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Evaluation of petrophysical properties using well logs of Khasib formation in east Baghdad oil field, central area

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Abstract

The assessment of petroleum characteristics through well log analysis has always been essential for identifying and evaluating hydrocarbon-bearing zones. This study presents a comprehensive re-evaluation and correction of five well log data sets from Khasib formation which is the primary reservoir in the East Baghdad oil field (10 kilometers east of Baghdad City). The corrected data sets were utilized to calculate key parameters, including water saturation, porosity, lithology, and shale volume. Lithology was determined using M-N cross-plots and neutron-density analysis, which showed that the Khasib formation mainly consists of limestone, with calcite as main mineral components and minor amounts of dolomite. Shale volume was assessed using both single and dual shale indicators. The three main logs of porosity neutron, density, and sonic logs were used for computing the porosity. Then, Archie equation was employed to determine water saturation. To verify the accuracy of the computation, a comparison between the results and the available core data was conducted, which indicated that porosity values ranged from 0.143 to 0.212, while water saturation varied from 0.643 to 0.951. In addition, core samples and geological reports confirmed that Khasib formation was clean with minimal shale content.

Keywords: petrophysical properties; analysis of well logs; carbonate reservoir; Khasib formation; east Baghdad oilfield; IP software.

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1- Introduction

Carbonate reservoirs contribute more than 30% of the world's daily oil production and more than 60% of its oil reserves. Compared to most sandstone reservoirs, the main challenges in developing carbonate reservoirs result from their often-heterogeneous nature [1, 2]. Since carbonate reservoirs contain a major proportion of the Earth’s remaining conventional petroleum resources, calculating petrophysical parameters and comprehending fluid flow dynamics for these reservoirs are challenging tasks. Fluid flow through heterogeneous carbonate reservoirs is a very different and challenging process than fluid flow through homogeneous sandstone reservoirs because carbonate rocks typically have a more complex pore system than sandstone [3, 4] and because carbonate minerals have a greater chemical reactivity due to the fact that carbonate rocks are primarily composed of calcite, which is reactive to formation brine [5]. Because of their very uneven shapes, the sand grains and carbonate material particles that make up sandstone and limestone reserve rarely fit together completely. Fluids occupy pore space, also known as porosity, which is the empty space generated in the beds between grains [6].

One of the crucial steps in helping engineers and geologists determine the petrophysical properties is the interpretation of well log data. In reservoir engineering, log data is important and utilized in the computation, particularly in reserve estimation. The type of problem and the quantity and quality of log data that analysts have access to determine the optimal interpretation for each given structure of interest [7].

The process of analyzing data made inside the wellbore to assess wells for potentially hydrocarbon-bearing rocks is known as formation evaluation. Well logs, laboratory testing of fluid characteristics, and cores are a few examples of these metrics [8]. The production potential of a hydrocarbon reservoir cannot be estimated without well logging, which is regarded as one of the most significant sources of information regarding the geology and petrophysical characteristics of reservoir formations [9].

Determining the shale volume, permeability, porosity, and fluid saturation is crucial for assessing the formation and estimating the amount of hydrocarbon present. The type of the reservoir can be determined by looking at these petrophysical characteristics, which can help with field development planning. The key factor in interpreting well logs is in the precious calculation of petrophysical parameters in carbonate reservoirs [10].

Compared to limestone or sand, shale is thought to be more radioactive. The gamma ray log can be used to determine the reservoir's shale volume. Shale volume is given as a decimal fraction or as a percentage. Overestimation of the shale volume from the gamma rays log is observed when radioactive materials are present in a porous reservoir other than shale, for instance where

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sand looks to be shale. To prevent overestimating or underestimating the shale volume in this situation, shale volume estimation using other logs is strongly advised [11].

Since porosity may be used to calculate the possible hydrocarbon storage volume in rock, it is a crucial feature. Porosity in carbonate reservoirs is between 0.01-0.35. Furthermore, permeability, a measure of a rock's capacity to allow fluid to pass through itis regarded as a crucial characteristic of rocks [12].

