Petroleum and Coal

Article **Open Access**

New Constraints of Reservoir Quality of Arab Formation (Surmeh) in one of the Oil Fields, Persian Gulf, South Iran

Bahman Soleimani[1], Maryam Azad[2]*

[1] *Faculty of Earth Sciences, Shahid Chamran University of Ahvaz, Ahvaz, Iran*
[2] *Shahid Chamran University of Ahvaz, Ahvaz, Iran*

Received October 3, 2022; Accepted February 3, 2023

Abstract

The study of petrophysical parameters plays a major role in the evaluation of hydrocarbon reservoirs. In this study, using well data in Geolog software, the petrophysical parameters of the Arab Formation (equivalent to Surmeh) in one of the oil fields in southern Iran were studied in two ways. Based on the petrophysical evaluation and using conventional cross-plots (neutron-density) and histogram of porosity and water saturation, the lithology of the Arab Formation was determined. The lithology consists of a combination of calcite, dolomite, and anhydrite. Comparison of the results of porosity changes is more consistent with the values obtained from core analysis. According to the calculated petrophysical properties, the upper part of the Arab (Surmeh) Formation was divided into seven parts. Comparison of water saturation showed that in all zones, the range of changes is high. By comparing the zones quality, zones 5 and 6 are introduced as the best reservoir zones.

Keywords: *Arab Formation (Surmeh); Petrophysical parameters; Water saturation; Geolog software.*

1. Introduction

Petrophysical assessment, the science of interpreting the information obtained from well drawings in the study of reservoir quality and reservoir zoning to determine the most appropriate horizons in the optimal use of reservoirs and development of oil fields [1]. The studied oil field is one of the fields located in the Persian Gulf. Parameters such as lithology, shale volume (Vsh), total porosity (PHIE) and water saturation (SW) are among the most important parameters that are determined in petrophysical evaluation to assess the reservoir quality of the formation [2]. The use of complementary methods can be useful in improving the results of reservoir evaluation. By X-ray diffraction (XRD) analysis, the identification of clay minerals (less than two microns) and the mineralogy of the whole sample (bulk) can be determined with high accuracy and speed. Minerals are identified with a standard file called the Joint Committee on Powder Diffraction Standard (JCPDS) and with the help of special software such as X plot and traces with a computer. Recent advances in XRD data processing have raised the accuracy of this technology to a high level. In the new data (analysis techniques, algorithms called Lorentzian profile-fitting algorithms are used to separate the diffusion peaks of different overlapping clay minerals [3-4].

Currently, several studies have been conducted on the use of multimine and XRD methods in the assessment of reservoir zones. Basu and Dutta [5-6] studied the properties of gas shales in the Cambay Basin of India. Mishra *et al.* [7] and Mendhe *et al*. [8] used petrophysical and clay mineral properties in the evaluation of gas shale reservoirs in the Ram Jani Basin in West Bengal, India. In a study, the prospects of gas shales in the gas shale complex of the Indian basin have been studied. In this research, they have studied the petrophysical properties and also modeled the gas fields of the basin and determined the amount of gas production potential. In these calculations, researchers have estimated and determined the volume of sedimentation of materials and the amount of maturity of the layers of these sediments in performing and performing these calculations and estimating the amount of gas. Kadkhodaie-Ilkhchi [9] in the study of oil fields in South Pars, Ahvaz, Abuzar and Khark examined the petrophysical and geochemical characteristics of different reservoirs. In this study, XRD data were used to complete the information. Jagadisan *et al.* [10] and Ghassem Al-Askari [11] also combined petrophysical, and XRD methods in their studies. Kiakojury *et al.* [12] in the reservoir evaluation of Dalan-Kangan Formations in South Pars field studied petrophysical properties and factors affecting it such as sedimentary facies, diagenetic controls. Nader *et al.* [13] performed the reservoir and diagenetic properties of Arab D and C units in the UAE marine sector using petrophysical and XRD methods. Jadoon *et al.* [14] used the XRD method to calibrate mineralogical modeling results in the evaluation of Permian gas shales in the Cooper Basin, Australia. Taheri *et al.* [15] in a study to determine the petrophysical parameters in one of the gas field using Geolog software and stated that the study of the properties of rocks and their relationship with existing fluids is the main goal of petrophysical research. In this research, well drilling data and Geolog software have been used to interpret and study the parameters of reservoirs and field development. Their results showed that if the shale effect ignored in the evaluation of gas reservoir, it can lead to significant errors in calculations and correct determination of petrophysical parameters.

In the present study, applying raw data obtained from well drilling of the Arab Formation (equivalent to Surmeh) in one of the Persian Gulf fields and also Geolog software, petrophysical parameters affecting the reservoir quality are investigated as well as the results of XRD and multimine methods are compared. The main purpose of this study is to show the importance and capability of software methods on the interpretation of reservoir formations.

2. Geological background

The Persian Gulf basin as a marine part of the Zagros region, is one of the sedimentary basins located on the Arabian plate, and can be considered as a remnant part of Neotethys basin. This region is one of the most oil-rich sedimentary basins in the world [16].

Fig. 1. Approximate location of the study area (after Berberian and King [20])

The high thickness of marine sedimentary rocks from Precambrian to Pliocene, lack of igneous activities, the presence of numerous and very rich in organic matter and porous and permeable reservoir rocks with suitable coating rocks, provide unique conditions for the production and accumulation of hydrocarbons in this basin [17-18]. The Zagros-Persian Gulf sedimentary basin, compared to other sedimentary basins in Iran has the most hydrocarbon resources in the world. In addition to Iran and the Persian Gulf, the basin is expanding in Oman, Saudi Arabia, the United Arab Emirates, Kuwait, Iraq, Syria, and southeastern Turkey [19]. The studied oil field is one of the oil fields in the Persian Gulf basin in which the Arab Formation equivalent to the Surmeh Formation has been studied (Fig. 1).

3. Stratigraphic characteristics of the understudy area

Geologically, the Arab (Surmeh) Formation deposited in the Upper Jurassic period, located beneath a layer (as a cap rock) named the Hith Formation (Upper Jurassic) is composed of anhydrite, which in some parts is separated by a carbonate layer [21-22]. According to the available information, the thickness of the Hith layer varies from 7 to 70 meters throughout the field.

