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Hydrocarbon gas chromatography as indicator of fluids types: A case study of Azhar field, Beni Suef Basin, Egypt

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ABSTRACT

Hydrocarbon gas chromatographic investigation is regarded as the initial indicator of a reservoir's fluid properties. This study shows the assessment of fluid types of A/R “A, E, and F” members by using gas chromatographic analysis. The analysis entails examining the gas composition found in the drilling mud. The interpretation of the lighter gas composition (C_1-C_5) in Azhar A-2 well indicated that the A/R “A” member is characterized by the presence of dry gas or wet gas, where Wh 0.5–17.5, Bh > Wh, and Ch < 0.5. A/R “B” and A/R “C” members are characterized by the presence of wet gas or condensate, where Wh = 0.5–17.5, Bh > Wh, and Ch > 0.5. A/R "D," A/R "E," and A/R “F” members had been characterized by the presence of oil, where Wh was 17.5–40, Wh > Bh, and Ch > 0.5. The interval in the A/R “F” member from 6605 to 6610ft indicates the presence of residual oil with Wh > 40 in the Azhar A-2 well. A/R “F” Member in Azhar E-1X contains residual oil with Wh > 40 and Bh much less than Wh, indicating poor effective porosity net pay by the integration between gas chromatographic analysis and petrophysical data. In this study, the methane ratio and wet C_5 (C1) ratio in the dry gas/wet gas zone are higher than in the oil zone.

1. Introduction

In fact, gas analysis during drilling is critical to the overall productivity assessment of the wellbore as well as the appraisal and characterization of the reservoir (Kandel et al., 2001). Drill fluid gas shows offer crucial information for assessing the hydrocarbon content. The prospective productivity of the wellbore can be ascertained by keeping an eye on these gas shows. Gas analysis helps during drilling operations to ensure well stability, well control, and an understanding of pore pressure. In terms of hydrocarbon types and amounts, reservoirs usually display specific geochemical signatures. In order to evaluate and characterize reservoirs, high-quality gas data is helpful in identifying these signs. Gas shows help locate hydrocarbon contacts such as the Gas-Oil Contact (GOC) and the Oil-Water Contact (OWC). To improve the accuracy of these identifications, specialised ratios are used for in-depth investigation. In addition to aiding in reservoir evaluation, gas analysis advances knowledge of the geological formations that are encountered in drilling operations.

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Well site geologists can use gas show monitoring during drilling operations as a useful tool for a variety of tasks, such as determining the reservoir's properties and hydrocarbon potential as well as ensuring the stability of the wellbore. In-depth research and the application of specific ratios help to further hone the data collected, which makes well-informed decisions on planning and evaluation easier to make (Dashti et al. 2015).

The wetness ratio (Wh) and the balance ratio (Bh), two important ratios, behave significantly depending on the hydrocarbon composition and gas density. As gas density increases, the wetness ratio (Wh) shows an increasing trend. This suggests that the fraction of heavy gas components is increasing relative to lighter gases.

A direct comparison between light and heavy hydrocarbons can be made using the balance ratio (Bh). For interpretative reasons, it is used in conjunction with the wetness ratio. The balance ratio decreases as fluid density increases because it is inversely proportional to the wetness ratio. The ratio is used to estimate or validate potentials for gas production. For instance, when dry methane is present, the balance ratio value will be extremely high. But as soon as there's any indication of heavy hydrocarbons connected to a productive source, it drops down quickly.

The distribution of heavy and light gas components can be deduced from the wetness ratio; an increasing trend suggests a higher proportion of heavy components. Gas production potential is evaluated using the balance ratio, which is inversely correlated with the wetness ratio. Higher values of the balance ratio are indicative of drier gas, whereas a rapid decrease indicates the presence of heavier hydrocarbons from a productive source. The composition and production potential of the gases in the wells under study can be understood with the help of this information.

The study focuses on the Azhar A-2 and Azhar E-1X wells in the Western Province of the Beni Suef Basin, which are located between 29° 08' and 29° 08' N and 30° 55' & 29° 08' E (Fig. 1). The main goal is to evaluate the types of fluids in the A/R "A, B, C, D, and F" members' wells and integrate well-logging datasets from both Azhar E-1X wells and the A/R “F” members' wells Well logs provide crucial subsurface information, including porosity, permeability, and lithology. Data from gas chromatography is used to examine the composition of gas samples. In the Azhar field, hydrocarbon gas chromatography is an essential tool for fluid characterization as well as a crucial asset for improving production efficiency, reservoir management, identification of fluids types and broadening our understanding of the hydrocarbon systems in the Beni Suef Basin, Egypt. The implications extend beyond the Azhar field, impacting regional hydrocarbon exploration and production strategies.