To ascertain the saturation of hydrocarbons in the formations, the water saturation value which is one of the hardest parts of log analysis should be evaluated [13]. The percentage of pore volume occupied by a specific fluid (oil, gas, or water) is known as saturation. Instead, then being based on the gross reservoir volume, all saturation values are based on pore volume [14].

The primary petrophysical characteristics and lithology of the Khasib formation in the central oil field of east Baghdad are the subject of this study. The objective of the research is to provide an improved comprehension of the reservoir features in order to supply funding to the development of future field economic feasibility, as the field is currently undergoing development plans. This study focuses on interpreting petrophysical properties and formation evaluation for the Khasib reservoir [14]. Effective porosity, water saturation, and all other factors required for the interpretation process can be analyzed utilizing IP software thanks to the pre-interpretation [15].

2- Area of study

Situated 10 km east of Baghdad city, in the governorates of Baghdad and Saladin, is the enormous oil field known as East Baghdad. The east Baghdad field contract area is 65 km long and 11 km wide, encompassing the area to the northwest of the Diyala River. There are eight billion barrels of proven reserves in East Baghdad. Geographically speaking, the East Baghdad oil field is separated into six regions: North Extensions, Al-Rashdiya, Al-Taji, South 2, Urban and South 1 sectors, in that order, going from northwest to southeast [16, 17]. South 2 and South 1 are included in the southern region of East Baghdad. The East Baghdad oil field's location is depicted on the Iraq oil location map in Fig. 1 shows the stratigraphic column of east Baghdad oil field [18].

Tanuma formation forms its upper boundary, while Kifil formation forms its lower boundary. Nine zones, K1 through K9, make up the Khasib formation. These divisions are based on the identification of lithological changes and depositional cycles [19]. The Khasib Formation is one of the carbonate formations that have a good hydrocarbon storage due to its relatively high porosity and permeability, since this formation constitutes one of the important reservoirs in many fields of central and southern part of Iraq. It can be divided into two parts, upper and lower. The formation age backs to Turonian-Coniacian period, during which various diagenesis processes have significantly affected its composition, resulting in development of distinct types of secondary porosity [20-22].

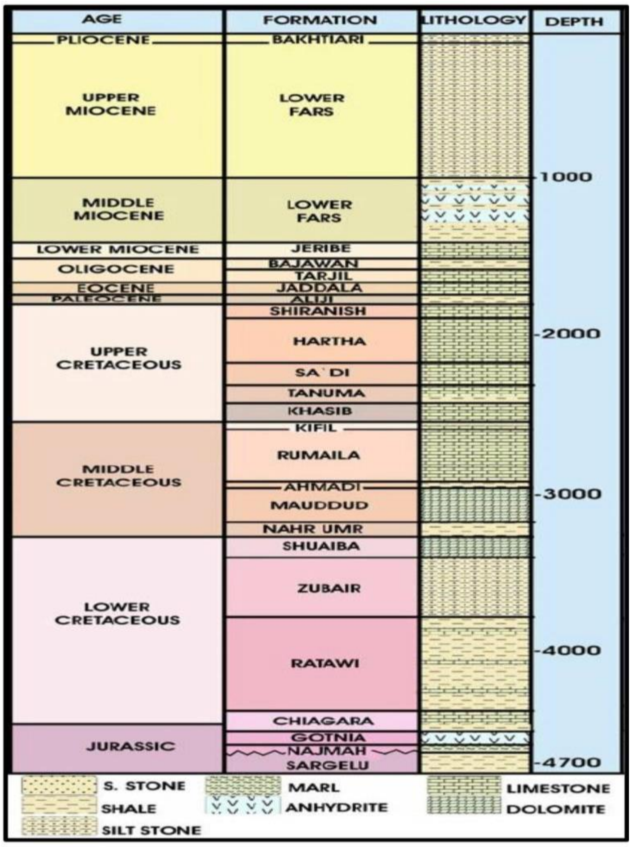

Fig. 1. East Baghdad stratigraphic column [16]