In the Zagros region, the Surmeh Formation was developed well in the Fars province, north of Khuzestan and northeast of Lorestan and it has the best outcrops in the Fars region. The formation consists of limestone and dolomite. In view of the oil and gas prospects, this formation in Sarv (Qeshm Island) and Mountain Mund fields is in hydrocarbon production stage. In large areas of Fars, the middle-upper Jurassic rocks are very homogeneous carbonate rocks with an evaporitic layer of anhydrite deposits (Hith Formation) in the top section of the Fars Formation. At the locality of type section (Surmeh Mountain, 120 km southwest of Shiraz), the Surmeh Formation with 762 meters thick is made of dolomite and dolomite limestone, which has a thin layer of low dense clay limestone in the middle part. Based on the mentioned clay limestone, the Surmeh Formation consists of three parts. The lower part is characterized by two layers with lithiotis fossil. The upper equator is not the same. In some cases, this boundary is the Hith anhydrite Formation (Upper Jurassic) and in other cases is the limestone of the Fahliyan Formation (Lower Cretaceous). In the second case, the transition from the Upper Jurassic to the Lower Cretaceous is gradual. The oolitic limestone of the Fahliyan Formation or the layer containing Thintinnid, representing the deep marine environment, is selected as the stratigraphic boundary. The age of the Surmeh Formation is the Middle-Upper Jurassic, although biological zones indicate the entire Jurassic period. The Surmeh Formation is equivalent to the "Arab Formation" in Saudi Arabia and other Arab countries, which is prone as huge oil reservoirs [23-25].

4. Methods and materials

In this study, well data related to one of drilled wells of the oil field located in the Persian Gulf has been used. Geolog software was also used as a scientific software for data analysis. In the present research, different petrophysical cross-plots (neutron-density, neutron-sonic), frequency histograms and porosity variation were used. The results are also compared to core data to improve the quality control of XRD data in comparing to multimin method. Petrophysical parameters were calculated to analysis the reservoir zones quality.

5. Discussion

5.1. Lithological cross plots

One of the major applications of well logs is lithological determination. In a drilled well, usually in the solid part, two components are considered, the first component is the matrix which includes the main grains and cement and the second component is shale. Some lithological features such as mineralogy, texture, structure, shale volume and fluid content affect the response of logs. The meaning of texture is the parameters related to the matrix and the meaning of construction is properties such as layering and fracture. Data from drilling and core fragments help to more accurately estimate lithology [26-27]. The aim of lithological determination of the formation is to understand the best point which having the least volume of shale and the porosity saturated with water. The crossplot that are widely used to determine lithology is neutron-density.

5.2. Neutron-density crossplot

This crossplote is used to calculate lithology and porosity. To graphically reading the porosity using this plot, the calculated density values must be plotted against the neutron. Neutron density crossplot, compared to other crossplots, is used to estimate different lithology and porosity [28-29]. This crossplot separates calcareous, dolomitic and sandstone lithology well. It should be noted that before plotting, the data should be corrected in view of shale and hydrocarbon values. In wells having breakout or thick drilling mud cake, density tool information may be irrelevant, and therefore the crossplot application is limited [30-31].

In neutron-density crossplot, three curves or matrix lines presents the lithologies of lime, sand, dolomite and anhydrite. Matrix line separation is desirable for lithology determination.

In gas packages, the presence of gas reduces the neutron reading as well as the density of the rock, and these factors cause the points plotted on the left and the top of the plot in gas packages should be neutralized the gas effect from the gas correction path [32-33]. In this crossplot, it should be noted that if the points are in the upper left corner of the plot, they can be a sign of gas. However, the separation of neutron porosity and density (in the case of neutron porosity less than density porosity) does not always mean the gas effect [34-35]. The presence of shale in the formation causes to transfer the points to the southeast of the crossplot. Therefore, before interpretation of the crossplot, it is necessary to correct both factors in terms of shale volume. By performing shale correction, the porosity obtained from the crossplot will be equal to the porosity of the matrix [32]. Based on the neutron-density plot, the lithology of the Arab Formation in the under study area is a combination of dolomite, calcite, shale, and anhydrite (Fig. 2). Although, the dominant lithology of the formation is dolomite.

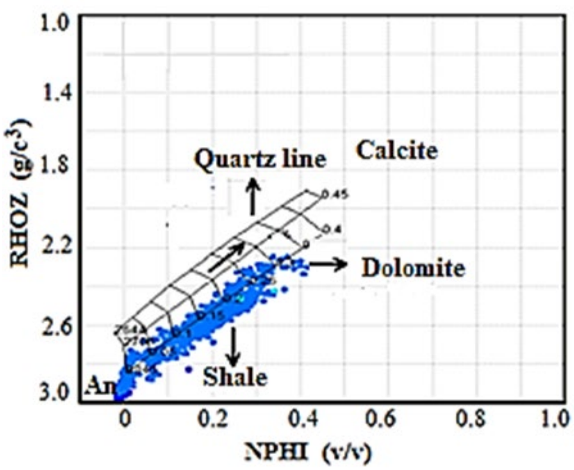

Fig. 2. Neutron - density crossplot for the lithology determination of the Arab Formation in X-drilled well. An indicating anhydrite.

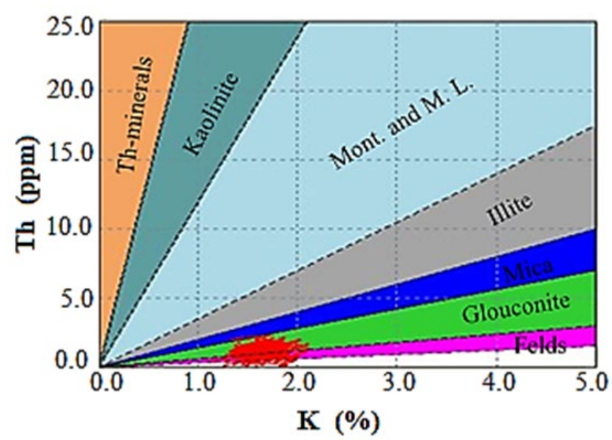

Fig. 3. Thorium (Th)-potassium (K) crossplot to determine clay minerals.

