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Utilizing Mud Log Gas Data for Real-Time Evaluation of Reservoir Fluid in the X Oilfield, Southern Iraq

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Abstract

Real-time identification of fluid characterization is important to execute and/or modify the proposed well program and provide a better understanding of the application of gas ratio analysis. In this study, reservoir fluids were characterized during drilling by analyzing light gases released as a result of formation rocks being penetrated. Drilling mud is used to carry reservoir gas during this process. The required data included the values of liberated gas molecules from the main reservoir section extracted by gas chromatograph (GC) during drilling, that data was collected from five wells (A, B, C, D, and E) in the X oilfield. The gas measurements included the gases from Methane (C1) to Pentane (C5) measured in real-time by the gas chromatograph in the mudlogging units. The ratios of C1-C5 gases were used to determine the values of wetness ratio (Wh), and hydrocarbon balance (Bh) in the 3rd and 4th pay reservoirs. Results showed good indications of fluid type compared to the actual well test and were capable of distinguishing between heavy and light hydrocarbons in the reservoir section. A joint interpretation of electric logs and mudlogging gas data leads to an enhanced understanding of well results, which in turn can be used to optimize future logging and well testing.

Keywords: Mudlog, fluid evaluation, light gas, Gas chromatograph.

استخدام بيانات تحليل نسب الغازات للتقييم الفوري لموائع المكمن في حقل (X) النفطي، جنوب العراق

الخلاصة:

يعد تحديد خصائص الموائع في الوقت الفعلي أمرًا مهمًا لتنفيذ و/أو تعديل برنامج البئر المقترح وتوفير فهم أفضل لتطبيق تحليل نسبة الغاز. تم في هذه الدراسة توصيف الموائع المكمنية أثناء الحفر من خلال تحليل الغازات الخفيفة المتحررة نتيجة اختراق صخور التكوين. ويستخدم طين الحفر لحمل الغازات المكمنية خلال هذه العملية. تضمنت البيانات المطلوبة قيم جزيئات الغاز المحررة من قسم المكمن الرئيسي المستخرجة بواسطة جهاز كروماتوغراف الغاز (GC) أثناء الحفر، وقد تم جمع البيانات من خمس آبار (A، B، C، D، وE) في حقل X النفطي. شملت قياسات الغاز الغازات من الميثان (C1) إلى البنتان (C5) التي تم قياسها في الوقت الحقيقي بواسطة كروماتوجراف الغاز في وحدات الطين. تم استخدام نسب الغازات C1-C5 لتحديد قيم نسبة التبلل (Wh) والتوازن الهيدروكربوني (Bh) في مكمني العطاء الثالث والرابع. وأظهرت النتائج مؤشرات جيدة لنوع السائل مقارنة بالفحص الفعلي للبئر وكانت قادرة على التمييز بين الهيدروكربونات الثقيلة والخفيفة في اجزاء المكمن. ويؤدي التفسير

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المشترك للمجسات الكهربائية وبيانات الغاز الطينية إلى فهم معزز لنتائج البئر، والذي بدوره يمكن استخدامه لتحسين عمليات الجس المستقبلية وفحوصات الآبار.

1. Introduction:

Mud logging is the process of continuously collecting, recording, and analyzing the meaningful solids, fluids, and gasses brought to the surface by drilling mud, it is considered one of the important components in any drilling rig equipment [1]. Mudlog can identify potentially productive hydrocarbon-bearing formations, identify markers or correlate geological formations, and provide data to the driller that enables safe and economically optimized operations [2]. A major development in the mud-logging gas system occurred in the last few years, the new advances included high-resolution Gas Chromatograph (GC) and mass spectrometer that can give good quality gas data during drilling, and can be used for the interpretation of formation evaluation, real-time detection of permeability barriers and seals, fluid contacts, and lithological variations [3].

