Iraqi Journal of Oil & Gas Research, Vol. 03, No. 02

Iraqi Journal of Oil & Gas Research

Journal homepage: https://ijogr.uotechnology.edu.iq

Application of well logging interpretation to determine the perforation interval

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Article information

Article history:
Received: September, 18, 2023
Accepted: October, 08, 2023
Available online: October, 08, 2023

Keywords:
Oil Well,Well log,
Well Perforation,
WOC, Net pay,
lithology.

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Abstract

The importance of using well logging data in well completion take into consideration in this paper, specifically for detection of well optimum perforation interval by using well logs data of (NS-1) well in Nasiriyah oil field in Yamama formation, which is detected process done by using the available well logging recorders such as (Gamma Ray log, SP log, RHOB log, NPHI log and Resistivity logs), the environmental correction has been done for available logs recording using Interactive Petrophysics software (IP) which used to determine Petrophysical Properties, further, construct a geological model by (petrel) software which used to detect the Water Oil Contact (WOC) in the geological structure to avoid to perforate nearby zone. The results show that the average Porosity is (11.2 %) and average Permeability is (12 md), whereas the minimum water saturation is (20.5%) at depth interval (3170-3230 m), while the WOC is located at depth (3378 m). Finally, the results show the optimum perforation zone is located at depth interval (3190-3210 m).

DOI: http://doi.org/10.55699/ijogr.2023.0302.1054, Oil and Gas Engineering Department, University of Technology-Iraq

1.Introduction

Well logging is the science of interpreting bore hole measurements for the appraisal of natural resources, followed by the technology of taking the measurements. Furthermore, information from well logging is useful for geological and geophysical evaluation, reservoir model building, and well drilling, completion, and operation. [1]

The efficient development of a hydrocarbon reserve depends in large part on well logging. The log measurement holds a crucial place in the life of a well. Wireline logging's historical responsibilities have been limited to involvement largely in two broad domains: formation evaluation and completion evaluation. [2]

Reservoir connection to the surface is usually a rather complicated one, where multiple plethora of physical attributes, chemical properties, statistical theory, work of engineering, geological properties, hydraulic works and the likes, science of materials and matter, as well as practicality of scientific methods, and the wellsite tacit knowledge that goes directly into completing a well. [3]

Cased-hole completions require perforations to allow reservoir fluids to flow into the wellbore. Perforation technology has evolved significantly in recent years, with advances in diameter, density, tunnel length, and orientation.

For example, perforator diameter has increased from around 0.25 inches to over 1 inch, allowing for more effective communication between the wellbore and the reservoir. Perforation density (shots per foot) has also increased, which can help to improve well productivity and reduce the risk of sand production.

In addition, perforation tunnel length has increased, which can help to improve well performance in tight formations. Perforation orientation can also be controlled to maximize the flow of reservoir fluids into the wellbore. Large caliber bullets were used to shoot perforations in the 1930s and 1940s, among other things. However, during World War II, advances in high explosives gave rise to shaped charges for perforating. A few operators have punctured case using water jets with abrasives. Petroleum engineers are in charge of making various design decisions prior to drilling a well. [4]

Predicting the magnitude and transient behavior of perforating shock loads is a critical step in ultra-deep well perforation, as it can help to avoid damage to tool strings and production equipment.

Perforating shock loads are generated by the detonation of explosive charges in perforating guns. These shock loads can be very large and can cause significant damage to downhole equipment if not properly managed. [5]

The number of perforations clearly affects the fracture morphologies. Reducing the number of perforations will increase the friction in the perforation holes. This stage encourages the uniform propagation of each fracture within a stage because the barrier to fluid passing through the holes will rise and the difference in fluid pressure between the outside and inner fractures will be less. [6]

Perforating technologies are selected based on the geological characteristics, fluid properties, and type of oil and gas well (straight, directional, or horizontal).
Common perforating technologies include:

- Perforating with a Wireline casing gun:
  - Overbalance perforating
  - Underbalance perforating
  - Pressurized perforating
- Perforating with Tubing-conveyance (TCP)
- Perforation through-tubing (TTP):
  - Conventional (Standard) TTP
  - Extended-diameter (Extra-large) TTP

Wireline casing gun perforation is used to perforate the casing and cement sheath to create openings for reservoir fluids to flow into the wellbore. It can be performed in overbalance, underbalance, or pressurized conditions.

Overbalance perforating is the most common type of wireline casing gun perforation. It is performed when the wellbore pressure is greater than the reservoir pressure. This helps to prevent the formation from flowing into the wellbore during perforation.

Underbalance perforating is performed when the wellbore pressure is lower than the reservoir pressure. This can be used to improve well productivity by creating larger perforation tunnels and reducing the risk of formation damage.