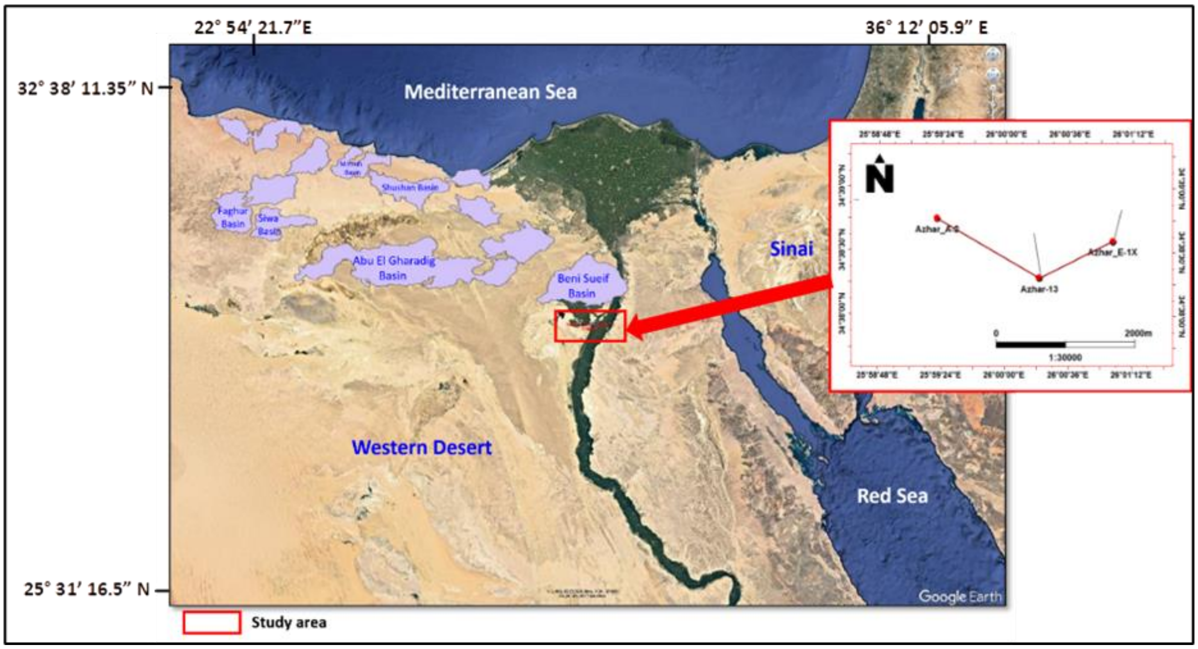

Fig. 1. Azhar Field Location map, Beni Suef Basin, Egypt.

2. Geological setting

The Beni Suef Basin is located south of Cairo in the northern region of Upper Egypt (Zahran et al. 2011). It is a sedimentary basin that was created over a lengthy geological period by the deposition of sedimentary rocks (Fig. 1). There is a direct relationship between the tectonic history of the area and the geological evolution of the basin. The Red Sea and the Gulf of Suez are linked to the basin due to their rifting and subsequent opening (Moustafa et al., 2008).

According to Salem and Sehim (2017), Shehata et al. (2018, 2020), Sakran et al. (2019); the Santonian Syrian-arc compressional regime affected the post-rift phase of the latest Cretaceous and the syn-rift extensional phase in the Early Cretaceous are the two major tectonic phases that the basin is subject to.

According to Zahran et al. (2011); Shehata et al. (2019); a comparatively thick lithostratigraphic succession from the Cretaceous to Paleogene may be seen in the Beni Suef basin. The Early Cretaceous Kharita Formation's thick fuvial siliciclastic deposits established the succession, followed by the Cenomanian Bahariya Formation's siliciclastic-dominated deposits,, intercalations of clastic/carbonate units from the Abu Roash Formation of the Cenomanian–Santonian Period, and ultimately descends to carbonates and chalk from the Khoman Formation of the Campanian–Maastrichtian Period.

The seven members of the Abu Roash Formation are G, F, E, D, C, B, and A, numbered from bottom to top. This study focuses on the evaluation of A/R “F, E, D, C, B and A” members of the Western Province of the Beni Suef Basin's Azhar A-2 and Azhar E-1X wells. Hydrocarbons can accumulate and become trapped in the basin due to structural elements like folds, faults, and anticlines. Successful petroleum exploration and extraction depend on an understanding of the basin's structural geology (Bosworth et al., 2015). A series of sedimentary rocks that have accumulated over millions of years can be found in the basin. Because hydrocarbon deposits are known to exist in the Beni Suef Basin, the petroleum industry is very interested in this region. In order to locate and acquire these natural resources, the basin has seen oil and gas exploration activity. The Beni Suef Basin's stratigraphy usually consists of a range of sedimentary formations, including sandstones, shales, and limestones, which provide insight on the area's geological history (Norton 1967) (Fig. 2).