3- Methodology

This study involved the petrophysical properties of five wells (EB11, EB14, EB29, EB74, and EB79) drilled in the Khasib Formation. The open-hole logs of the investigated wells that were readily available (Caliper, Spontaneous potential, Gamma-ray, Density, Sonic, Neutron, and Resistivity Logs) were utilized. The definitions were created using the Interactive Petrophysics software, an interactive method for describing the invasion impacts, and log corrections. The input data was measured using one reading every 0.1425 m depth. Effective porosity and all other parameters required for the interpretation procedures are determined during the pre-interpretation (corrected for shale effects). As the accuracy of the input would lead to the excellent quality of the output, quality control was applied for all logging interpretation processes, correction to lessen the influence of the borehole condition.

4- Results and discussion

4.1. Correction part

The software Interactive Petrophysics (IP v3.5) offered a correction module that was used to do the correction. Since Schlumberger Oilfield Services provided the well log data, Log Interpretation Charts (2000 Edition) of

Schlumberger have been used. GR is updated to mud characteristics (weight and kind) and downhole condition, mud properties were the driving force behind this change. Since induction resistivity does not fluctuate between readings, drilling mud in the invasion zone did not have an impact on the raw log values as shown in Fig. 2.

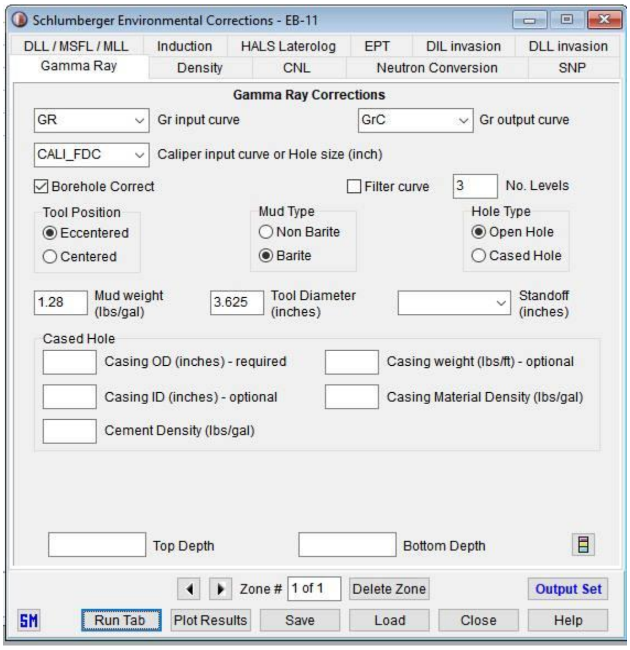

Fig. 2. Correction window (IP software/ Schlumberger)

Drilling mud and the logging equipment employed cause a slight shift in the readings of the density and micro resistivity logs. Numerous factors, including properties of formation, drilling mud and lithology, have an impact on neutron log. The corrected data showed an increase in neutron density. A log plot of the well EB29 corrections is displayed in Fig. 3. The red dot lines indicate the corrected reading, while the green solid lines indicate the log reading.

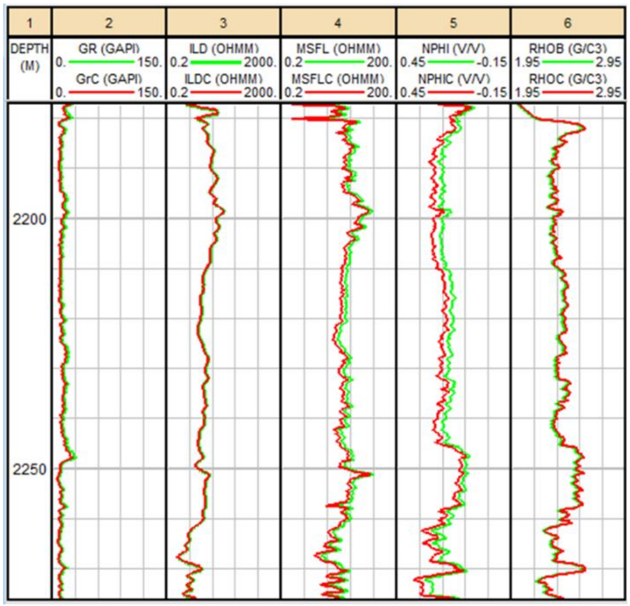

Fig. 3. Correction log plot of EB29 (IP software)