Pressurized perforating is performed using a wireline casing gun that is equipped with a pressure chamber. This helps to protect the perforating gun from damage in high-pressure environments. TCP is used to perforate the casing and tubing to create openings for reservoir fluids to flow into the wellbore. It is typically used in wells with high production rates or in wells with multiple production zones. TTP is used to perforate the tubing and cement sheath to create openings for reservoir fluids to flow into the wellbore. It is typically used in wells with existing completions or in wells with difficult completion conditions. Conventional TTP uses a perforating gun that is lowered into the wellbore on a wireline. The gun is then fired to create perforations in the tubing and cement sheath. Extended-diameter TTP uses a perforating gun that is equipped with a special extension device. This extension device allows the gun to reach and perforate areas of the tubing and cement sheath that would otherwise be inaccessible. The best perforating technology for a particular well will depend on the specific well conditions and the desired results.

Due to its importance in the well completion process, the perforation process has been the subject of numerous studies and research.

In a 2022 study, Kadhim et al. investigated the optimal perforation interval by determining the oil zone interval, petrophysical properties, and productivity ratio to assess the effectiveness of the perforation process. To achieve their goal, they used geological and petrophysical data as well as drilling data.

To create a 2D cross-section of the wellbore openhole (WOH), geological and petrophysical data were used with Petrel (2009) software. They found a perforated interval with a thickness of 8.5 meters and 112 perforations at a depth of 3865.5-3874 meters. The perforation calculation revealed a productivity ratio of 1.1709 and a perforation flow rate of 2769.547 BOPD. [7]

Zakera (2019) predicted a novel technique for perforation interval in a depleted reservoir for maximizing productivity using pulsed neutron-neutron (PNN) logging in a cased well of an oil reservoir in the middle east.
PNN logging emits neutrons into the near-wellbore zone and measures the neutron count decay due to scattering and capture. It is used to determine current oil saturation and detect channeling in perforated and non-perforated intervals behind the casing.
In other words, Zakera used PNN logging to find the best place to perforate a depleted reservoir to get the most oil out of it. PNN logging is a tool that can be used to measure how much oil is in a reservoir and to find any areas where water is flowing into the well, which can reduce oil production.[8]

HAN, (2018), introduced a review paper that summarizes Optimum Design of perforation scheme for horizontal well. in this review paper Han summarizes the problem in horizontal wells that the horizontal trajectory does not guarantee that all in the remaining oil in the region. He found that the perforation of a horizontal well should be dependent on the actual drilling trajectory, choosing a different perforation angle for each layer depending on its actual position. [9]

Onuh (2006) found that the longer, wider, and more densely spaced the perforations are, the higher the production rate will be. This is because perforations create a pathway for oil to flow from the reservoir into the wellbore. The larger and more numerous the perforations are, the easier it is for oil to flow.

It is important to note that there is a trade-off between perforation geometry and cost. More complex perforation patterns with longer, wider, and more densely spaced perforations will be more expensive to create. However, the increased production rate may offset the additional cost.

The best perforation geometry for a particular well will depend on the specific well conditions and the desired results which is the ultimate objective of this research [10].

2. Methodology

2.1. Detection of optimum perforation interval

The following procedure must be followed in order:

1. Data preparation: Well log data is corrected and environmentalized to ensure accurate

interpretations.

2. Petrophysical analysis: Petrophysical properties such as porosity, permeability, clay volume, and water saturation are calculated from well log data.
3. Water-oil contact (WOC) detection: The WOC depth is identified using well log data and geological information.
4. Geological modeling: A geological model of the reservoir is created using Petrel software. This model is used to visualize the WOC and well location in 3D.
5. Net pay determination: The net pay is identified using petrophysical interpretation and geological modeling.
6. Perforation interval selection: The perforation interval is selected based on the following criteria:
    - Avoid the WOC.
    - Avoid the shale zone.
    - Select the high porosity and permeability zone.
    - Select the low water saturation zone.

Additional considerations:

- The type of reservoir (e.g., sandstone, carbonate, shale)
- The well completion design (e.g., cased-hole, open-hole)
- The desired production rates

The optimal perforation interval will vary depending on the specific well conditions and production goals. It is important to consider all of the above factors when making a selection.

2.2. Lithology & Petrophysical properties

Lithology and Petrophysical properties are the variables where the interpretation of the logging data and the formation evaluation depends on when trying to provide the most optimum results from the data on-hand.

To calculate the average gamma ray (GR) reading in sands that are clean (GR_{sa}) and shale values (GR_{sh}). The Definition of the shale volume, (V_{sh}), will be defined as:

$$V_{sh} = (GR - GR_{sa}) / (GR_{sh} - GR_{sa}) \quad (1)$$

Where:

V_{sh} = shale volume
GR = gamma ray log, API
GR_{sa} = gamma ray sand, API
GR_{sh} = gamma ray shale, API

By conducting a comparison of the (V_{sh}) with the recorded response pf the neutron/density, a value of (V_{sh}) is determined to be used as a cutoff value.