The crushed reservoir rock during drilling will liberate the gases into the drilling mud, these gases will be detectable when reach the surface. The circulating drilling mud enters the gas trap where an impeller agitates the mud (Figure 1), releasing trapped gasses into the air inside the gas trap; a sample of this gas is pumped into the Mudlog unit where the gas chromatograph measures the gas type and quantity [4].

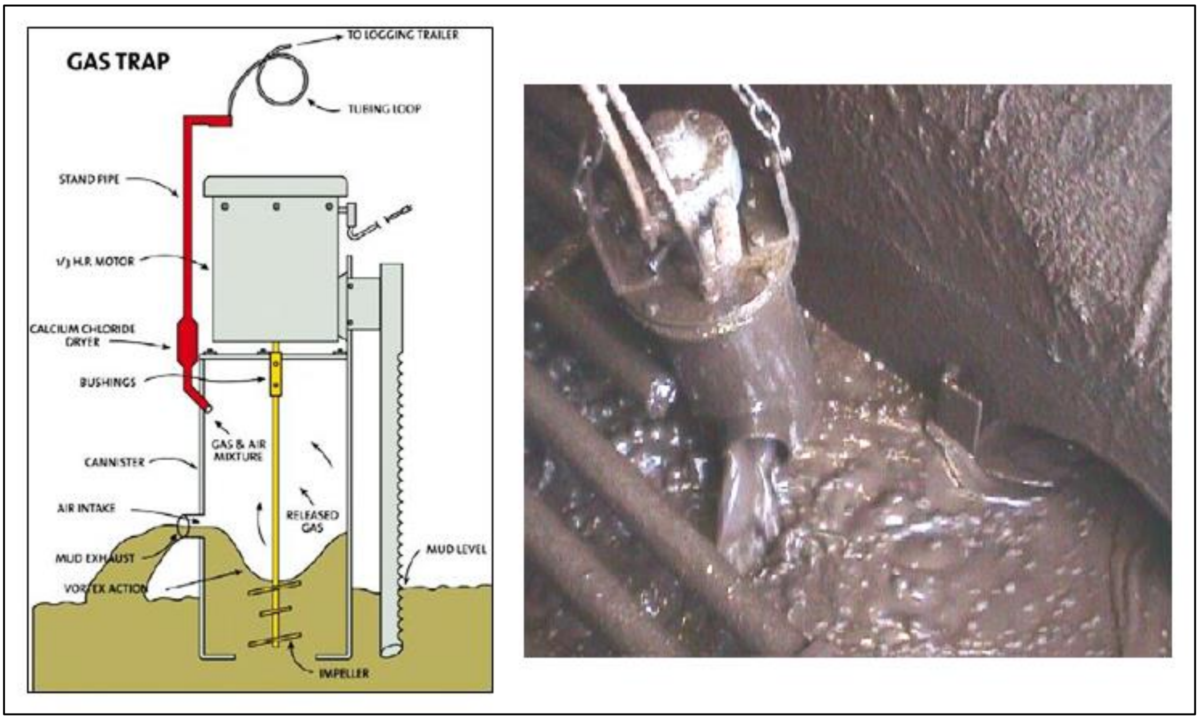

Fig. (1): The gas trap system [5]

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Determination of reservoir fluids can be done with different methods. However, the chromatograph gas ratios that include: balance and wetness ratios are the most appropriate for real-time analysis, those ratios are calculated and plotted instantly, providing a direct evaluation of the reservoir fluid character during the drilling of any oil or gas well and act as the "hydrocarbons fingerprints" [6]. The hydrocarbon type (dry gas, condensate, light oil, residual oil) can be defined by the ratios of C1-C5, i.e., determine the wetness, balance, and character of the extracted gases [7].