3.2. Identification of lithology

Understanding the lithology classification is essential since it is the source for all subsequent porosity and S_w estimates. Cross plots are diagrams based on the direction and cross-section of two logs response (dependent on pore fluid and matrix lithology). Due to its rock-fluid composition, this deposit may have a pore system of variable porosity. The neutron density cross-plot is an ancient research technique that is commonly used to evaluate the porosity and lithology of quartz, calcite, and dolomite. In this cross-plot, the sandstone (silica), limestone and dolostone are three lithology lines (dolomite). Lithology lines are typically marked by porosity values in percentages. Cross plot M-N is used to categories the image, density, and neutron mineral mixture to provide lithology-dependent quantities M and N. Cross plots of porosity combinations (density versus neutron cross plot, M-N and cross plot matrix identification). The density-neutron plot, a cross plot with neutron log readings on the x-axis and density log readings on the y-axis, uses gamma-ray ranges to clearly display and demonstrate the mineral type.

$$M= (\Delta tfl - \Delta tlog)/(\rho b - \rho f) \times 0.01 \quad (1)$$

$$N= (\text{Ø}Nf - \text{Ø}N)/(\rho b - \rho f) \quad (2)$$

Where: Δtf = interval transit time for fresh water =189 m/s and 185 m/s for salt mud. Δt = sonic log reading. ρb = density log reading. ρf= density of fresh water = 1 g/cm3 or 1.1 g/cm3 for salt mud. ØNf = Porosity of Neutrons for Fluid =1. ØN = neutron porosity.

The density-neutron plot of well EB29, as shown in Fig. 4, indicates that limestone is the main mineral matrix of the formation. This result is in line with the geological findings derived from the wells, which characterize the Khasib formation as limestone that is porous. The density, neutron, and sonic log interpretations are used to create the M-N graphic. The parameters M and N are impacted by lithology.

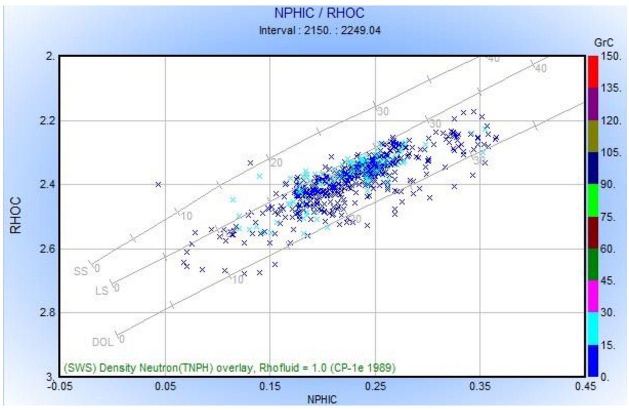

Fig. 4. Cross plot of density – neutron lithology of EB29 (IP software)

Fig. 5 displays the EB29 M-N plot well. Since the carbonate zone is where the majority of the points are accumulated, the M-N plot shows that the formation is made of limestone.

Furthermore, it is evident that the formation has no discernible secondary porosity, thus assessing the formation porosity does not need taking this into account. These findings have led to the employment of limestone characteristics in conjunction with other formation calculations, as necessary.