On the other hand, the Porosity is to be calculated utilizing the density log measurement through the equation below:

$$\varphi = (\rho_m - \rho_{log}) / (\rho_m - \rho_f) \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where:
ρ_m = matrix density (g/cc)
ρ_{log} = log reading (%)
ρ_f = fluid density (g/cc)

It is to be noted that the sections with water bearing will show a very good estimation of porosity and can be used as a good approximation for a true resistivity value n the sense (Rt) which supplements Archie's equation, this equation is: [11]

$$Rt = Rw\,\varphi^{-m}\,S_w^{-n} \text{ ....(3)}$$

Or

$$S_w = \left[\left(\frac{Rt}{Rw}\right)\varphi^{m} \right]^{(-1/n)} \text{ ....(4)}$$

Where:
Rw = resistivity of formation water (measured in ohm)

m = the cementation factor

Sw = water saturation

n = saturation exponent

φ = Porosity, fraction

Due to a lack of data, inadequate knowledge of the reservoir properties, and complex fluid-rock interactions, determining net pay is never completely definite. Traditionally, a permeability cutoff is selected, and the portion of the reservoir with permeability higher than the cutoff value is referred to as the net pay.

3. Results and Discussion

3.1. Preparing Data for Log Analysis

Using Interactive Petrophysics (IP v3.5) software, we performed depth matching and environmental corrections on the well log data. This is necessary to account for the differences between the actual conditions in the borehole and the calibration of the well logging tools, which can be affected by factors such as hydrostatic pressure, hole size, mud resistivity, mud weight, and mud type. Once the data has been corrected, it can be interpreted using the steps outlined in the Methodology section.

In simpler terms, we used IP v3.5 software to clean up the well log data and make it more accurate. This is important because well logging tools can be affected by a number of factors, such as the pressure and temperature of the borehole, the type of mud being used, and the size of the hole. By correcting the data, we can ensure that it is more representative of the actual conditions in the reservoir.

Table 1: Well condition data

Mud Weight	10.8 ppg
Bit Size	8.5 in
R mud	0.0103
R mud cake	0.2
Temperature	175 F^o
Formation Salinity	30,000 ppm
SW_i	0.23

we cleaned up the well log data to make it more accurate. We did this because well logging tools can be affected by the environment in which they are used, such as the pressure and temperature of the borehole, the type of mud being used, and the size of the hole. By correcting the data, we can ensure that it is more representative of the actual conditions in the reservoir. This has been conducted utilizing Schlumberger environmental correction charts 2005, which are included with the software used.

The blue solid lines in Figure 1 show the uncorrected log readings, while the red dotted lines show the corrected log readings. The difference between the two lines shows how much the data was affected by the environment.

3.2. Porosity

Determination of porous volume (porosity) is the second phase of well log examination; only if the environmental adjustments are accurately measured, porous volume can then be correctly calculated. There are several methods to estimate porosity, such as using density log, neutron log, sonic log, or a combination of them. The most common method is a combination of neutron-density logs, as shown in Figure 2.

3.3. Permeability

Permeability is a critical parameter in field studies and reservoir related work, as it is utilized and employed in the development planning and geological descriptions of all reservoirs in general. Well log data is one of the most common and straight forward sources of permeability data, as it is relatively inexpensive and provides a continuous profile of permeability throughout the well. A number of factors do have a genuine effect on permeability estimation, such as shale content, effective porosity, and irreducible water saturation. In this research paper, permeability is calculated using two models: the Timur model and the Schlumberger model, as shown in Figure 3.