The thorium-potassium crossplot used to identify the type of clay minerals. The plot showed that there is no illite mineral. This is also confirmed by XRD data. The abundance of illite mineral, except for certain intervals in the Arab Formation, is less than 1% by weight. The presence of glauconite is a sign of a regenerative environment.

5.3. Shale volume (Vsh)

Conventional shale volume determination methods can be divided into two groups:

A- Methods based on graphs whose response is primarily a function of shale volume and are known as shale detectors [36-37]. Like gamma ray graphs, these images can also be used to qualitatively identify the type of clay mineral, of which thorium-potassium crossplot is one of these methods. According to this cross-plot, most of the clay minerals in this borehole, is of mixed layer type (Fig. 3).

B- Methods that are based on graphs in which the percentage of shale is not the first effective parameter, but affect the responder in different ways. Such as neutron log, SP log, a combination of two neutron-density (ND) and neutron-acoustic (N-sonic) logs. The use of gamma plot and neutron-density differences are two of the best indicators. The SP graph, as the initial graphs, shows values less than the actual value.

5.4. Estimated porosity

Porosity is the most important property of rock, because the capacity and volume of oil accumulation in rock depends on it [38]. In this study, the mean of total porosity (PHIT) and effective porosity (PHIE) were calculated using porosity diagrams (density, neutron and acoustic) and the results are presented in Table 1.

Table 1. Average shale volume (Vsh), effective porosity, total porosity and water saturation

Vsh %	25	PHIE %	8.86
PHIT %	9.83	SWE %	42.44

The porosity in the reservoir zones, with the exception of zone one, is well matched in the Multimin and XRD ratio diagrams. Comparison of histogram plots of porosity frequencies, with and without considering XRD data, shows differences. In general, in the method without considering XRD data, the amplitude of porosity changes in different zones is less.

The dispersion of anhydrite by XRD method is approximately less than 30% by weight. It is more dispersed in deeper zones. Comparison of anhydrite abundance based on ratio with and without XRD data shows that it is more consistent but its distribution is not uniform in all zones. The dispersion of dolomite in the studied borehole using XRD method indicates a frequency higher than 40% by weight (except in deep intervals). Comparison of dolomite dispersion in two methods indicates a relatively good agreement and confirms the high overall ratio of this component.

The amount of porosity in the studied well using XRD data in general (Fig. 4-A) and in different zones (Fig. 4-B) and also without considering XRD data (Fig. 5-A) in general and in different zones (Fig.5 -B) and compared with the porosity data presented. All the results together are shown in Figure 6.

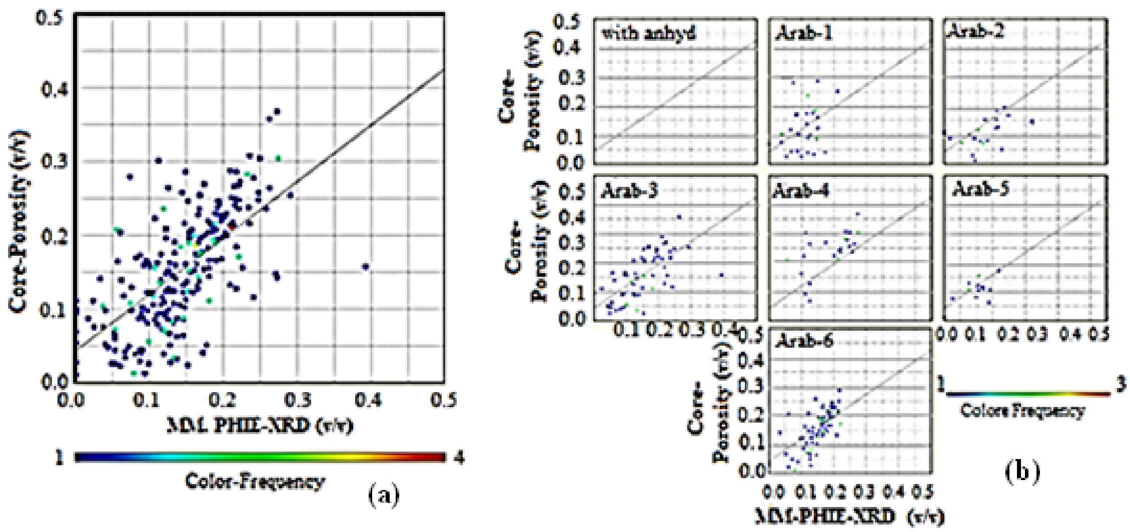

Figure 4. Dispersion of porosity in the studied borehole considering XRD and core data: (a)- in general and (b)- in different Zones

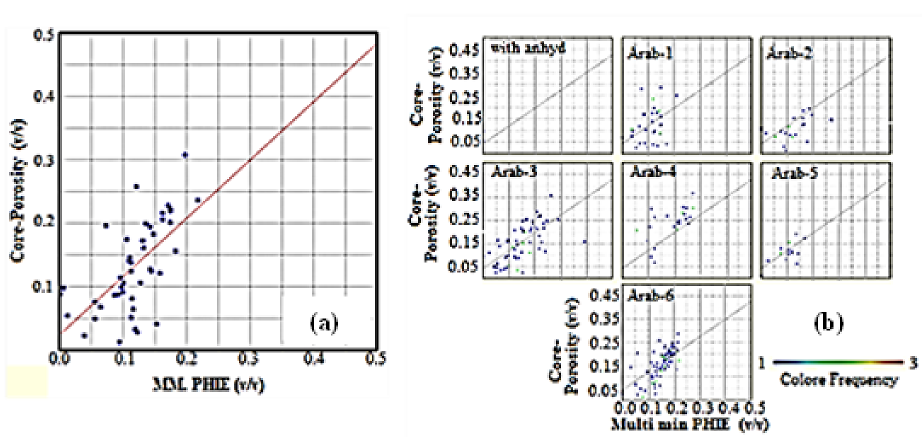

Figure 5. Porosity variation in the studied borehole using multimin methods and core data: (a)- in general distribution, and (b)- in different Zones