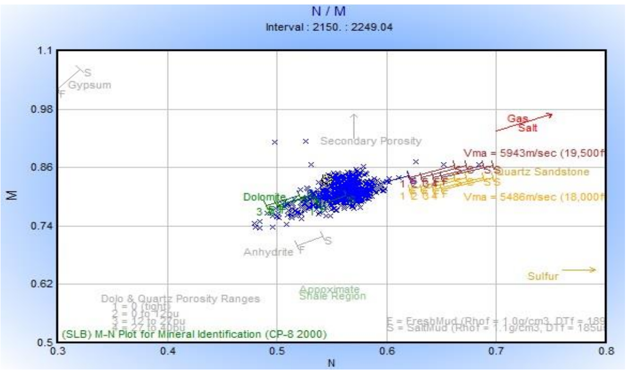

Fig. 5. M-N cross plot of EB29 (IP software)

3.3. Calculations of shale volume

The shale effect on the reservoir's rocks is one of the most contentious concerns in the formation appraisal. Generally speaking, shale is more radioactive than carbonate or sand. Thus, the volume of shale in a porous media can be determined using the gamma-ray log and other logs. The shale volume was estimated by three distinct shale indicators: neutron density, SP, and gamma-ray. Results Significant volumes were acquired for each indication, specifically, VLCSP from the SP log, VCLND from the neutron-density log, and VCLGR from the gamma-ray log. In order to minimize logging tools' high reading mistakes, the minimum shale volume (VCL), which is the minimum shale response of all used indicators, provides the desired result from shale volume calculations by which the shale volume of the formation was provided. Fig. 6 illustrates a sample of a shale volume results curve. The tool curve track with the lowest shale volume, the sum of all the indicators is the one that a shale curve is generated from. The formation is separated into nine zones because of a discernible fluctuation in shale volume along the well tracks, as indicated by the data. Fig. 6 displays the EB29 zones, which are visible in the second track. According to geological assessments and core samples taken from these wells in the Khasib Formation, the carbonate reservoir's shale content is Nile.

3.4. Porosity estimation

One of the most significant characteristics of a reservoir is its porosity, which indicates the possible volume of hydrocarbon storage. The porosity levels in carbonate reservoirs vary from 1% to 35%. Laboratory core samples or the interpretation of porosity well logs are used to determine porosity. In this study, porosity was computed using porosity logs (density, neutron, and sonic). Furthermore, the volume of shale was subtracted from the overall porosity in order to compute effective porosity. Fig. 7 provides an illustration of the porosity results. Density porosity (PhiDen), neutron porosity (PhiNeu), and sonic porosity (PhiSon) are shown in tracks 2, 3, and 4, respectively. The final track (PHIE) shows the effective porosity.

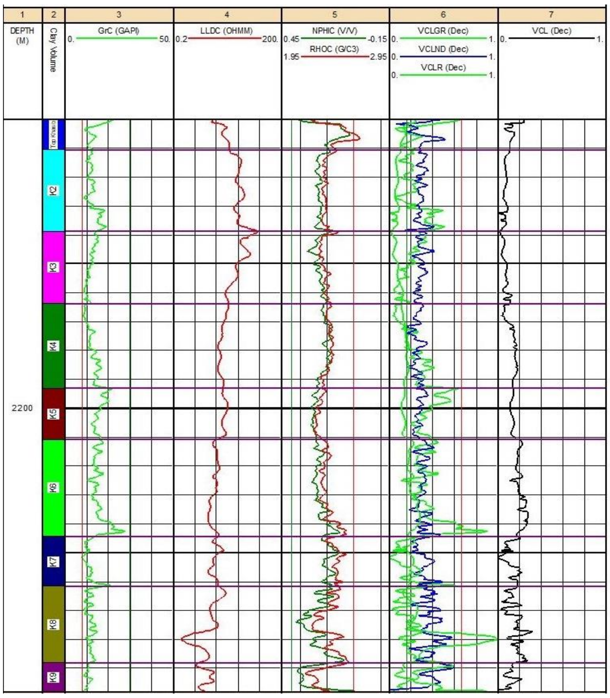

Fig. 6. Log plot of shale volume of EB29 (IP software)

