Iraqi Journal of Oil & Gas Research, Vol. 2, No. 2 (2022)

Iraqi Journal of Oil & Gas Research

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

Detection of perforation intervals in oil well completion based on geological, drilling and well logging data

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Article information

Article history:
Received: August, 01, 2022
Accepted: October, 02, 2022
Available online: October, 08, 2022

Keywords:
Oil Well, Perforation
Well log, Drilling
Geological data,
WOC.

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Abstract

Optimum perforation location selection is an important task to improve well production, and hence the reservoir development process. This paper aims to detect the optimum perforation interval by determining the oil zone interval, petrophysical properties, and productivity ratio to check the efficiency of the perforating process. Drilling, geological and Well log data were used to achieve this study. Geological data such as the depth WOC and the contour map are used to make a 2D cross-sectional of the WOC by using petrel 2009 software. It has been used to determine the well location in the structure, whether it was in the crust or the flank of structure. The drilling history data such as mud weigh, mud cake resistivity...etc. are used to make environmental correction for well logs device to obtain corrected borehole readings. The well logs data are inserted into Interactive Petrophysics software to make the environmental corrections, interpretations and determine the oil zone interval.

DOI: http://doi.org/10.55699/ijogr.2022.0202.1032, Department of Petroleum Technology, University of Technology-iraq

1. Introduction

Well completion, which is the process of making a drilled well ready for production or injection, has improved significantly in recent years. It has a great influence on increasing the hydrocarbon production.

It involves all the necessary steps to prepare the drilled well for production. It often begins with the set of casing to the production formation and ends with the installation of tubing and perforating the casing [1]. There are four main types of completion: open hole, liner hole, cased-hole, and sand exclusion completion.

All cased-hole completions must be perforated, and these perforations affect the well's capacity to produce reservoir fluids. Thus, the accurate selection of perforation depth and intervals is very important task for petroleum engineer. This can be done by using various geological, drilling and well logging data.

Geological characteristics that can be used to perform the well perforation including, lithology type, water oil contact (WOC) depth, and the well location on contour [2]. Drilling history information such as formation pressure, mud weigh, mud resistivity are also important in determining perforating interval [3]. In addition, well logs provide valuable information about the formation within a few feet of the wellbore [3]. well logging services are used to acquire geological and geophysical information to allow a more detailed evaluation of the reservoir. The well logging is used to detect perforation intervals, evaluate perforation, determine the lithology and type of fluids that are exist in a particular zone. the well logs are used to calculate specific properties of the layers that drill the well through such as oil saturation and shale content [2].

There are several studies and research about the perforation process due to its great importance in the process of wells completion. Bell (1972), Klotz (1974) and McLeod (1983) studied the crushed zone is believed to have a 70 to 90 % reduction in permeability. As the result the well productivity decrease in a large percent according to the effect of crushed zone [4-6].

Behrman (1991) examined the characteristics and effect of the permeability damage around the perforation in core targets. He concluded that a region is created around the perforation in which loss of permeability occurs due to the breaking of the larger grains which are replaced by smaller grains [7].

Mahmoud Asadi, , F.W. Preston(1994) studied the reduction in productivity caused by the crushed zone surrounding a jet perforation tunnel. A Berea sandstone sample was perforated by using a 3.5 gr. RDX type charge. Using a black oil simulator, productivity of a well was found and compared to one where no permeability reduction was assumed for the crushed zone. Productivity of the well was obtained for each permeability orientation. A 55% permeability reduction around the perforation tunnel, as the result of the perforation process, led to a 60% reduction in well productivity [8].

Berman and Hallek (1998) presented extensive comparison data between the penetration and strength of Berea sandstone and concrete targets, which showed that the penetration length decreased linearly with the increase in the compressive strength of the formation. Since the rate of penetration through sandstone is higher than it is in concrete because sandstone has less strength [9].

A.Venkitaraman,(2000) established perforating at underbalance allows us to produce the sand during the initial stages and thus avoid having to manage transient sand production during later stages of well production. so it can have used to minimize the sand problems after period of production [10].