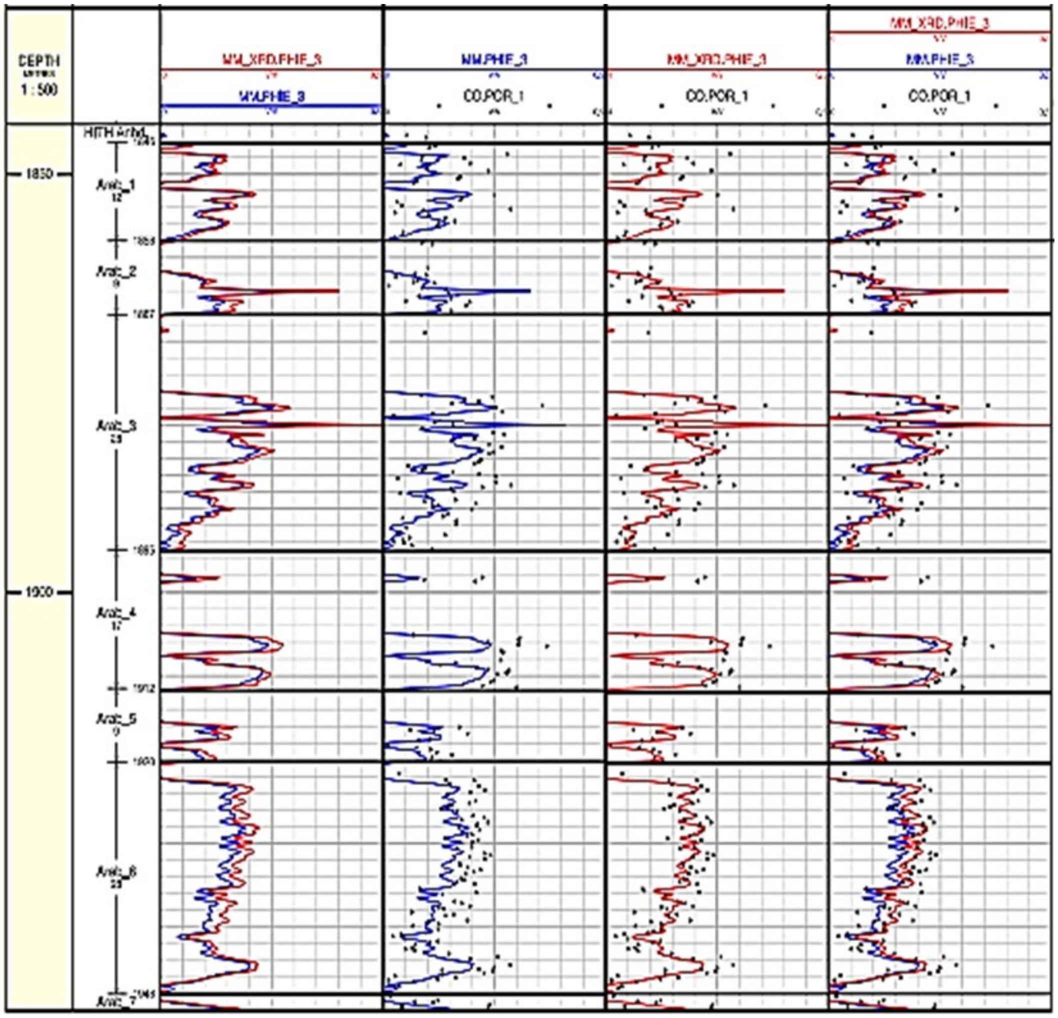

Fig.6. Porosity variation in the studied borehole using different methods

Comparing the porosity changes by two methods, the results are proportional to the core changes. Comparison of water saturation ratios based on the multimin and XRD methods shows that the range of variation is large in all zones. However, the frequency of water saturation except Arab zone 1 (which is the lowest ratio in XRD method and very small in multimin method), but Arab zones 3, 4 and 6 showing higher values by XRD method.

5.5. Water saturation

Saturation is the ratio of the volume occupied by a fluid to the total volume of porosity. In the case of water fluid, saturation denoted as SW. The residual fraction, including oil and gas, is equivalent to (1-SW) and is known as hydrocarbon saturation and marked with the symbol S_{Hy} [39]. Correct estimation of water saturation in hydrocarbon reservoirs is one of the most important steps in petrophysical evaluation of the formation. Water saturation is calculated by the resistance graphs and using appropriate formulas. The basis of this problem is actually due to the difference in conductivity between the formation water and hydrocarbons. The method of calculating the amount of water saturation in Geolog software has been used according to the available information from the Dual Water method [40]. The original Dual Water model was introduced by Clavier *et al.* [41], and the final version was completed in 1984. This model is based on three principles:

1. The conductivity of the wires is due to cation exchange capacity (CEC).
2. The amount of CEC of pure clay is proportional to the specific level of clay mineralization.

3. Clay is considered as a factor that produces a chemical bond to the water.

Clay minerals are insulating on their own, and their electrical conductivity is due to the water attached to them. This conductivity is not related to the type of clay mineral but is a function of temperature and salinity of the formation [41-42]. However, other variables such as stress, rock composition, porosity and geometric shape, packing condition and grain sorting also affect the conductivity of the rock [43]. According to the above three principles, the dual water relationship was presented as follows [44-45]:

$$C_t = \frac{\phi_T * S_{WT}^n}{a} * \left[\left(1-\frac{S_{wb}}{S_{wt}}\right) * C_{wf} + C_{wf} * \left(\frac{S_{wb}}{S_{wt}}\right)\right]$$

where, S_W is water saturation, S_{WT} is total water saturation and S_{WB} is water saturation attached to the clay structure.

The percentage of water saturation frequency was calculated between 26 to 74%. Figure 7 shows the overall distribution of water saturation in the studied borehole by the two methods and core data. By comparing the changes in the two graphs, the amount of water saturation with the effect of XRD data is more than the core data. This should be taken into account in estimating the amount of reserves of the reservoir.