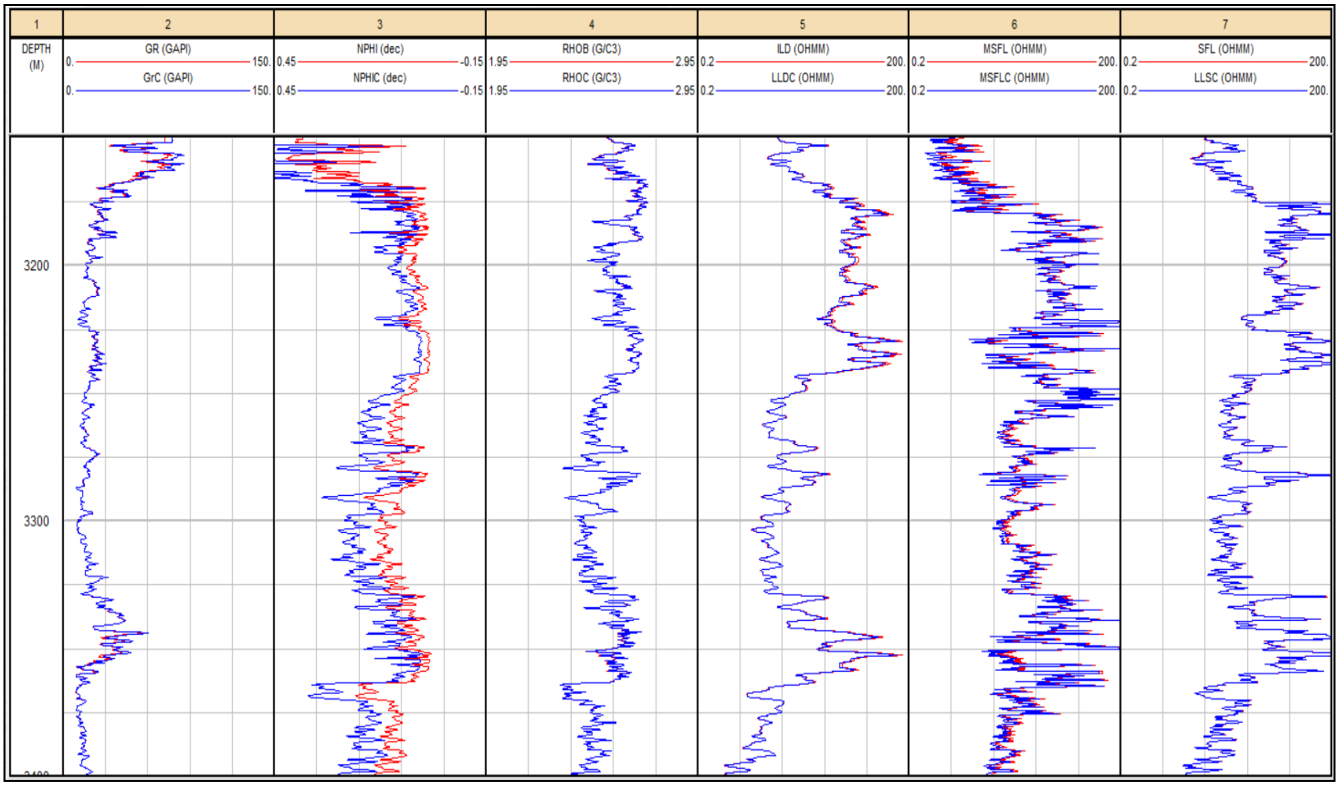


Figure 1: Reading of the logging tools combined with corrected Reading logs.