2. Methodology

The general method is described in the following steps:

1. The mudlog gas data was collected and reviewed from five wells (A, B, C, D, and E) in the X oilfield.
2. Used Haworth and Whittaker ratios to compute the following parameters [8]:
   - Wetness ratio (Wh) = $\left(C2 + C3 + C4 + C5 / C1 + C2 + C3 + C4 + C5\right) * 100$….. (1)
   - Hydrocarbon Balance (Bh) = $(C1 + C2) / (C3 + C4 + C5)$ ………………….. (2)
   - Character ratio (Ch) = $(C4 + C5)/C3$ ……………………………………….. (3)

   C1: Methane, (C2): Ethane, C3: Propane, C4: Butanes (i+n), and C5: Pentane (i+n) measured in ppm unit.

3. Evaluate the fluids type within the reservoir section using the Pixler plot.
4. Obtained resistivity log data for the five wells. Different fluid types have different resistivity values. As a result, the values obtained from the gas ratio calculations; which could indicate oil, gas, or water, were compared to the resistivity values from the wells as well.

In practice, a very simple relationship between the wetness and balance ratios is used to determine changing fluid types and contact points as drilling progresses. If the balance ratio is greater than the wetness ratio, gas is predicted (Table 1). The closer the curves are to each other, the denser the gas, and the more likely the reservoir will be productive. If the wetness ratio is greater than the balance ratio, then oil is predicted. If the curves are too close to each other, the lighter the oil. The greater the separation of the curves, the heavier the oil and the more likely the reservoir is unproductive or contains residual oil. The gas-oil contact (GOC) is, therefore, defined by the cross-over points of the two curves (Table 2). The oil-water contact is typically determined when there

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is a sharp increase in the wetness ratio, accompanied by a greater proportion of heavier hydrocarbons associated with residual oil traces [5].

Table (1): Hydrocarbons Interpretation based on wetness ratios [3]

Wetness Ratio	Fluid Potential
Wh < 0.5	Dry gas
Wh 0.5 - 17.5	Potential gas Gas, density increases with Wh
Wh 17.5 - 40	Potential oil Oil, density increases with Wh
>40	Residual oil, Nonproductive, very low-gravity oil

Table (2): General interpretation of Gas Ratios [3]

Gas Ratio		Interpretation
Wh < 0.5	Bh > 100	Light dry gas with no or very low production potential
Wh 0.5 – 17.5 and Wh < Bh < 100	Wh < Bh	Productive gas, density, and wetness increase as the two curves converge
Wh 0.5 – 17.5 and Ch < 0.05	Bh < Wh and	Condensate Gas or wet gas
Wh 0.5 -17.5 and Ch > 0.5	Bh < Wh and	High Gravity, high GOR oil
Wh 17.5 – 40	Bh < Wh	Oil, Gravity decreases as the curves diverge
Wh 17.5 – 40	Bh << Wh	Residual oil

2. Pixler plot

Pixler (1969) developed a qualitative identification for the Nonproductive, gas production and oil production zones, depending on the ratios between methane and the other components (C1/C2, C1/C3, C1/C4, and C1/C5) as presented in Figure (2). Pixler plots have always been used to recognize the signature of a formation fluid. Their significance has always been qualitative, but they help to differentiate one fluid from another with little doubt [5], [9].

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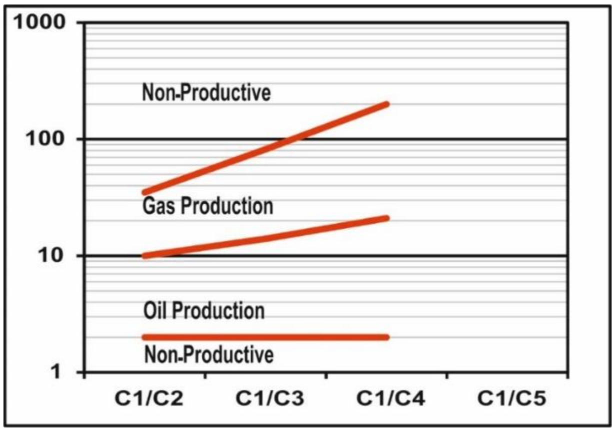

Fig. (2): Pixler plot [8]