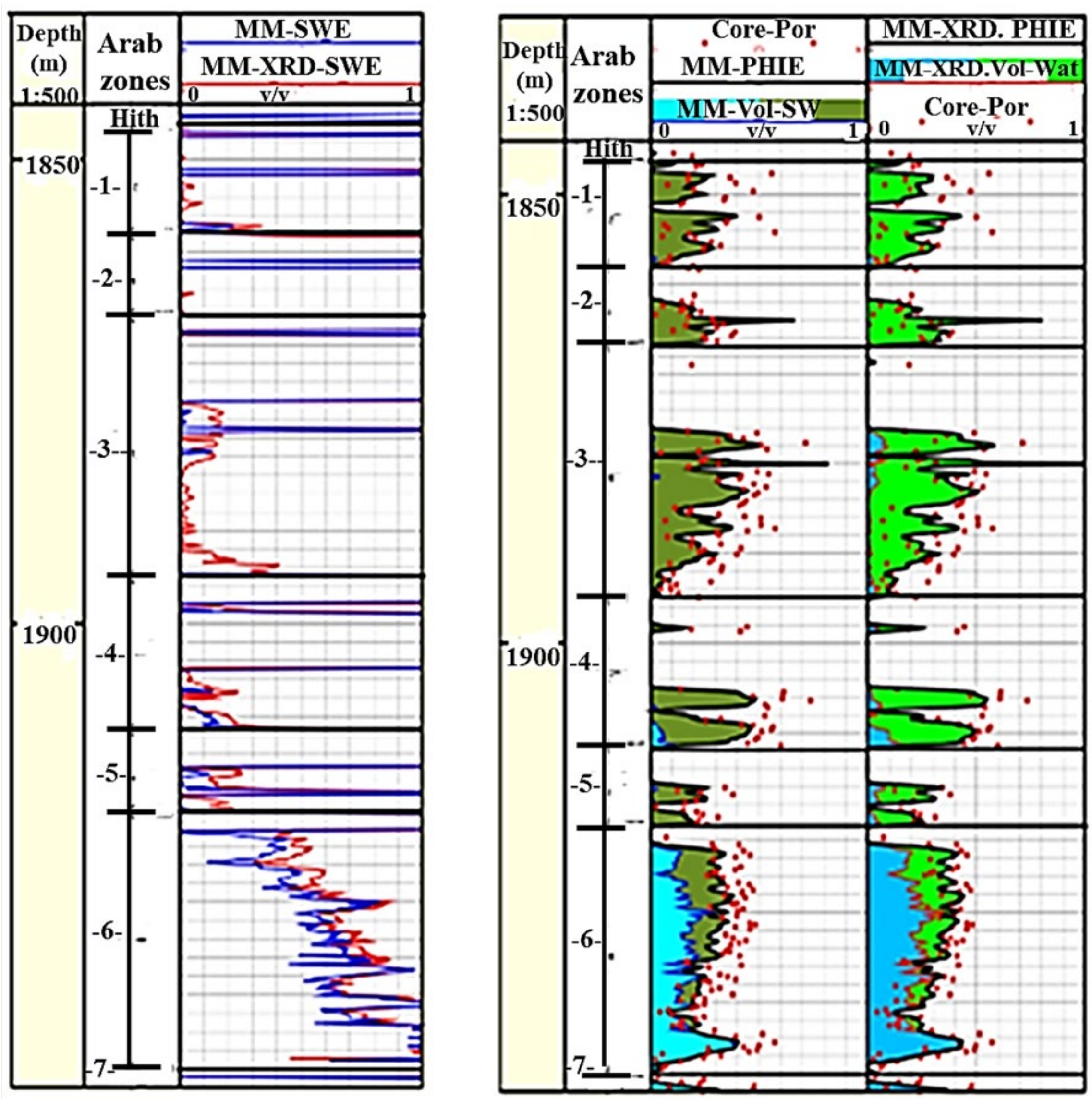

Fig. 7. Total distribution of water saturation in the studied borehole using XRD method and core data

The histogram plots of the abundance of water saturation in the studied well (Fig. 8) show differences with and without applying XRD data in interpretation. Arab zone 1 is showing the lowest value using XRD method and does not have a significant amount in the next method (multimin). And in the case of Arab zones 3, 4 and 5, the first method also shows lower values than Multimin. This result verifies the effect of water saturation on these methods output. Of course, it should be noted that the XRD method is used to determine lithology and is not a reliable method to determine water saturation in Geolog software.

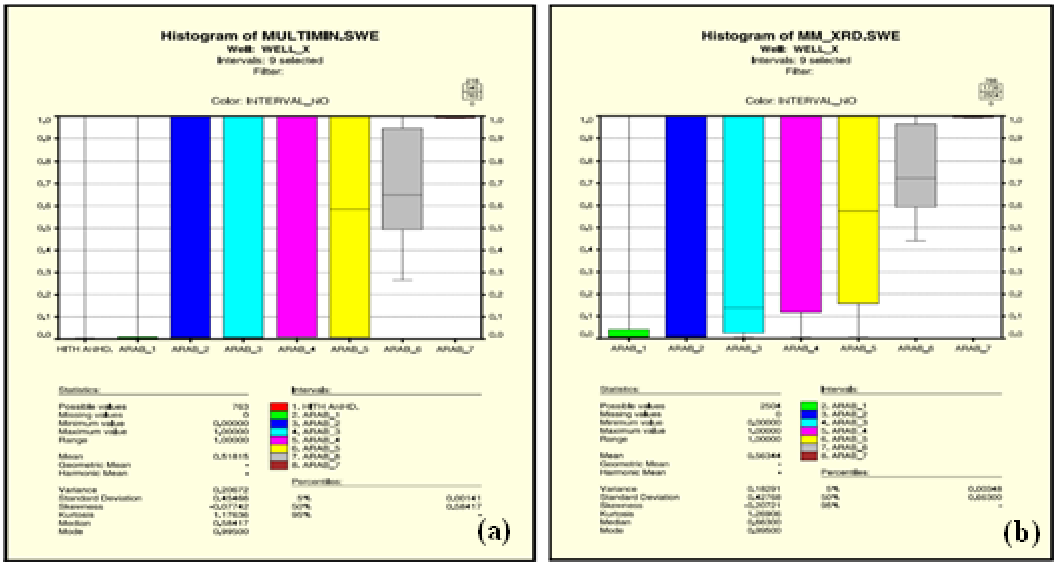

Fig. 8. Histogram plots of the total water saturation scatter diagram (a) Multimin and (b) XRD methods in the studied well

5.6. Comparison of statistical parameters in two methods

The statistical parameters of porosity and water saturation such as standard deviation values, skewness, cretaceous, median and mode in two methods are presented in Table 2. The rate of change of values is close to each other. Comparing of statistical parameters of porosity and water saturation factors in two methods shows the consistency of the changes.