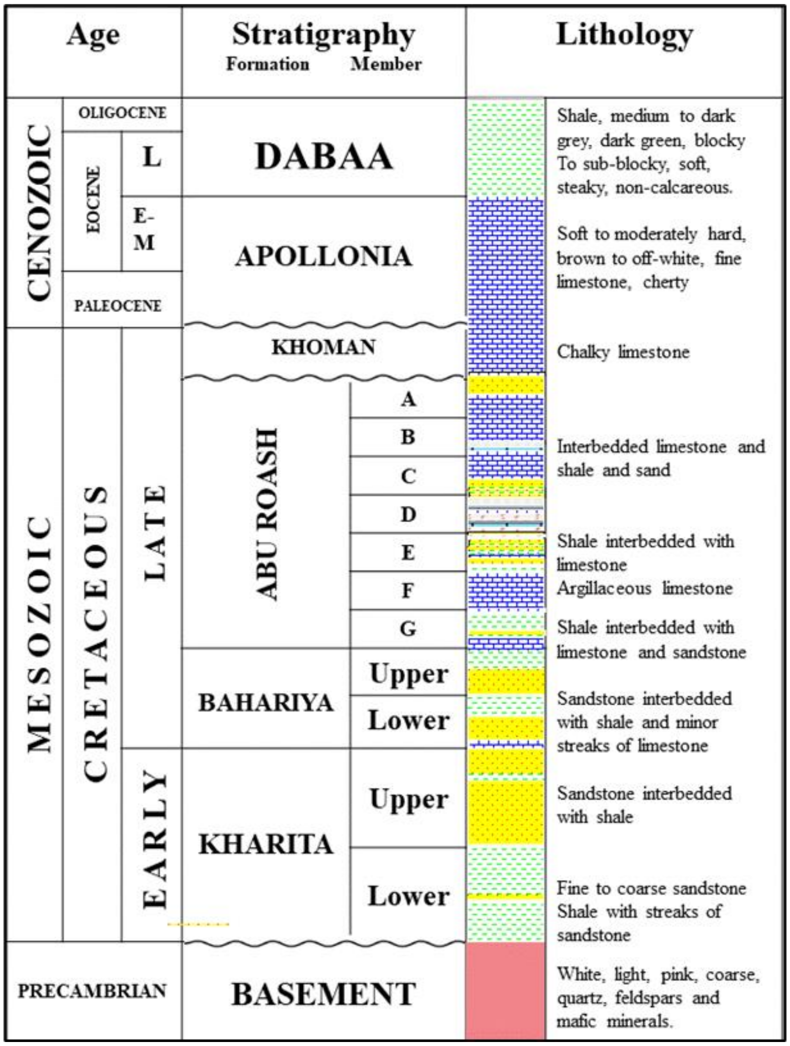

Fig. 2. The study area's stratigraphic column

3. Methodology

Gas chromatographic data (C1–C5) from two wells (Azhar A-2 and Azhar E-1X) as well as well logs are used in this study. Gas peaks from reservoir sections are analyzed for wetness, balance, and character ratios using formulas derived from the work of Harworth et al. (1984) and Harworth et al. (1985). It was combined with this reservoir's petrophysical data.

Wetness ratio was calculated using the formula: $Wh = \left(\frac{C2+C3+C4+C5}{C1+C2+C3+C4+C5}\right) * 100$ (Haworth et al. 1985; Pierson 2017).

Balance ratio was calculated using the formula: $Bh = \left(\frac{C1+C2}{C3+C4+C5}\right)$ (Haworth et al. 1985; Pierson 2017).

Character ratio was calculated using the formula: $Ch = \left(\frac{C4+C5}{C3}\right)$ (Haworth et al. 1985; Pierson 2017).

Using the gamma ray logs approach, the volume of shale was approximated in this study using the following equation (Islam et al. 2013):

$$\mathrm{IGR} = \frac{(\mathrm{GR\ log} - \mathrm{GR\ min})}{(\mathrm{GR\ max} - \mathrm{GR\ min})}$$

Where IGR = gamma ray index and GRlog = the formation gamma ray reading, GRmin = min. gamma ray and GRmax= max. gamma ray, density log reading IGR=Vsh in the linear model.

Usually, the effective porosity is determined by adjusting the total porosity using the predicted shale volume. The formula for calculating effective porosity may be written as the following (Atlas 1979):

$$\emptyset eff = \emptyset T - [\emptyset sh * Vsh]$$

where ØT is the total porosity and Øeff is the effective porosity.

Within a shale zone, Øsh=porosity reading, and Vsh=shale volume.

The following formula was used to determine the water saturation from Archie's model (Archie 1942):

$$Sw = \frac{(a * Rw)}{(Rt * \varphi m)^{1/n}}$$

Where φ is porosity, m is the cementation exponent, Sw is the uninvaded zone's water saturation, a is the tortuosity exponent, n is the saturation exponent, Rw is the formation water resistivity at formation temperature, and Rt is the true formation resistivity.