3. Results:

Equations 1, 2, and 3 were used to obtain the ratios of Haworth and Whittaker. In the main reservoir, distinct differences were found between the upper and lower reservoir units. Next, ratio curves were plotted against methane (C1), resistivity, and the gamma-ray log. Because well B shows a transition from the oil potential zone to the gas potential zone, it has been selected to display the final results curves. Plotting the ratios of the upper reservoir unit oil saturation and the proposed condensate gas saturation, with varying oil gravities between the two members (Figure 3). It was noted that similar WH & BH ratios indicate a high oil gravity zone. Generally, along the upper reservoir unit, wetness values were between (20-40 %), while balance values were between (3-12 %) without curves crossing but a varying levels of convergence.

Wetness and balance ratios at the lower reservoir part have different patterns with many curves crossing in addition to curves convergence. Wetness values mostly were between (10-30 %), while balance values mostly were between (6-30 %)**.** As much as WH & BH ratios cross each other (Figure 4).

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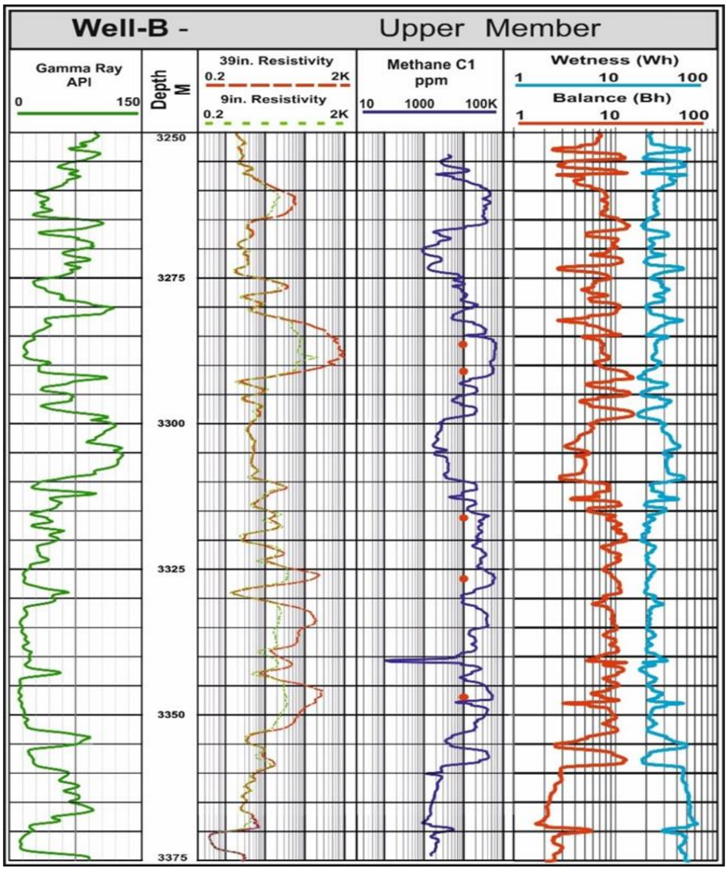

Fig. (3): Wetness and balance ratios in well B –upper sandstone member (red dots represent samples value for Pixler diagram)