Table 2. Comparison of the values of statistical parameters of the two methods: multimin and XRD data

	Method	Std. Deviation	Skewness	Kurtosis	Median	Mode
Porosity (%)	Multimin	7.583	32.609	2.22627	9.350	11.250
	XRD	8.428	38.207	2.48387	10.211	12.250
Water saturation (%)	Multimin	45.466	-7.742	1.17636	58.417	99.500
	XRD	42.768	-20.721	1.26906	66.300	99.500

Examination of changes in petrophysical parameters in the studied borehole without considering XRD data showed that this formation is of good quality at most depths. Comparing the results of the methods used, it was found that the resolution is higher with the inclusion of XRD data than the other method, multimin.

Production zones (pay zone) were calculated by Geolog software and by defining specific criterion for the studied well (Table 1) to identify productive zones include shale volume, porosity and water saturation percentage. Generally, regarding all three factors, if pay zone only have low shale volume, is called clean zone, and if they have good porosity in addition to the less or absence of shale, it can be introduced as reservoir horizon. Therefore, due to the lack of shale, there is a good condition in most depths of the reservoir. The stratigraphic column of the studied well (Fig. 9) shows that this formation has good reservoir quality at most depths.

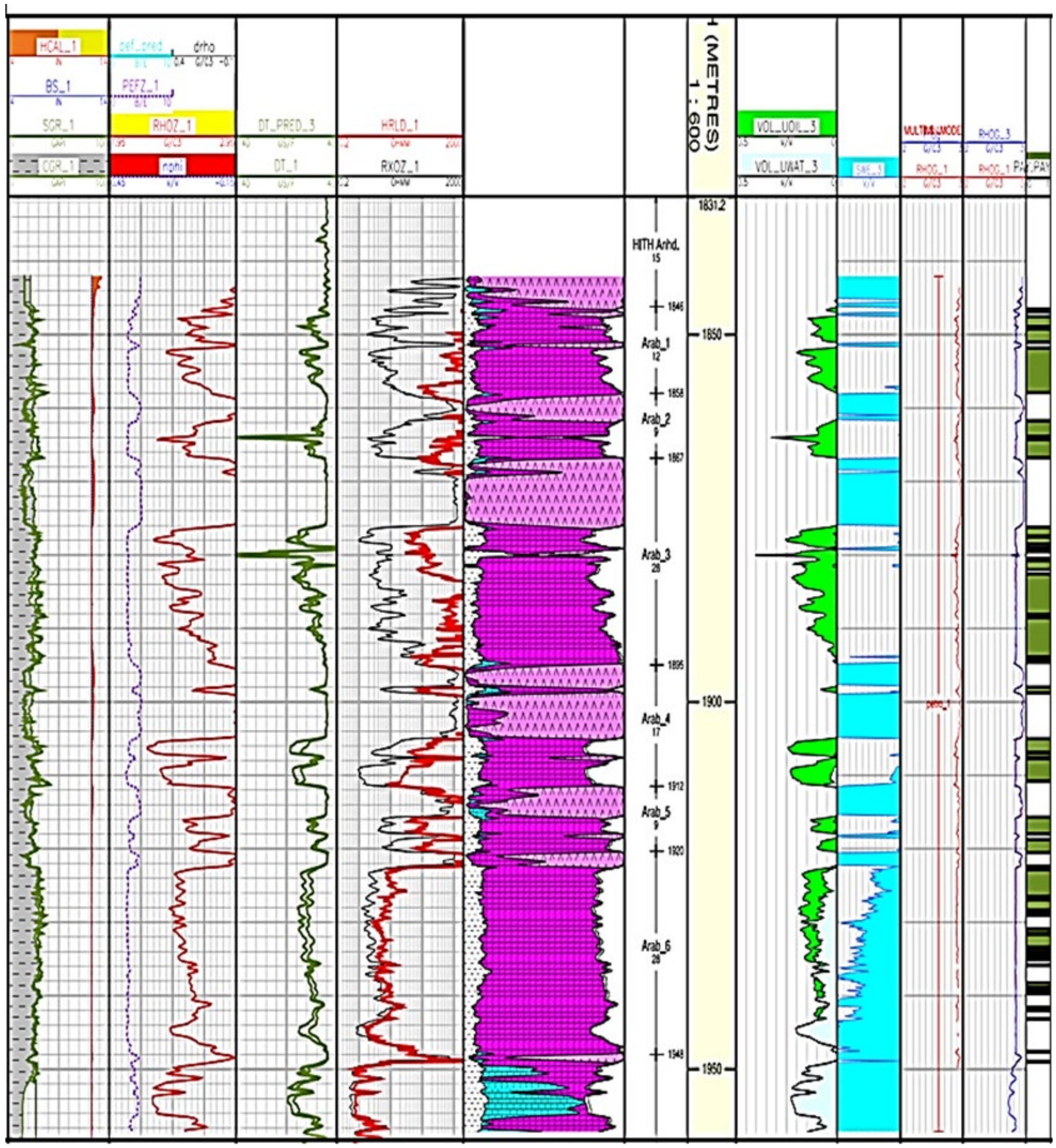

Fig. 9. Final petrophysical analysis of the studied well using multimin method. Column 1: Gamma Log (GR); Column 2: Neutron Log (NPHI); Column 3: Sonic Log (DT); Column 4: RXO Log; Column 5: Lithology; Column 6: Arab well zoning; Column 7: Well depth; Column 8: Water and oil saturation; Column 9: Water saturation: Columns 10 and 11: Resistance logs; Column 12: Pay zone.

6. Conclusion

By comparing the lithology results of the two methods used, it was revealed that the resolution is greater with the inclusion of XRD data than the method without the inclusion of XRD data. The XRD method has been better in identifying shale volume than the separation of dolomite and anhydrite. Comparison of statistical parameters of standard deviation, tilt, cretaceous, median and mode values of porosity and water saturation in two methods with and without XRD data is a sign of correlation and adaptation of the rate of change. Examination of the lithology columns of the studied well without considering XRD data showed that this formation is of good quality at most depths. Using neutron Cross-Density diagram, the dominant lithological density of the studied well has been identified as dolomite. The thorium-potassium crossplot used to identify the type of clay mineral showed that there was no illite mineral. This was also confirmed by XRD data. The abundance of illite minerals, except for certain depths in the Arabian Formation, is less than 1% by weight. The presence of glauconite indicates a shallow reduction environment. Comparing the results of porosity changes with XRD data and without XRD data is proportional to the core changes, the values obtained by the method with XRD data are closer to the values obtained by core analysis. Comparison of water saturation based on multimuin and XRD ratios shows that there is a wide range o However, the frequency of water saturation with the exception of Arab Zone 1 (which is the lowest in the XRD method and very small in the Multimine method), in the Arab Zones 3, 4 and 6 by the XRD method, shows higher values of variation in all zones.