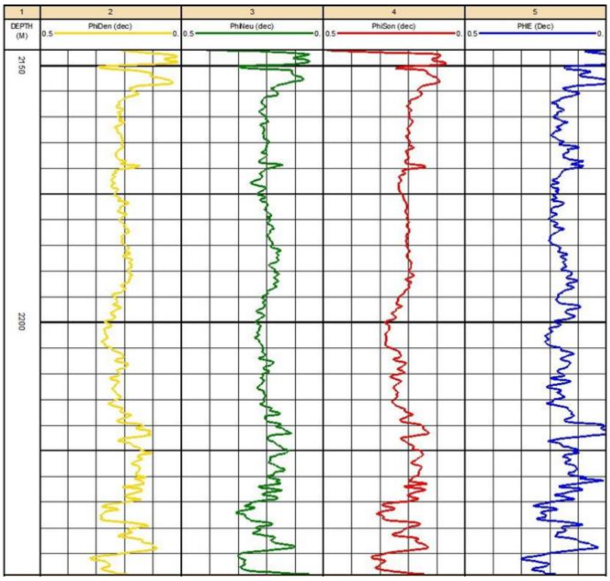

Fig. 7. Log plot of porosity results of EB29 (IP software)

By contrasting the calculated effective porosity with the core porosity, the validity of the data is validated. Table 1 shows the porosity of core samples during the cored intervals that were available for this investigation, as well as the effective porosity interrupted from well records.

The absolute percent error is computed in the manner below to illustrate the accuracy of the prediction.

$$APE = \left| \frac{PHI_{log} - PHI_{core}}{PHI_{core}} \right| \times 100\% \qquad (3)$$

Where PHI_{core} is the porosity of the core sample and PHI_{log} is the anticipated porosity. The absolute percentage error yielded findings ranging from 0.46 to 6.83 percent. To obtain more precise results It has been determined that log porosity and core porosity are correlated; its correlation coefficient (R^2) is 0.856563.

$$PHI_{log} = -0.02667853 + (1.080926228 \times PHI_{core}) \qquad (4)$$

Table 1. Core porosity versus comparison of log porosity for available cored wells.

Well	Interval, m	Log porosity	Core porosity	APE %
EB11	2198.3 – 2269.8	0.172	0.161	6.83
EB14	2164 – 2199.5	0.214	0.213	0.46
EB29	2167.6 – 2195.6	0.229	0.226	1.32
EB74	2277.5 - 2379	0.195	0.199	2.01
EB79	2031.7 - 2050	0.204	0.201	1.49

Eq. 5, which was created by a straightforward modification of Eq. 4, corrects the expected porosity. PHI_{core} is obtained by solving the equation, and the result is regarded as the corrected porosity (PHI_C).

$$PHI_C = \frac{PHI_{log} \;\; +0.02667853}{1.080926228} \qquad (5)$$

Table 2 shows the average porosity for each well understudy derived from the corrected porosity. Because of the variability of the formation, the porosity varied between the wells, ranging from 0.212 to 0.143.

Table 2. Porosity results for all wells as calculated from well logs.

Well	Well Interval, m	porosity
EB11	2177.2 – 2276.8	0.209
EB14	2153.5 – 2255.7	0.212
EB29	2147.0 – 2249.04	0.183
EB74	2276.1 – 2384.8	0.175
EB79	2031.3 – 2138.4	0.143

3.5. Calculations of water saturation

One of the most crucial petrophysical characteristics for information interpretation is water saturation. The estimation of oil in place is based on water saturation, and the discovery of perforation zones likewise primarily depends on this information in the formation. Water saturation from well logs is calculated empirically, primarily based on resistivity measurements. One of the most popular computation techniques is Archie equation. Pickett's plot for well EB14 is shown in Fig. 8.

The three blue lines in the illustration, the red line in the illustration shows 100% water saturation, while the other symbols represent 50%, 30%, and 20% of the saturation levels, respectively, according to their distance (closest is highest) from the red line. The cementation factor is the slope value of the line at 100% water saturation. The values of (R_w, m, n, and a) for each well used in this investigation are shown in Table 3. Fig. 9 displays an example of a log plot of the water saturation findings obtained from a core sample using the archie method.

