evaporative formations are the most important gas formations in Iran, which have a very high heterogeneity. One of the most common relationships for calculating water saturation is Archie equation [2]. Categorization of carbonate rocks based on hydraulic flow units, petrophysical flow units, depositional textures and pore types leads to increased accuracy of these parameters and water saturation calculations [3]. Therefore, identification of geological parameters (depositional texture, lithology, pore type, pore throat radius and cement type) and petrophysical characteristics (porosity and permeability) affecting the reservoir heterogeneity, is very important. Also, increasing the accuracy of Archie coefficients and water saturation through providing the best classification scheme of carbonate rocks, are essential for calculating hydrocarbon in place. The diversity of the presented parameters suggests that the effect of these parameters on water saturation accuracy in the studied reservoirs should be compared with the actual data obtained from the core tests. Direct measurements of water saturation of the core by the Dean-stark experiment is one of the common methods in the industry for calculating water saturation [4]. The purpose of this study is to identify the reservoir parameters affecting water saturation to calculate in situ hydrocarbons, based on rock types and flow units. Another goal of this study is to provide the best rock type and reservoir unit to calculate the optimal water saturation and accurately determine the Archie parameters.

MATERIALS AND METHODS

The available data are from 1 exploratory well and include 270 meters of cores, 270 meters of electrical resistivity logs and 1308 thin sections. After determining Archie's coefficients, water saturation was calculated based on Archie's equation (equation1).

$$S_w = [(aR_w) / (\phi^m R_t)](1/n) \quad (1)$$

This equation determines the Sw based on the porosity (Ø), resistivity of the formation (Rt), formation water resistivity (Rw), cementation (m) and saturation exponents(n).

In this study, a total of 1252 porosity and permeability tests were performed on plug samples. Dean-Stark extraction method was used to determine core water saturation. Then, to identify the petrophysical and geological parameters effective in the average water saturation difference, rock types were determined based on Winland, reservoir quality index, pore type and depositional texture methods.

Pore type

In this study, pore types have been classified based on Choquette and Pray classification scheme [5]. Petrographical analysis indicate that 7 pore types, including fracture, interparticle, intraparticle, moldic, fenestral, vuggy and intercrystalline, are present in Kangan and Dalan formations.

Depositinal texture

Depositional textures have been arranged based on Dunham classification [6] system. Determination of rock types based on sedimentary textures shows the existence of 5 rock types including mudstone, wackestone, packstone, grainstone and boundstone for Kangan and Dalan formations.

Water saturation

To determine the values of cementation exponents and to determine the relationship between porosity and formation resistivity factor, the laboratory measured porosity (helium porosity test) and the electrical resistance of the saturated sample on clean plug have been used. Then, from the plot of the formation resistivity factor against porosity, the amount of cementation exponents in the whole well and then in each rock type was calculated (Figure 1A, Figure 1B). To determine the values of saturation exponents and the relationship between the formation resistivity index and water saturation, the amount of formation

resistivity in different saturations was measured in the laboratory on clean plugs. Then, from the plot of the formation resistivity index against water saturation, the amount of saturation exponents in the whole well and then in each rock types was calculated (Figure 1C, Figure 1D).