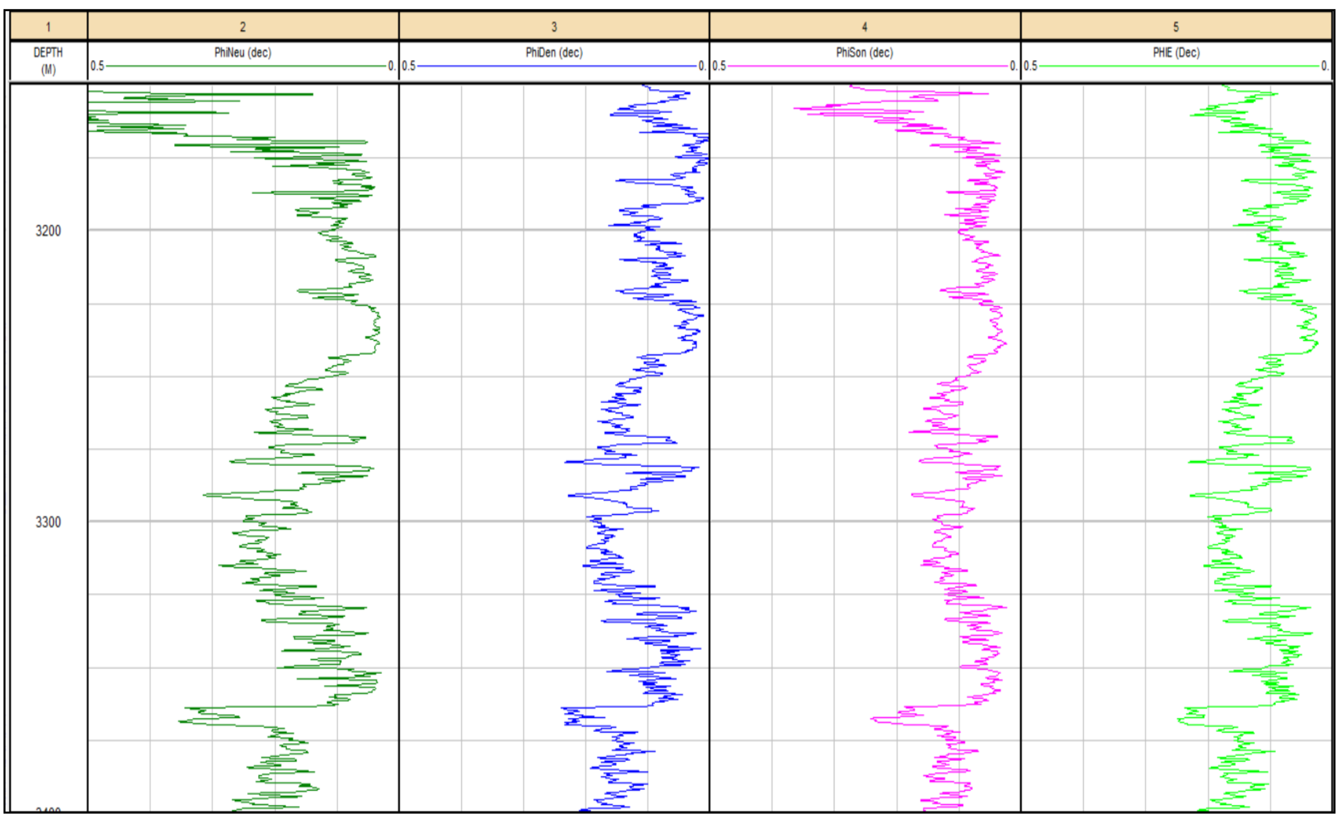


Figure 2: Effective porosity results obtained by neutron - density logs method.