Acknowledgements

The authors need to thank the research departments of the Shahid Chamran University of Ahvaz and the Tehran Petroleum Industry Research Institute in providing data (RIPI). It is also necessary to express our gratitude to the anonymous referees, and all those who have helped and guided us in this work.

References

[1] Tiab D. Advances in petrophysics. Flow units. Lecture notes manual, University of Oklahoma, 2010; 8: 15.

[2] Hearst JR, Nelson PH, Paillet FL. Well Logging for Physical Properties: A Handbook for Geophysicists, Geologists, and Engineers. New York, John Wiley and Sons, 2000: 483 pp.

[3] Mendenhall MH, Mullen K, Cline JP. An Implementation of the Fundamental Parameters Approach for Analysis of X-ray Powder Diffraction Line Profiles, J Res Natl Inst Stand Technol. 2015; 120: 223–251. doi: 10.6028/jres.120.014.

[4] Yano N, Yamada T, Hosoya T, Ohhara T, Tanaka I, Kusaka K. Application of profile fitting method to neutron time-of-flight protein single crystal diffraction data collected at the iBIX. Sci. Rep., 2016; 6 (1): 1-9. https://doi.org/10.1038/srep36628.

[5] Basu S, Dutta T. Shale gas prospectivity in Cambay Shale integrating Basin modeling and petrophysics: A case study from Cambay Basin, India. Petrotech-2010. 31 October-3 November 2010, New Delhi, India.

[6] Sharma V, Sircar A. Shale gas potential of North Cambay Basin, Gujarat, India. Jour. Indian Association of Sedimentologists, 2014; 33 (1&2): 51-57.

[7] Mishra S, Mendhe VA, Kamble AD, Bannerjee M, Kumar V, Varma AK, Singh BD, Pandey JK. Prospects of shale gas exploitation in Lower Gondwana of Raniganj Coalfield (West Bengal), India. Palaeobotanist, 2016; 65: 31–46.
http://14.139.63.228:8080/pbrep/handle/123456789/2115

[8] Mendhe VA, Mishra S, Varma AK, Kamble AD, Bannerjee M, Singh BD, Sutay TM, Singh VP. Geochemical and petrophysical characteristics of Permian shale gas reservoirs of Raniganj Basin, West Bengal, India, Int. J. Coal Geol.,2018; 188: 1-24.
https://doi.org/10.1016/j.coal.2018.01.012

[9] Kadkhodaie Ilkhchi A. Estimation of the geochemical and petrophysical parameters from well logs and seismic attributes using intelligent systems in the southern Iran hydrocarbon fields. PhD Thesis, Tehran University, 2009; 429P.

[10] Jagadisan A, Chen JH, Althaus SM. Improved methods for determination of petrophysical properties of unconventional tight rocks using particulate samples. ACS Omega, 2022: 7(11): 9636–9641. https://doi.org/10.1021/acsomega.1c07034.

[11] Ghassem Al-Askari MK. XRD evaluation of clay minerals in shaley formation and its comparison with cross plotting of log data. Progress in Petrochem Sci., 2018; 1(3): 64-70.
doi: 10.31031/PPS.2018.01.000513.

[12] Kiakojury M, Sheikh Zakariaei SJ, Riahi MA. Investigation of petrophysical parameters of Kangan Reservoir Formation in one of the Iran South Hydrocarbon Fields. Open Journal of Yangtze Oil and Gas, 2018; 3 (1): 36-56. doi: 10.4236/ojogas.2018.31004.

[13] Nader FH, De Boever E, Gasparrini M, Liberati M, Dumont C, Ceriani A, Morad S, Lerat O, Doligez B. Quantification of diagenesis impact on the reservoir properties of the Jurassic Arab D and C members (Offshore, U.A.E.). Geofluids, 2013; 13: 204–220. doi: 10.1111/gfl.12022.

[14] Jadoon K, Roberts E, Blenkinsop TG, Wust RAG, Shah SA. Mineralogical modelling and petrophysical parameters in Permian gas shales from the Roseneath and Murteree formations, Cooper Basin, Australia. Petroleum Exploration and Development, 2016; 43 (2): 277-284. 10.1016/S1876-3804(16)30031-3 file

[15] Taheri K, Ansari AH, Kaveh F. Determination of Petrophysical Parameters of Reservoir Rock with a Special Look to Shale Effect (Case Study: One of the Gas Fields in Southern Iran). Petroleum Petrochemical Engineering Journal, 2021; 5(2): 1-10. doi: 10.23880/ppej-16000262

[16] Agha-Nabati SA. Geology of Iran. The Geological Survey and Mineral Exploration of Iran, 3rd edition, 2008: 586 pages (in Persian).

[17] Bordenave M, Hegre J. Current distribution of oil and gas fields in the Zagros Fold Belt of Iran and contiguous offshore as the result of the petroleum systems. Geol. Soc. Lond. Spec. Publ., 2010; 330: 291–353. http://dx.doi.org/10.1144/SP330.14.

[18] Atashbari V, Tingay, M, Amrouch K. Stratigraphy, Tectonics and Hydrocarbon Habitat of the Abadan Plain Basin: A Geological Review of a Prolific Middle Eastern Hydrocarbon Province. Geosciences, 2018: 8(12): 1-17. https://doi.org/10.3390/geosciences8120496.

[19] Alsharhan AS, Nairn AEM. Sedimentary Basins and Petroleum Geology of the Middle East. Elsevier, Netherlands, 1997: 887p.

[20] Berberian M, King GCP. Towards the paleogeography and tectonic evolution of Iran. Canadia. J.Earth Sciences , 1981; 18: 210-256.