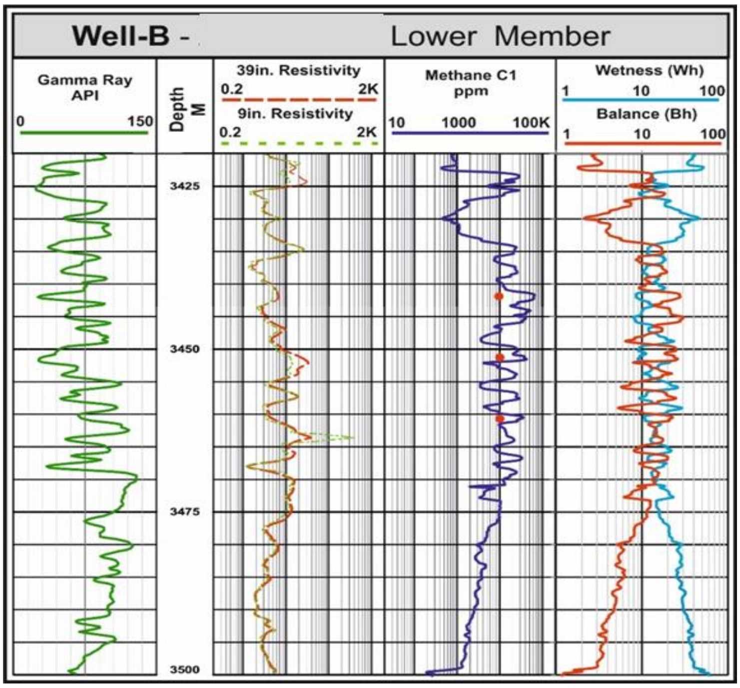

Fig. (4): Wetness and balance ratios in well B - lower reservoir (red dots represent sample value for Pixler diagram)

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Selected values representing specific depths (Tables 3 and 4) have been represented on the Pixler chart using methane ratio to other gases (C1/C2, C1/C3, C1/C4, and C1/C5). High C1 values were selected for the Pixler plot, each depth represents a different unit within the upper and lower members of well A (Figures 5A and B) and well B (Figures 5C and D), all graphs show different patterns in terms of the curve's location within the different zones.

Table (3): Raw gas data used to plot Pixler diagram for Wells A & B.

Well	Depth m	C1 ppm	C2 ppm	C3 ppm	iC4 ppm	nC4 ppm	iC5 ppm	nC5 ppm	Member
A	3397.5	13383	2908	2014	177	1010	243	457	Upper Sandstone Member
	3408	17603	3663	2416	210	1127	263	482	
	3415.5	15858	3645	2636	232	1291	305	544	
	3454.25	9247	2353	1852	182	1016	252	388	
	3459	15492	4212	3283	306	1719	419	646	
	3546	20870	2503	1512	165	926	246	429	Lower Sandstone Member
	3573	18626	2590	1777	269	1093	303	428	
	3576	4259	724	621	94	516	158	267	
B	3286.5	32526	5527	3061	346	1273	5	320	Upper Sandstone Member
	3291.5	27727	3972	1706	142	523	0	107	
	3316	21897	3343	1653	190	672	1	165	
	3327.75	27200	4082	1825	189	660	3	155	
	3347.25	28540	4928	2425	250	857	0	201	
	3441.5	31350	1731	757	86	295	0	84	Lower Sandstone Member
	3451.25	18428	1113	501	64	202	0	63	
	3460.5	17402	1237	522	45	202	0	54	

Table (4): Raw gas data used to plot Pixler diagram referred to measured depth for H1 unit of five wells

Well	Depth m	C1 ppm	C2 ppm	C3 ppm	iC4 ppm	nC4 ppm	iC5 ppm	nC5 ppm	Member & Unit
A	3415.5	15858	3645	2636	232	1291	305	544	Upper Sandstone Member Unit H1
B	3291.5	27727	3972	1706	142	523	0	107	
C	3236	15882	2458	973	92	288	71	114	
D	3232.5	7116	3280	309	928	197	274	15.2	
E	3241.5	73895	13673	7733	877	2837	806	1145	

The lower sandstone member in both wells tends to contain higher gas concentration compared with the upper member in both wells. Despite all graphs showing positive curves toward the gas productive zone, the Well-B gives a notable pattern that exceeds to gas productive zone, especially the lower member where gas concentrations start from a point within the gas productive zone.