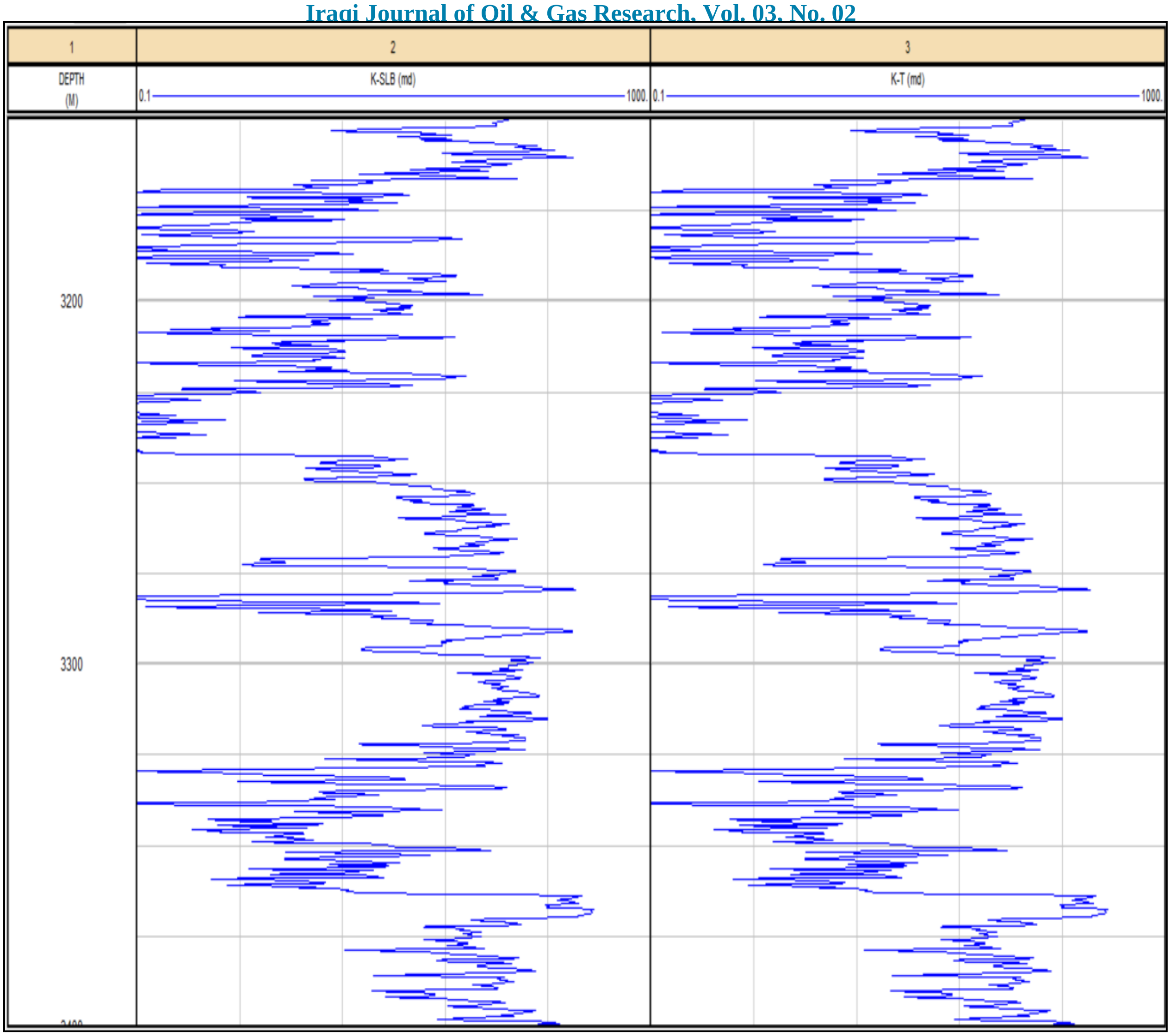


Figure 3: Permeability determination by Schlumberger & Timur models.

3.4. Clay Volume

In order to estimate the volume of the shale, usually there are few methodologies to help to calculate the Clay Volume, those methods are single clay indicators, those are Gamma Ray, Neutron, SP and Resistivity, and some of those are Double clay indicators, like Density-Neutron, Density-Sonic and Sonic-Neutron, But the most common method for this purpose is potentially the Gamma Ray is which is employed for the calculation of the shale volume. This calculation of the volume of the shale is a very important step to be conducted, as this will be very beneficial in the evaluation of water saturation value, in the case where the reservoir does contain some shale content and is considered shaly, then the reservoir itself will have the potential to observe a higher water saturation, since in theory the shale in its own self does have the capacity to be bounded together strongly with the molecule of the water. Hence, this volume of shale can be utilized to point towards a net pay zone, this is highlighted in Figure (4).

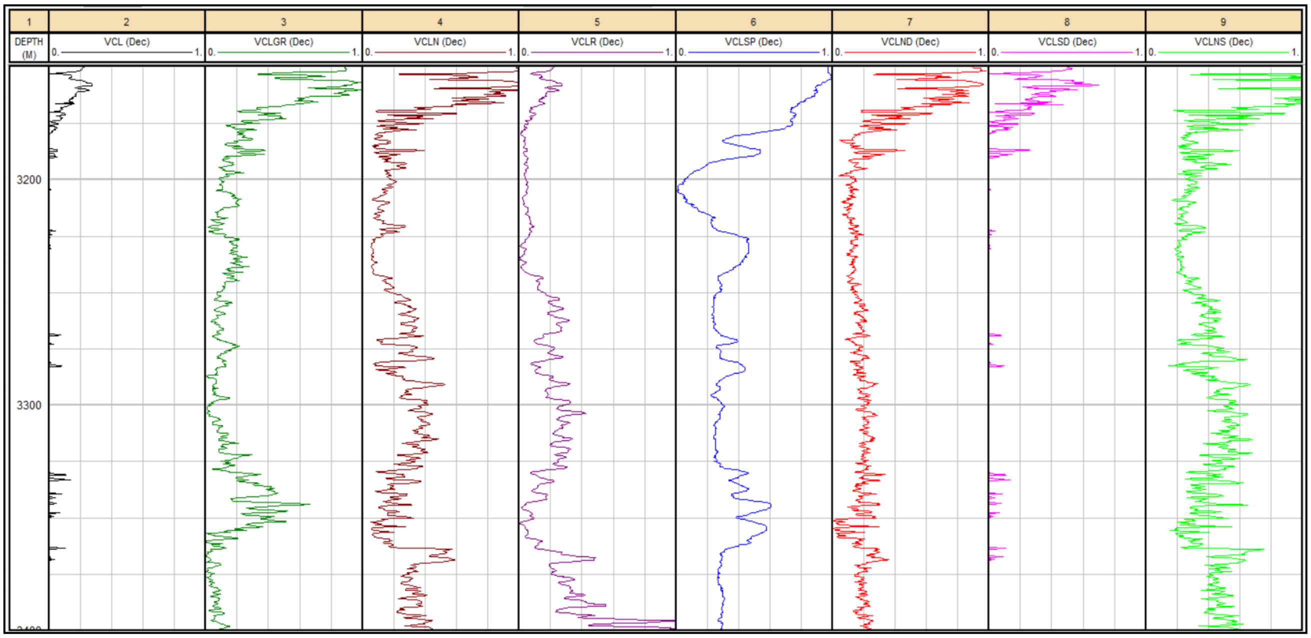


Figure 4: Determination of Clay volume.

3.5. Water Saturation

The most difficult petrophysical calculation is the water saturation, which is needed to calculate it more significant counterpart, the hydrocarbon saturation (1 - SW). There are multiple methodologies to reach the water saturation value through a calculation, in this research, Archi model has been utilized which includes the usual Archi parameter, those typically have set values and are for carbonate rock a=1, n=2, m=2 in Figure (5). With regard to the other readings of clay volume and porosity in the same interval of the water saturation the results plotted that the

most stable and not high oscillation readings are the interval between (3170-3230) m, provides us a primary indication of the net pay interval.