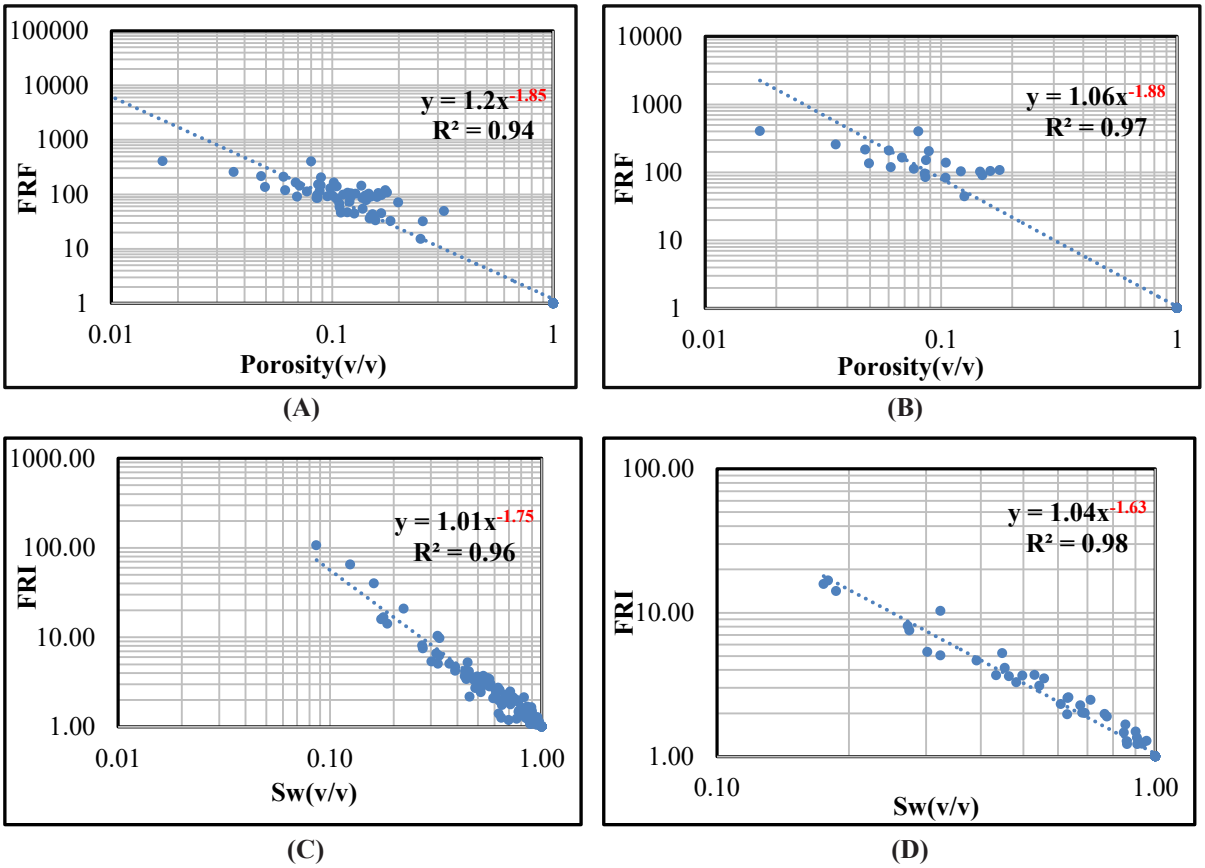

Figure 1. An example of log–log cross plot of porosity versus FRF for specified Winland method; **A:** Winland method (pore throat radius of 2-5 microns) **B:** Winland method in the whole well, An example of log–log cross plot of water saturation versus FRI for specified Winland method, **C:** Winland method (pore throat radius of 2-5 microns), **D:** Winland method in the whole well. R2, a and m are obvious

RESULTS AND DISCUSSION

Comparison of water saturation of the electrical models with the Dean-Stark between different rock types

To determine the best rock types for calculating the correct water saturation in the reservoir, the values of water saturation in different rock types including Winland, reservoir quality index, depositional texture and pore type were calculated. The lowest average water saturation difference between the Dean-stark method and the electrical model shows the best rock typing method in calculating water saturation and determining Archie's coefficients. The results showed that determining the rock types based on the reservoir quality index and pore typing yields the lowest difference between Dean-Stark water saturation and electrical models, while determining the rock types based on depositional texture and Winland method will have higher water saturation difference between the two methods (Figure 2).