4. Results and discussion

The relationship between wetness and balance ratios is the basis for determining the types of fluids and contact points during drilling (Harworth et al., 1984). It is expected that gas will be present if the balance ratio is higher than the wetness ratio. The denser the gas and the greater the probability of productiveness of the reservoir, the closer the curves of the two ratios are to one another (Harworth et al., 1984). It is expected that oil is present if the wetness ratio is higher than the balance ratio. The lighter the oil, the closer the two ratios' curves are to one another. On the other hand, heavier oil is indicated by a greater separation between the curves. The wetness and balance\`e ratio curves' crossover points define the gas-oil contact (GOC) (Harworth et al., 1984). Understanding the reservoir's change from gas to oil can be gained by observing this crossover point. Usually, when the wetness ratio increases significantly, the oil-water connection is identified. A higher percentage of heavier hydrocarbons linked to traces of residual oil are present along with this increase. Essentially, this useful relationship offers a rapid evaluation of the many fluid types and contact points that change throughout the drilling operation. Wetness and balance ratios can be compared, and the patterns of their curves can be used to anticipate the existence of gas or oil as well as identify important contacts such the oil-water and gas-oil contacts (Harworth et al., 1984).

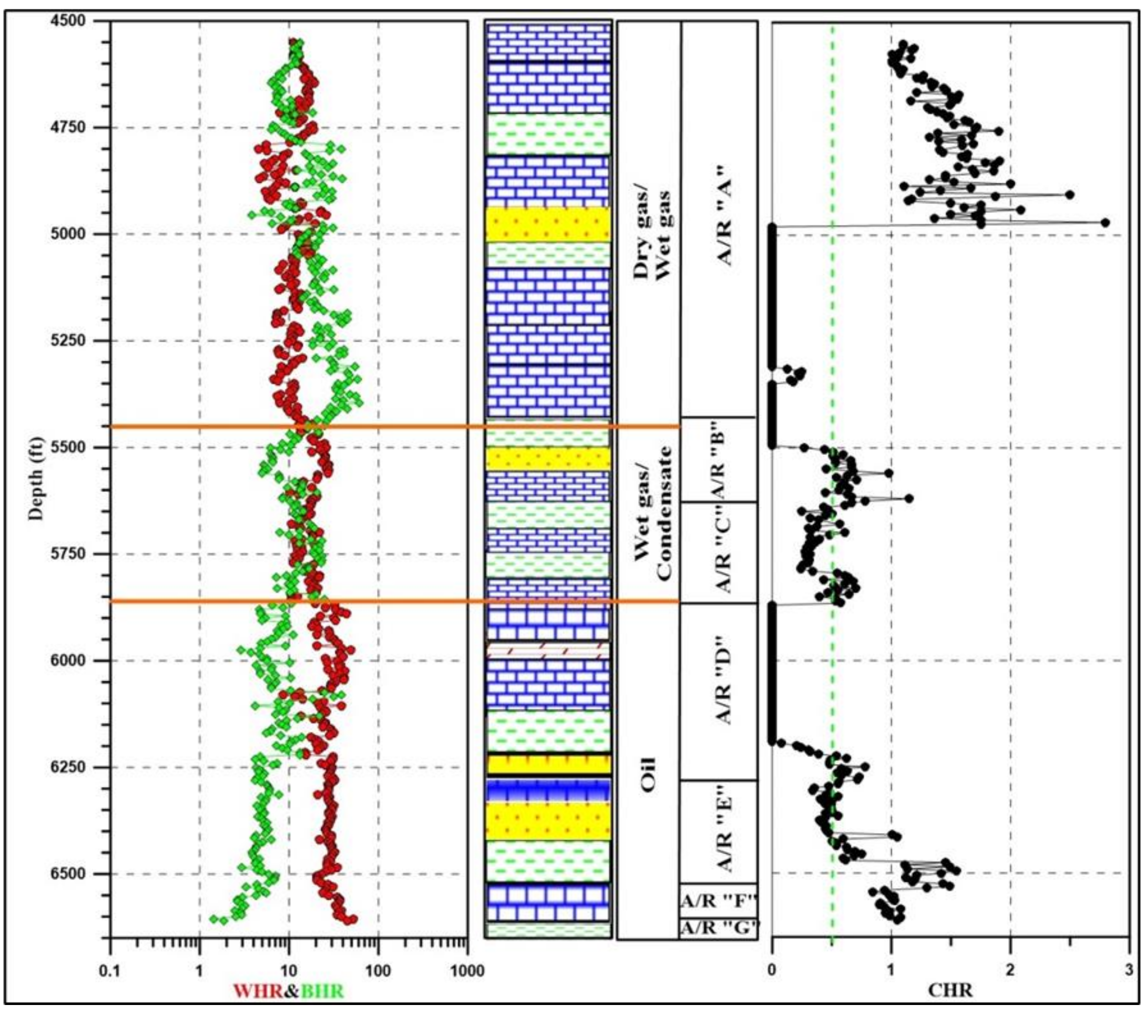

Fig. 3. Mud gas diagnostic ratio log for Azhar A-2 well. The diagnostic ratios defined by Haworth et al. (1985), WHR (wetness ratio), BHR (Balance ratio) and CHR (character ratio).