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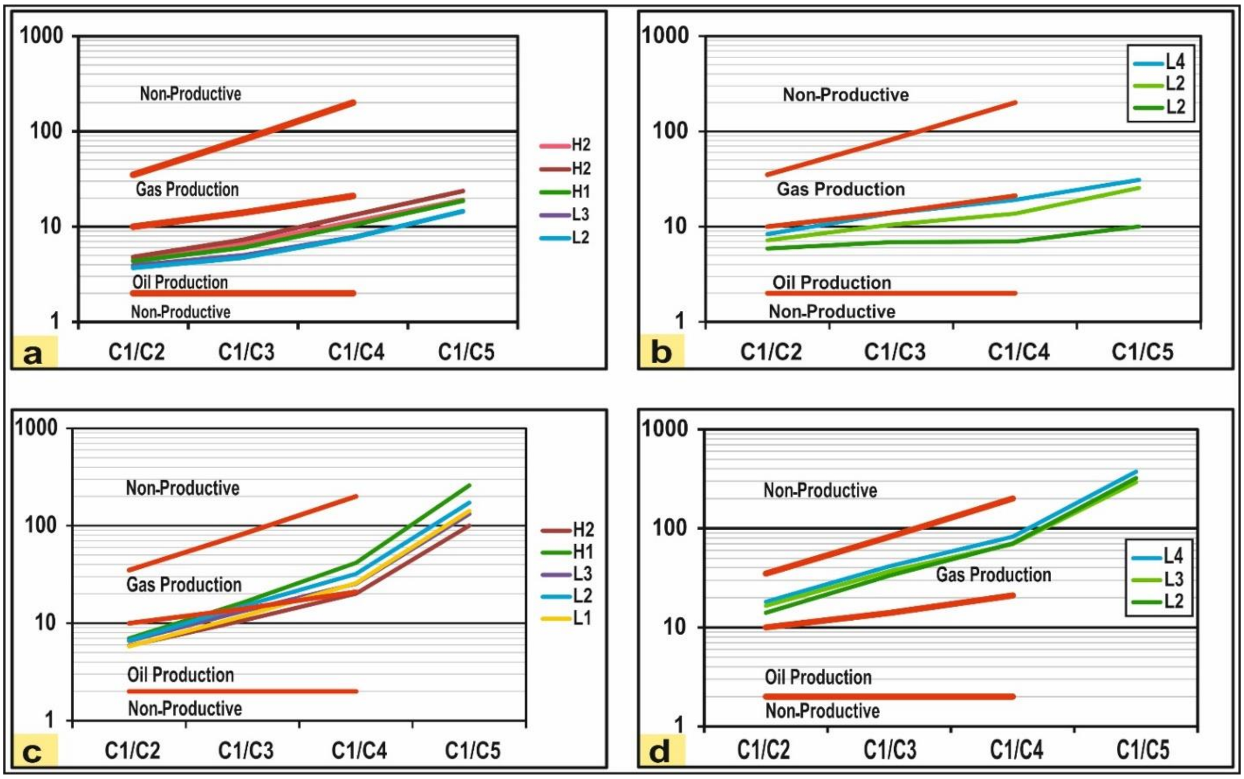

Fig. (5): Pixler diagram of Zubair formation for Wells A and B. a) The upper part of Well A. b) The lower part of Well-A. c) The upper part of Well-B. d) The lower part of Well-B.

A selected unit (belonging to the upper sandstone member) from five wells has been represented on the Pixler chart for correlation purposes and the resulting curves illustrate how this approach is a valid method for such a correlation. All wells located in the north part of Zubair field show a similar curve behavior except for Well-B, which is located in the southern part. However, gas ratios for Well-B & Well-C have similar values till C5 in opposite to the rest of the selected wells (Figure 6).

Pixler plot of the lower member of Well-A has been correlated to the production log test (PLT) data and the results almost corresponded with the consideration of PLT (Figure 7). According to the PLT results, unit L2 shows a distinct behavior where the upper part of the unit is more likely to produce gas more than oil while the lower part produces oil much more than gas.