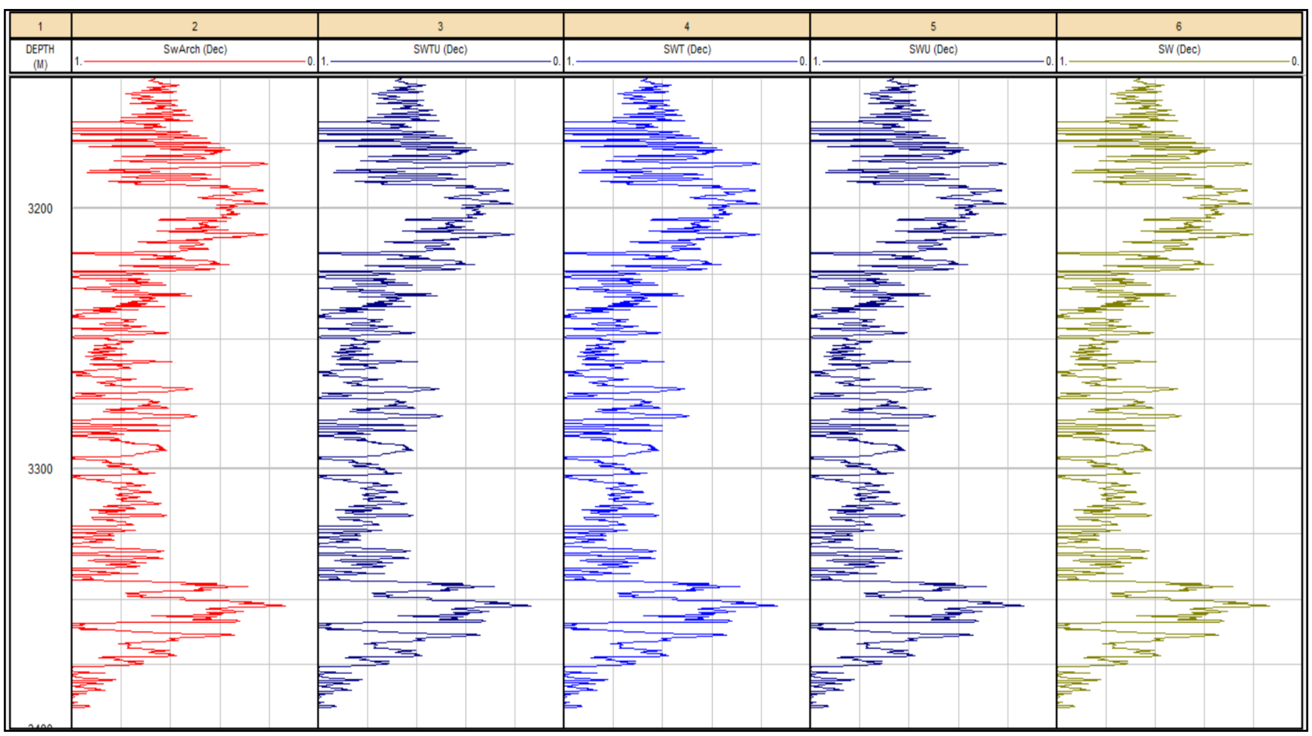
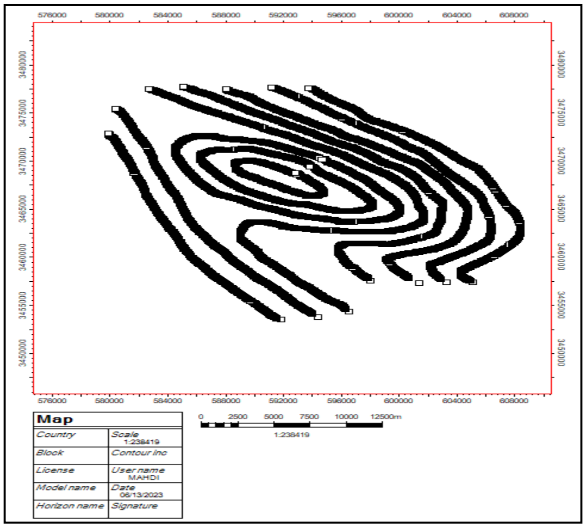
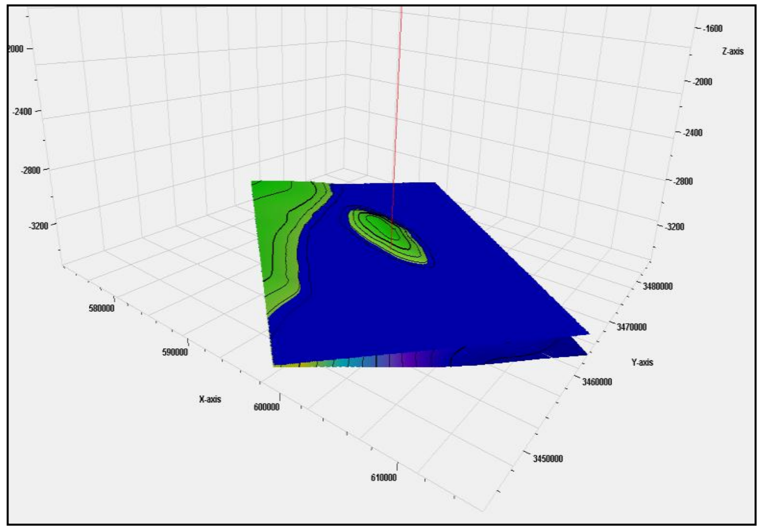