Making educated conclusions regarding the reservoir's composition and potential productivity is made easier with the help of this method.

Wh ratios are recognized as the following: if Wh is < 0.5, the fluid is very dry gas, If Wh is 0.5-17.5, the fluid is gas, where density increases with increasing Wh, If Wh is 17.5-40, the fluid is oil, where density increases with increasing Wh and if Wh > 40, the fluid is residual oil (Harworth et al., 1984 and Mode et al., 2014).

Bh ratio calculated as a nearly inverse relationship to the Wh ratio and it used to differentiate between coal bed anomalies from oil shows (Harworth et al., 1984 and Mode et al., 2014).

Plotting Wh and Bh together allows for flexible character interpretation: if Bh is >100, the fluid Very dry gas. If Bh is > Wh, the fluid is Gas, with gas density rising as the curves become closer to one another. Wh denotes a gas phase. If Bh is < Wh, the fluid is Gas/oil or gas/condensate, and Wh denotes a gas phase. Oil is shown, with oil density rising as the curves separated with Wh in the oil phase and Bh < Wh. If Wh > 40 and Bh much less than Wh, the fluid is Residual oil (Harworth et al., 1984 and Mode et al., 2014).

The use of the Ch ratio in interpreting data suggests that elevated methane levels may be indicative of a fluid with lighter hydrocarbon content. Gas-cap, dual oil/gas, and water-wet zones are examples of situations. Analysis of Ch: Ch < 0.5: The interpretation of gas by Wh and Bh is accurate.Ch > 0.5: Oil is associated with the gas character denoted by Wh and Bh (Harworth et al., 1984 and Mode et al., 2014).