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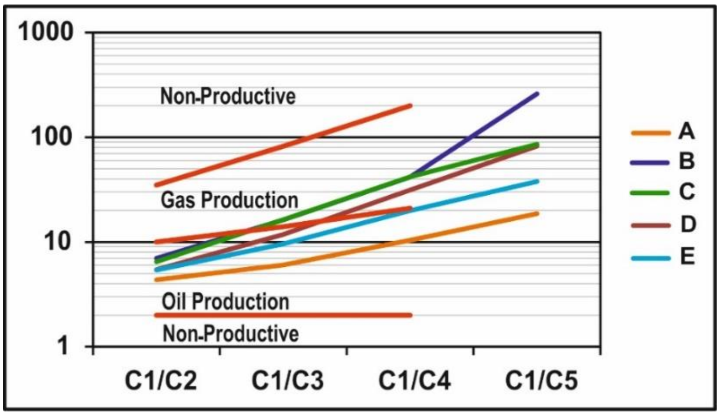

Fig. (6): Pixler plot for the H1 unit in the upper member for five wells. Well-B has the only distinct C1-C5 values as it's located in the southern part of the field. Well-A shows the lowest values as it's far from the crest compared with the other wells. Well-C is almost matches B.

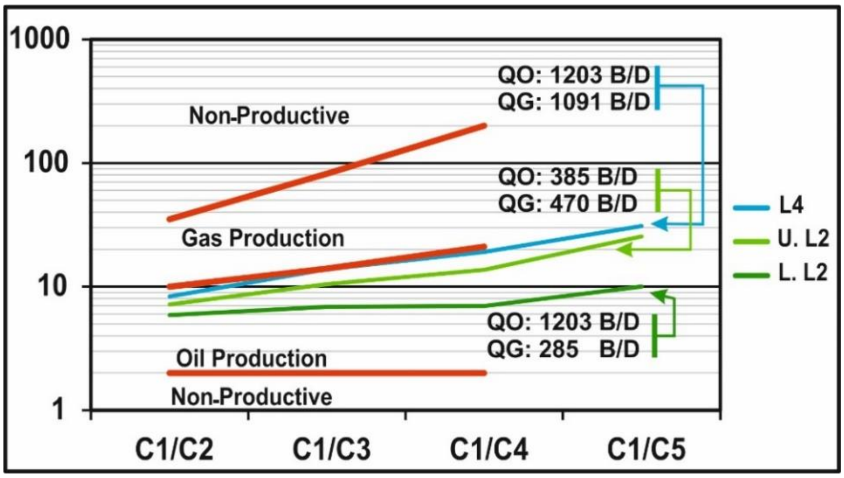

Fig. (7): Pixler diagram of lower member – well-A integrating with PLT results. The L4 unit ratio has the highest trend and moved toward the gas production area which is confirmed by PLT. Unit L2 shows a different trend vale between the upper and the lower part of L2, where the upper tends to produce gas much more than the lower part while the lower part is more likely to produce oil. (QO: flow rate of Oil; QG: flow rate of equivalent oil from gas; B/D: barrel per day)

4. <u>Discussions</u>

4.1 Wetness and Balance ratios interpretation

The wetness ratio (Wh) shows an increasing trend when the amount of heavy gas components increases proportionally against the lighter gases causing an increasing oil gravity (low API). While balance ratio (Bh) is only a comparison between light and heavy hydrocarbons. Both ratios have been used together for interpretative purposes. According to the equations, the Bh ratio is inversely proportional to the Wh ratio, so it increases as the fluid density decreases and vice versa.

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Gas presence is indicated by Bh > Wh. Dense gas has closer curves. Wh > Bh indicates oil presence. Closer curves indicate lighter oil. Distant curves indicate an unproductive zone or residual oil. Bh and Wh crossover marks gas-oil contact. The steep increase in Wh with heavier hydrocarbons and a decrease in Bh indicates oil-water contact.