CONCLUSIONS

The results of this study indicate that in carbonate reservoirs, the water saturation values of the Dean-Stark test are different from Archie method and other electrical models. To determine the geological and petrophysical parameters affecting the water saturation distribution in carbonate reservoirs, a comparison

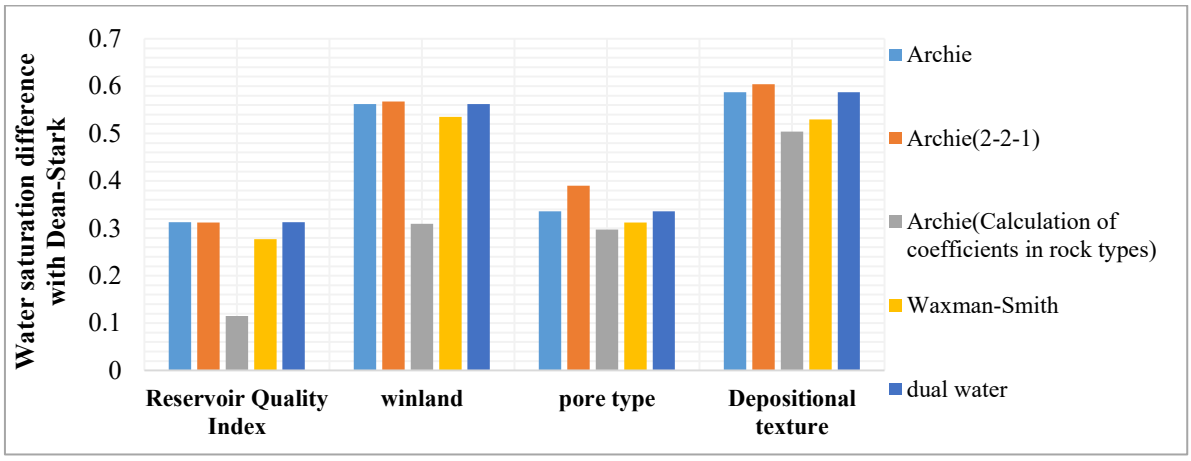

Figure 2. Water saturation difference from Dean-Stark experiment with Archie model with laboratory coefficients and Archie model with constant coefficients (2,2,1) and Waxman-Smith and dual water model and Archie method (calculation of coefficients in rock types) in different rock types

of the average water saturation difference of the electrical models was performed with the Dean-Stark tests. The results of water saturation in rock types showed that pore throat radius is a parameter that is the product of geological processes and affects water saturation and petrophysical properties of rocks. This parameter is directly related to the increased permeability and reduction of the difference between the water saturation values of Archie with the Dean-stark tests. Regarding the determination of rock types based on depositional textures and pore type, it was found that the cement types, sediment textures and pore type that is affected by diagenetic processes and sedimentary environment (facies) control the permeability and distribution of water saturation in the reservoir. The results showed that changes in water saturation in Kangan and Dalan formations have been affected by sedimentation and diagenetic processes. Comparing the water saturation of electrical models with Dean-Stark test, it was found that if the rock type is determined and the Archie coefficients are calculated in each flow unit, the resulting water saturation is very close to the core water saturation values (Dean-Stark). Also, a comparison between different rock types showed that the electrical model of water saturation, whose coefficients are measured in rock types based on the reservoir quality index method and pore type, is the best response is obtained from water saturation values compared to Dean-Stark. The average difference of water saturation between electrical models and Dean-Stark in the reservoir quality index method is 27%, which is 24% and 29% less than the Winland method and depositional texture, respectively. The values of the average difference of water saturation between electrical models and Dean-Stark in the pore type method are 33%, which is 18% and 23% less than the Winland method and depositional texture, respectively. These results show that in order to select the sample to determine the coefficients of Archie, these two methods of determining rock types in these formations are appropriate. Therefore, considering the necessity of determining rock types and also the very high ability of these two rock types in calculating water saturation and therefore accurately calculating the amount of hydrocarbons in reservoirs, the use of rock species determination by reservoir quality index and pore type is the best way to achieve accurate and reliable results is water saturation. Therefore, using these methods for other wells in this field, can also be a good idea for more accurate analysis and estimation of water saturation of nearby wells.

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