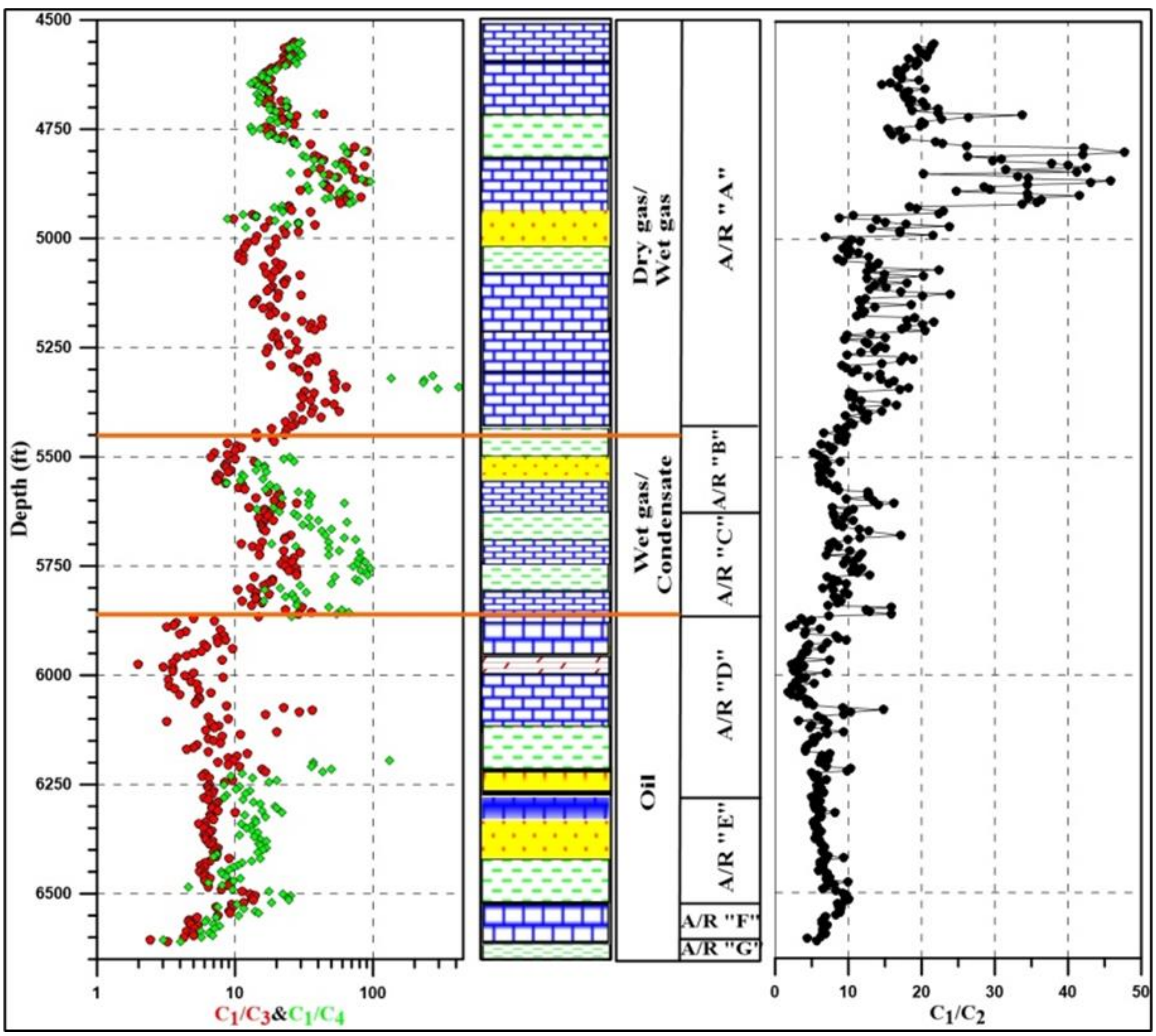

Fig. 4. Mud Gas concentration Log for well Azhar A-2 well.

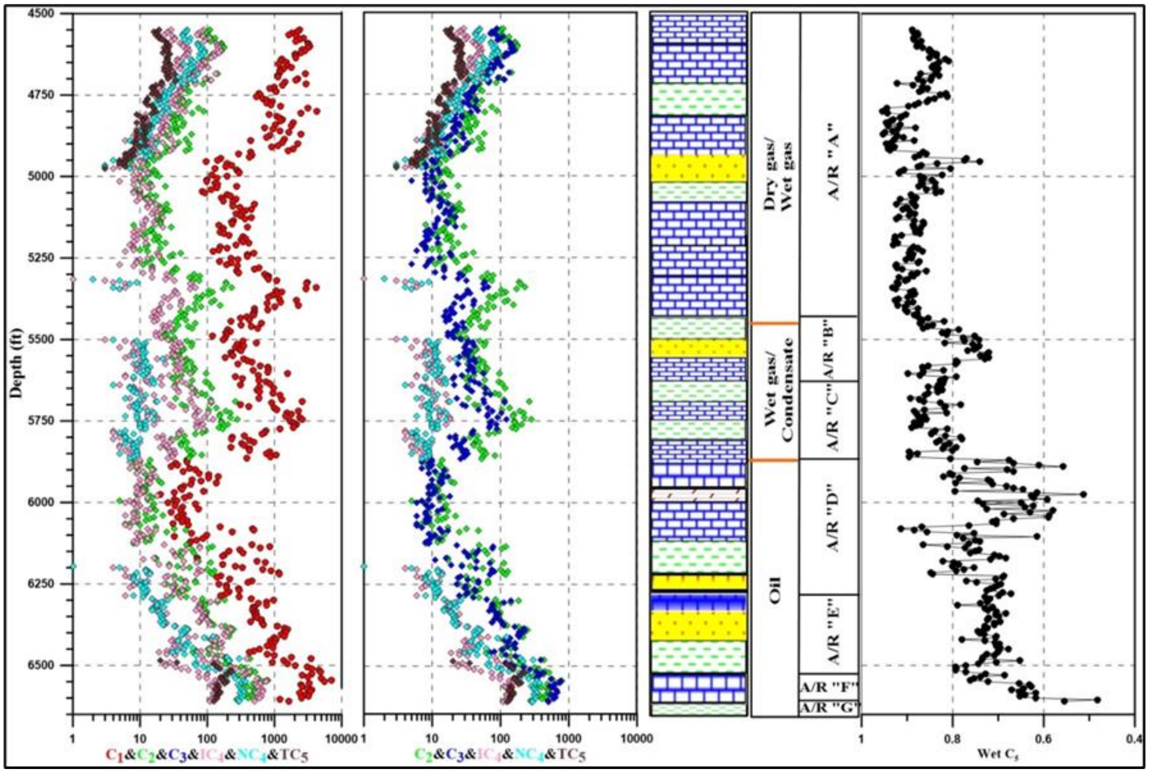

Fig. 5. Relation between C_1/C_2, C_1/C_3 and C_1/C_4 ratios of Mud gases for Azhar A-2 well.