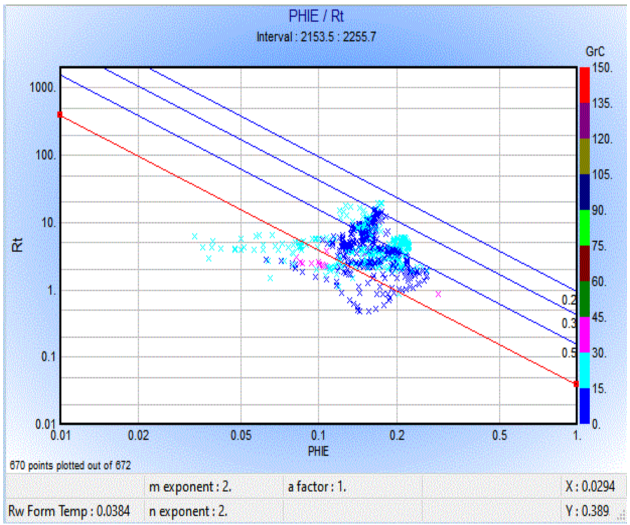

Fig. 8. Pickett's plot of EB14 (IP software)

Table 3. Archie parameters of all wells

Well	R_W	m	n	a
EB11	0.0267	1.9	2	1
EB14	0.0384	2	2	1
EB29	0.0305	1.47	2	1
EB74	0.0247	1.65	2	1
EB79	0.0427	1.55	2	1

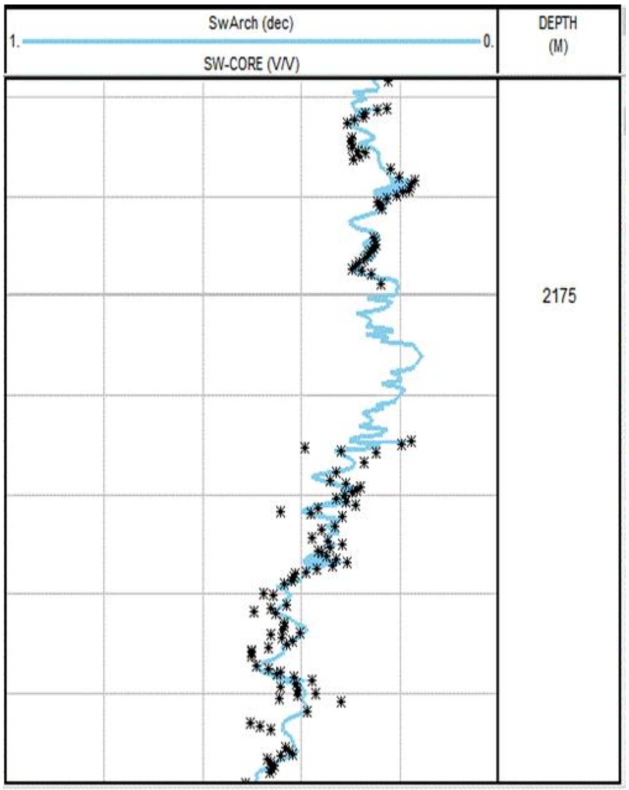

Fig. 9. Log plot of water saturation of EB74 (IP software)

Table 4 shows a comparison between the average water saturation calculated using the Archie technique and the water saturation measured from core samples. The absolute percentage inaccuracy is calculated. With an APE spanning from 3.1 to 32.5 percent, the Archie technique produces values that are more in line with core water saturation.

Table 4. S_w arch and S_w core comparison for available cored wells.

Well	Interval, m	$S_w arch$	$S_w core$	APE %
EB11	2198.3 – 2269.22	0.611	0.822	25.6
EB14	2164.3 – 2198.5	0.362	0.351	3.1
EB29	2167.6 – 2195.6	0.445	0.338	32.5
EB74	2277.5 - 2379	0.404	0.424	4.71
EB79	2031.7 - 2050	0.496	0.695	28.63

Table 5 shows how saturated the water is on average in each well. The findings demonstrate that EB14 well has the highest water saturation at 95.1%, while EB79 well has the lowest percentage at 64.3%. These findings suggest that water makes up the majority of the formation's fluid.