[21] Alsharhan AS, Kendall CGStC. Depositional Setting of the Upper Jurassic HithAnhydrite of the Arabian Gulf: An Analog to HoloceneEvaporites of the United Arab Emirates and Lake Mac Leod of Western Australia. AAPG Bulletin, 1994; 78 (7): 1075–1096.

[22] Zeigler MA. Late Permian to Holocene paleofacies evolution of the Arabian Plate and its hydrocarbon occurrence. GeoArabia, 2001; 6 (3): 445–504. https://doi.org/10.2113/geoarabia0603445.

[23] Kent PE. Recent studies of South Persian salt plugs. American Association of Petroleum Geologists Bulletin, 1958; 42: 951–952. doi:10.1306/0BDA5C2D-16BD-11D7-8645000102C1865D.

[24] Hampiyan R, Rahimpour Bonab H, Kamali MA, Mousavi Harami SR. The study of factors affecting reservoir quality of upper Surmeh (Arab) in the Balal and Salman oil fields, the Persian Gulf. Petroleum Research, 2015; 25 (83): 68-81. https://doi.org/10.22078/PR.2015.534

[25] Sfidari E, Amini AH, Kadkhodaie-Ilkhchi A, Chehrazi A, Zamanzadeh SM. Depositional facies, diagenetic overprints and sequence stratigraphy of the upper Surmeh reservoir (Arab Formation) of offshore Iran, Journal of African Earth Sciences, 2019; 149: 55–71. https://doi.org/10.1016/j.jafrearsci.2018.07.025.

[26] Al-Amri M, Mahmoud M, Elkatatny S, Al-Yousef H, Al-Ghamdi T. Integrated petrophysical and reservoir characterization workflow to enhance permeability and water saturation prediction. Journal of African Earth Sciences, 2017; 131: 105-116. https://doi.org/10.1016/j.jafrearsci.2017.04.014.

[27] Fu D, Su C, Wang W, Yuan R. Deep learning based lithology classification of drill core images. PLoS ONE, 2022; 17(7): e0270826. https://doi.org/10.1371/journal.pone.0270826.

[28] Fertl WH. Openhole cross plot concepts a powerful technique in well log analysis. Journal of Petroleum Technology, 1981; 33(3): 535-549. https://doi.org/10.2118/8115-PA

[29] Yang L. A petrophysical evaluation of the Trenton-Black River formation of the Michigan basin. Master's Thesis, Michigan Technological University, 2015, 52p. http://digitalcommons.mtu.edu/etds/914.

[30] Fattah KA, Lashin A. Investigation of mud density and weighting materials effect on drilling fluid filter cake properties and formation damage. Journal of African Earth Sciences, 2016; 117: 345-357. http://dx.doi.org/10.1016/j.jafrearsci.2016.02.003.

[31] Adebayo AR, Bageri, BS, Al Jaberi J, Salin RB.A calibration method for estimating mudcake thickness and porosity using NMR data. Journal of Petroleum Science and Engineering, 2020; 195: 10p. https://doi.org/10.1016/j.petrol.2020.107582.

[32] Ortega E, Torres-Verdín C. New Analytical Method To Calculate Matrix- and Fluid-Corrected Total Porosity in Organic Shale. SPE Res Eval & Eng., 2015; 18 (04): 609–623. https://doi.org/10.2118/170909-PA

[32] Varhaug M. Basic Well Log Interpretation. Oilfield Review, 2016: 2p.

[34] Rezaei MR, Chehrazi A. Principles of Perception and Interpretation of Well Surveys. University of Tehran Press, Second Edition, 2010; 700 p.

[35] Yar M, Haider SW, Ghafoor RA, Khan TM. Evaluation of reservoir properties using wireline logs of well Sarai-Sidhu-1, Punjab Platform, Central Indus Basin, Pakistan. Iranian Journal of Oil & Gas Science and Technology, 2018; 7 (4): 36-44. http://ijogst.put.ac.ir.

[36] Poupon A, Clavier C, Dumanoir J, Gamard R, Misk A. Log analysis of sand-shale sequences: A systematic approach. J. Petroleum Technology, 1970; 22: 867-881. https://doi.org/10.2118/2897-PA
[37] Skupio R, de Alemar Barberes G. Spectrometric gamma radiation of shale cores applied to sweet spot discrimination in Eastern Pomerania, Poland. Acta Geophys., 2017; 65 (6): 1219-1227. https://doi.org/10.1007/s11600-017-0089-7.
[38] Chen F, Lu S, Ding X, Zhao H, Ju Y. Total porosity measured for shale gas reservoir samples: A Case from the Lower Silurian Longmaxi Formation in Southeast Chongqing, China. Minerals, 2019; 9 (1): 5, 12P. doi:10.3390/min9010005.
[39] Ojo BT, Olowokere MT, Oladapo MI. Sensitivity analysis of changing reservoir saturation involving petrophysics and rock physics in 'Royal G' field, Niger Delta. Results in Geophysical Sciences, 2021; 7. https://doi.org/10.1016/j.ringps.2021.100018.
[40] Geolog7, user s Guid, 2011. Statistical toolbox, Geolog CDRoom. The Paradigm works, Inc.
[41] Clavier C, Coates G, Dumanoir J. Theoretical and experimental basis for the Dual-Water model for interpretation of shaly sands. Society of Petroleum Engineers Journal, 1984; 24 (2): 153-168. https://doi.org/10.2118/6859-PA.
[42] Awadh S. Physico-chemical characterization and salinity distribution of the oilfield water in the Upper Sandstone Member of the Zubair reservoir at Rumaila North Oilfield, Southern Iraq. Iranian J. Oil and Gas Science and Technology, 2018; 7 (1): 20-39 doi: 10.22050/IJOGST.2017.80561.1388
[43] Kantzas A, Bryan J, Taheri S. Fundamentals of Fluid Flow in Porous Media. Perm Inc. Com. Open Source, 2016: 336P.
[45] Sam-Marcus J, Enaworu E, Rotimi OJ, Seteyeobot I. A proposed solution to the determination of water saturation: using a modelled equation. J. Petrol. Explor. Prod. Technol, 2018; 8:1009-1015. https://doi.org/10.1007/s13202-018-0453-4.

To whom correspondence should be addressed: professor Bahman Soleimani, Faculty of Earth Sciences, Shahid Chamran University of Ahvaz, Ahvaz, Iran, E-mail: soleimani_b@scu.ac.ir