In this study, the relationship between Wetness and Balance curves is used to indicate the fluid characterization, so the A/R “A” Member shows greater separation between the two curves, where Wh 0.5-17.5, Bh > Wh and Ch < 0.5, indicating the presence of Dry gas/Wet gas (Fig. 3). A/R “B” and A/R “C” Members show the closer the curves of the two ratios to one another, where Wh 0.5-17.5, Bh > Wh and Ch > 0.5, indicating the presence of Wet gas/condensate (Fig. 3). A/R “D”, A/R “E” and A/R “F” Members show greater separation between the two curves, where Wh 17.5-40, Wh > Bh and Ch > 0.5, indicating the presence of Oil (Fig. 3). The interval in A/R “F” member from 6605-6610ft shows Wh > 40, indicating the presence of residual oil.

In the hydrocarbon composition, the ratio of C_1/C_2 indicates the relative the amount of methane (C_1) to ethane (C_2). Methane is more prevalent than ethane at lower thermal maturity levels, as shown by a greater C_1/C_2 ratio (Behar, et al., 1992). On average, the C_1/C_2 ratio decreases with increasing thermal maturity. More organic matter is being converted into heavier hydrocarbons, which is the cause of this. In the natural gas and oil industries, the C_1/C_2 ratio is an essential diagnostic tool. It aids in determining the kind and maturity of organic materials in a given geological formation that is producing hydrocarbons (Prinzhofer et al, 2000). It is crucial for understanding the characteristics of hydrocarbons in reservoirs for geochemistry and petroleum exploration. The C_1/C_2 ratio assists in identifying reservoirs by offering important information about the hydrocarbon composition. The oil and natural gas sectors frequently use the C_1/C_2 ratio as a diagnostic tool. It helps in estimating the potential for hydrocarbon production in a particular geological setting and understanding the maturity level of organic matter (Tedesco, 2012).

In this study, the methane ratio and Wet C_5 ($C_1/(C_1+C_2+C_3+C_4+C_5)$) ratio in Dry gas/Wet gas zone is higher than in oil zone (Fig. 4). C_1/C_4 ratio is higher than C_1/C_3 in the case of Oil zone, indicating that Oil zone not Wet-water zone. In the case of Dry gas/Wet gas zone, the C_1/C_4 ratio is lower than C_1/C_3, indicating that Dry gas/Wet gas zone is Wet-water zone (Fig. 5).

5. Petrophysical analysis related to gas concentration log

Essential parameters for the petrophysical evaluation of the reservoirs include the Formation evaluation, lithological interpretation, effective porosity, bulk volume interpretation, and cutoff calculations. In this section, the Abu Roash F Member reservoir in the study region will have their total porosity, effective porosity, water saturation, shale volume, net sand thickness, net pay thickness, and hydrocarbon saturation assessed. This complex integrative process is carried out using the log analysis software application [Interactive Petrophysics Volume 4.2 (IP)].

This study indicates the petrophysical parameters of A/R “F” Member through the interval (6240-6290ft) in Azhar E-1X well. It characterized by Net pay=1ft, effective porosity=16% and Water Saturation=8% (Fig. 6). Gas concentration log indicated that this pay contain residual oil with Wh > 40 and Bh much less than Wh (Fig. 7).