Table 5. Interpretation of water saturation findings from well logs for all wells

Well	Well Interval, m	Water saturation
EB11	2177.2 – 2276.8	0.773
EB14	2153.5 – 2255.7	0.951
EB29	2147 – 2249.04	0.692
EB74	2276 – 2384.8	0.853
EB79	2031.3 – 2138.4	0.643

5- Conclusion

Petrophysical research has employed a comprehensive dataset of well-log data from five actual wells to characterize the reservoir of the Khasib formation in the central east Baghdad oil fields. The analysis of density-neutron and M-N cross plots revealed that the specific limestone lithology of the Khasib formation is primary lithology of the formation. A corrected gamma ray log was used to estimate shale volume in wells (EB-11, EB-14, EB-29, EB-74, and EB-79) since it is the best method for detecting uranium emissions that may be present in the organic content of the rock formation. Porosity is calculated using a combination of neutron density logs to determine effective porosity for reservoir units and a sonic model to determine porosity for non-reservoir units. The Archi equation was applied to determine water saturation in uninvaded zones, recognized as the most reliable method for this calculation. The analysis showed that the normal range for porosity in carbonate reservoirs was found to be between 0.143 and 0.212, while water saturation ranges from 0.643 to 0.951. Due to its variability with depth and well locations, the high-water saturation is the determining element in determining pay zones. Based on the wells' computer-processed interpretation (CPI), the reservoir's upper zones also referred to as the upper Khasib, are the pay zones.

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الخصائص البتروفيزيائية لتكوين الخصيب في حقل شرق بغداد النفطي/ المنطقة الوسطى

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[١] قسم هندسة النفط، كلية الهندسة، جامعة بغداد، بغداد، العراق

الخلاصة

لقد كانت خصائص تقييم النفط من خلال تحليل سجل الآبار ضرورية دائمًا لتحديد وتقييم المناطق الحاملة للهيدروكربونات. يعتبر تكوين الخصيب بمثابة الخزان الرئيسي لحقل نفط شرق بغداد، الذي يقع على بعد ١٠ كيلومترات شرق مدينة بغداد. يقدم هذا العمل إعادة تقييم وتصحيح خمس مجموعات من بيانات سجل الآبار. يتم استخدام مجموعات البيانات المصححة لحساب تشبع الماء، والمسامية، والليثولوجيا، وحجم الطفل. تم تحديد الصخور باستخدام مخطط (أم–أن) ورسم سجل الكثافه مقابل سجل النيوترون، وتظهر هذه المخططات أن تكوين الخصيب يتكون بشكل رئيسي من الحجر الجيري وأن المكونات المعدنية الأساسية هي في الغالب الكالسيت مع كميات صغيرة من الدولوميت. تم استخدام السجلات الثلاثة الرئيسية : سجل النيوترون وسجل الكثافه وسجل الصوتيه لحساب المسامية. تم استخدام معادلة أرتشي لتحديد تشبع الماء، وللتحقق من دقة الحساب، تمت مقارنة النتائج مع البيانات الأساسية التي تم الوصول إليها. أن مساميتها تتراوح من ١٤٣.٠ إلى ٠,٢١٢، وأن تشبعها بالماء يتراوح من ٠,٦٤٣ إلى ٠,٩٥١. وأظهرت العينات الأساسية والتقارير الجيولوجية أن تكوين الخصيب كان نظيفا ولا يوجد به أي طفل. وأكدت التقارير الجيولوجية أن تكوين الخصيب نظيف ويحتوي على نسبة ضئيلة من الصخر الزيتي.

الكلمات الدالة: الخصائص البتروفيزيائية، تحليل مجسات الابار، المكامن الكاربونية، تكوين الخصيب، حقل شرق بغداد النفطي، برنامج IP.