In the upper reservoir section, zones with methane (C1) above 10000 ppm, Wh value less than 40, and higher than Bh value are productive for oil. GR and resistivity logs confirm these zones as clean and high-resistive areas. Some zones show low oil density with Wh and Bh curves being slightly close to each other, indicating oil-bearing zones. However, other zones show residual oil or water, with the curves getting far from each other and the wetness ratio exceeding 40, suggesting a residual oil or oil-water contact. The lower sandstone member shows a change in oil gravity with distinct changes in hydrocarbon fluid types between oil and gas potential zones. High GR readings suggest shale barriers or high gas density units. The most productive gas intervals are (3441-3446m) and (3449-3452m) with an established oil-water contact at 3476m.

The resistivity values in both members show a range greater than 4 ohm.m, which indicates the presence of hydrocarbons as per the common oil presence value in the X oilfield. The ratio curve behavior shows a noticeable difference between the upper and lower parts of the reservoir. In general, the upper part exhibits an oil-productive zone, while the lower part exhibits gas potential. This outcome is further validated by the API test result, which indicates that the upper part has 33 API, while the lower part has 38 API.

4.2 Pixler Plots interpretation

Since Pixler plots provide a visual interpretation of the results due to presenting them on a depth-related log is difficult, specific depth points have been chosen from the upper and lower reservoir members for two wells (well-A in the north of the field and well-B in the south), for comparison purposes, Pixler diagram indicates which fluid would be encountered at selected depth points. Generally, five units of the upper part and three units of the lower part have been presented on the Pixler plot for both wells. Pixler of well-A shows both members are oil-bearing zones with a trend of gas production in the lower member units. For the upper part, differences between units in terms of gas ratios are small suggesting that these units have similar fluid character even when shale barriers exist located between units. Pixler of well B shows a different pattern where the upper part is oil bearing zone and tends to be a high-gravity oil while the lower part is a gas-bearing zone or condensate gas as the values fall within the gas production area.

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The lower member plot in well A and the PLT results are valid for the reservoir's depth points. The L4 unit has the highest oil and gas production, while the upper L2 unit has the highest gas production rate, and the lower part of the same unit has oil gas production. Pixler diagram results help reservoir engineers choose the suitable perforation interval using gas to support production.

Another Pixler plot has been plotted to represent the H1 unit for 5 wells, the plot has been done for correlation purposes, and it clearly shows that well B has a different gas ratio. The gas concentrations indicate a light hydrocarbon occurred. All wells represent one oilfield but the differences noted are due to the wells location among the field, which can be related to the field structure whether on the flank or close to the crest. Well-B (H1 unit), which has the highest gas values, is located in the southern part of the field. Well-C (H1 unit) shows a quite similar pattern to well-B except for the C1/C5 ratio, while it is located in the north part, both units have the same depth.

5. Conclusions

1- Chromatograph analysis provides effective real-time fluid characterization while drilling operation, which it's easily can be used at the well site (by Mudlogging unit).

2- Wetness (Wh) and balance (Bh) ratios provide an effective interpretation procedure especially when the results are integrated with the other wireline log data. Changing with fluid type and fluids contact has been determined in addition to the changing in oil gravity for upper and lower members of Well-B which was confirmed by the actual oil gravity test.

3- The lower part of the main reservoir in X oilfield had gas potential, while the upper member is an oil-bearing zone.

4- The Pixler diagram presents a visual interpretation of the plots indicating reservoir fluid character (oil zone, gas zone, or non-productive zone).

5- Gas chromatographic ratios analysis and Pixler diagram haven't conclusive results as they need to combine resistivity log to confirm the presence of oil/gas or both. However, the Pixler diagram can be applied only for selected depth points as it's difficult to integrate with depth referred logs.

6- In the X oilfield, the Pixler diagram depicts how gas concentrations vary between the northern and southern field and increase towards the crest far from the flanks. In addition, it can be used for correlation purposes for a specific unit in the field, such as the results of the H1 unit, or different units within one reservoir.

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