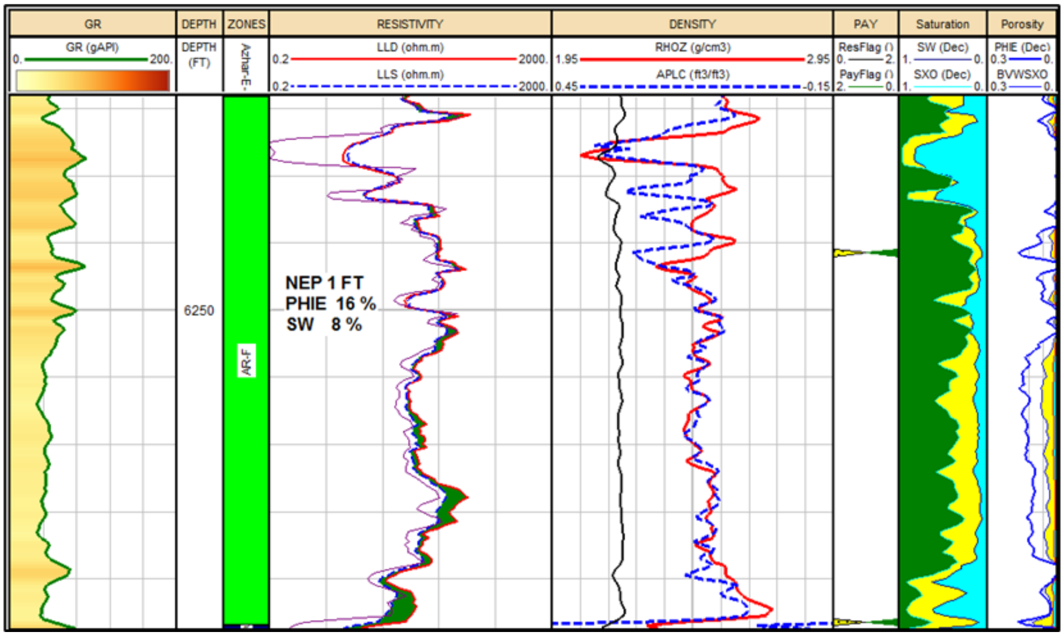

Fig. 6. AR-F Member Lithosaturation Plot, Azhar-E-1X well

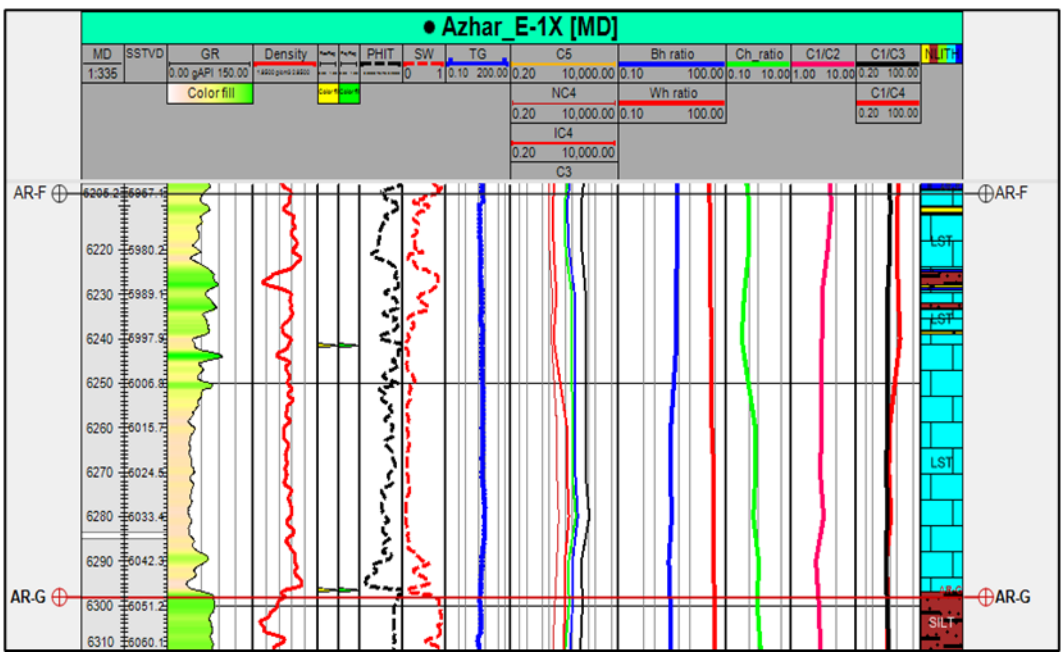

Fig. 7. Gas analysis of AR-F Member, Azhar-E-1X well

Conclusion

For effective interpretation, the results of the mud log gas data must be plotted on a depth log. This integration allows for a comprehensive understanding of subsurface conditions and facilitates the correlation of gas data with other relevant well data.

According to the relationship between wetness and balance ratio, three types of fluids are indicated in Azhar A-2 well. The A/R "A" Member shows Wh 0.5–17.5, Bh > Wh, and Ch < 0.5, indicating the presence of dry gas or wet gas. A/R "B" and A/R "C" members show Wh 0.5–17.5, Bh > Wh, and Ch > 0.5, indicating the presence of wet gas or condensate. A/R "D," A/R "E," and A/R "F" members show Wh 17.5–40, Wh > Bh, and Ch > 0.5, indicating the presence of oil. The interval in the A/R "F" member from 6605 to 6610 feet shows Wh > 40, indicating the presence of residual oil.

A/R "F" Member in Azhar-E-1X well contains residual oil with Wh > 40 and Bh much less than Wh, indicating poor effective porosity net pay by the integration between gas chromatographic analysis and petrophysical data.

According to the relation to C_1/C_3 and C_1/C_4 ratios, C_1/C_4 ratio is higher than C_1/C_3 in the case of Oil zone, indicating that Oil zone not Wet-water zone. In the case of Dry gas/Wet gas zone, the C_1/C_4 ratio is lower than C_1/C_3, indicating that Dry gas/Wet gas zone is Wet-water zone.

There are various factors impact the accuracy and reliability of hydrocarbon gas chromatography (GC) results in the Azhar field as the following; Complexity of Fluid Mixtures, Impact of Reservoir Conditions, Potential Contaminations, Incomplete Separation in GC, Heavy Component Sensitivity, Non-Hydrocarbon Components, Operator Expertise and Standardization, Spatial Resolution Limitations and Environmental Influences. To overcome Limitations, many Complementary Techniques are suggested to enhance fluid characterization studies in the Azhar field. This could include the use of mass spectrometry, nuclear magnetic resonance, or other advanced analytical methods to provide a more comprehensive understanding.

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