Figure 5: Water saturation determination using Archi parameters.

3.6. Determine The WOC

Arriving at a decision of selecting a well location on field contour map is a rather crucial one, because of the fact that it will eventually impact the well petrophysical properties profile and in turn its performance and life long behavior. Which are determined by how one would typically complete the well and decide on the interval to be produced from. A 3-dimensioanl View of WOC has been visualized using Petrel geological modelling Software as in the Figure below (7), this showcases the modelled depth of the WOC and the location of the with respect to the structure. This depth of the WOC has been taken from final geological report for one of the wells NS-1 is (3378 m), setting the lower limit for the perforation interval when completing the well.





. **Figure 7:** WOC in Petrel Software.

3.7. Density-Neutron Cross-Plot

The density-neutron cross-plot is very useful in providing lithological information with high-resolution by clearly distinguishing between the different rock types, those of sandstone, limestone, and dolomite. As shown in Figure 8, the plot indicates that limestone is the main lithology of the Yammama formation.

3.8. Determine Net Pay & Perforation Interval

Once the water-oil contact (WOC) has been determined, the net-pay zone can be identified by performing a petrophysical interpretation of the properties calculated for each zone of interest depth. The oil zone is located at a depth range of 3170-3230 meters with a thickness of 60 meters, as shown in Figure 5. The presence of oil in this zone is indicated by the high resistivity log readings in permeable zones and the separation of the neutron-density curves (which occurs when the neutron curve crosses over the density curve and vice versa) when passing through oil-bearing limestone.

Figure 6: Contour Map of B3 Unit in Yamama Formation digitized by Didger.

The optimal perforation interval is determined to be in the range of 3190-3210 meters, as shown in Figure 6. This interval has the highest porosity and permeability, as well as the highest oil saturation. It is also 168 meters from the WOC and 15 meters from the closest shale zone.

Based on the above criteria, the optimal perforation interval is determined to be in the range of 3190-3210 meters, with a thickness of 20 meters, 168 meters from the WOC, and 15 meters from the closest shale zone. The petrophysical properties of this interval are shown in T able 2.

Table 2: The petrophysical properties of the optimum perforation interval.

AVG. porosity	**13.5 %**	**AVG. permeability**	**25 md**
Min. Water saturation	**20.5 %**	**AVG. Clay volume**	**3.4%**

Figure 9: Net Pay and Shale with WOC Locations.

Figure 10: Perforation Interval with Units of Yamama Formation.

4. Conclusions

This paper has mainly highlighted and focused on the determination of the required perforation interval of an oil well, mainly based on a final geological report setting, the drilling data as well as well logs data. The key conclusions that may be made from the main results can be summarized as below:

- The results of the main petrophysical properties highlights that the effective porosity that is prevailing in the perforated zone is around 13.5%, Permeability is around 50 md, the water saturation is around 31.2 % and the clay volume is around 3.4%, hence, those calculated properties are able to give a very good decision on the interval to be perforated which has been selected.
- The 3-dimensional view of the WOC which has been shown in Figure (3.3) showcases that the WOC in 3378 m depth, as well as the location of the well in the flank of the reservoir's structure.
- We can observe from the petrophysical Model and the multiple indications for the geological model, that the Yamama formation at Al-Nasiriyah Oil Field showcases very unique petrophysical properties which are increasing downdip and in turn Decreasing towards the flanks of the reservoir's structure.
- The best reservoir unit has been observed to be the Yamama Unit-B, which has showcased a relatively high Porosity with a relatively low water saturation figures, this indeed represents the measurable indication of the oil-bearing unit which is present in the formation, on the other hand, the Yamama Unit-A does exhibit the lowest petrophysical unit relatively speaking.

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