Wang Zhiming1 , Wei Jianguang1 , Zhang Jian(2010) investigated Early water breakthrough and a rapid increase in water cut are always observed in high permeability completion intervals when perforations are uniformly distributed in the wellbore in heterogeneous reservoirs. The optimized perforating strategy applies a low perforation density in high permeability intervals and a high perforation density in low-permeability intervals [11].

Elsharafi et al. (2017) studied the effect of perforation parameters on vertical wellbore productivity. This study was concentrated on the effect of damaged skin factor, crushed zone skin factor and perforation skin factor. They concluded that, increasing the depth of the hole causes an increase in fluid flow while the skin factor decreases. Also, the flow rate decrease with increasing the skin factor [12].

Yan et al. (2019) studied the damaged area of cementing interface after perforation in a cylindrical body by using numerical methods and experiments. The shaped jet induces damage around the tunnel of perforation but is limited to a specific range, and a damage index is used to characterize quantitatively the cement sheath damaged area after perforation. It is indicated that the profile of the damaged zone in the cement-sheath gives a particular shape like a funnel along the direction of perforation. The damaged area increases with the diameter of liner and decreases with the compressive strength of cement. The damage generated by perforation can be occurred within the cement sheath because of the high pressure and high temperature [13].

Haider Sami , Emad Abdullah, Hussein Sadeq (2020) Studied pressure drop analysis in perforated vertical wellbores for different perforation parameters. The effect of the density of the perforations, the phase angle of the perforations, the diameter of the perforation and the flow rate of the crude oil from the perforations on the pressure drop and the productivity index of the perforated vertical wellbores were studied.

Thus, the detection of perforation interval is one of the important task in production engineering due to its high impact on the well production and the wrong detection lead to waste of time and money because we have to re-perforation the casing.

In this paper, the optimum perforation interval will be detected by using different drilling, geological, and well logs data. Furthermore, the efficiency of the perforating process will be checked by calculating of the productivity ratio.

2. Methodology

2.1. Detection of perforation interval

To select the optimum perforation interval, the following factors must be considered [2]:

1. The distance of the lower end of the perforated interval from water and oil tangency level to avoid the problem of product water with oil because of the water coning phenomenon.

2. Choosing formations with high permeability and porosity and avoiding perforating shale zone.

3. Avoiding perforating casing connection.

4. perforation should be placed at better rock mechanical properties in terms of rock ability to initiate fractures; these mechanical properties include minimum horizontal stress, Young’s modulus.

In this paper, the following procedure have been followed to determine the optimum perforation interval:

1. A 2D cross-section has been developed using petrel 2009 software for the zone under study by using geological data (i.e. contour map, WOC depth) to show the well location in the structure, whether it is in the crust or the flank of structure.

2. Collecting the drilling history data from the FWR of a well to use it in making environmental corrections for the well logs device.

3. Using interactive petro physical software IP (3.5V) for making the environmental corrections and logs interpretation of the well log data.

4. Determining the lithology type and shale zone from the (i.e. GR Log, SP Log, make correlation with geological data).

5. Determining WOC, GOC from (density-neutron log, resistivity log, make correlation with geological data).

6. Calculating the oil zone properties such as porosity, permeability, water saturation and shale volume.

7. Finally, selecting the optimum perforation interval, considering the following criteria:

   A. Avoid the WOC, GOC.

   B. Avoid the shale zone.

   C. Select the high porosity and permeability zone.

   D. Select high oil saturation zone.

2.2. Productivity ratio calculation

Productivity ratios are represented in the form of a dimensionless apparent skin effect S_d. The skin effect is a function of the cement sheath radius r_w; perforation diameter or notch thickness d; penetration beyond the cement sheath a; vertical perforation spacing interval h; and the number of perforations per plane m.

The skin effect is calculated as a function of these five variables in dimensionless form (Figure 1). These dimensionless numbers are defined as [14].

$$d_D = \frac{d}{r_w}\sqrt{\frac{k_r}{k_z}} \qquad \text{.....................(1)}$$

$$h_D = \frac{h}{r_w}\sqrt{\frac{k_z}{k_r}} \qquad \text{.....................(2)}$$

$$a_D = \frac{a}{r_w} \qquad \text{.....................(3)}$$

$$m = 360/\theta \qquad \text{.....................(4)}$$

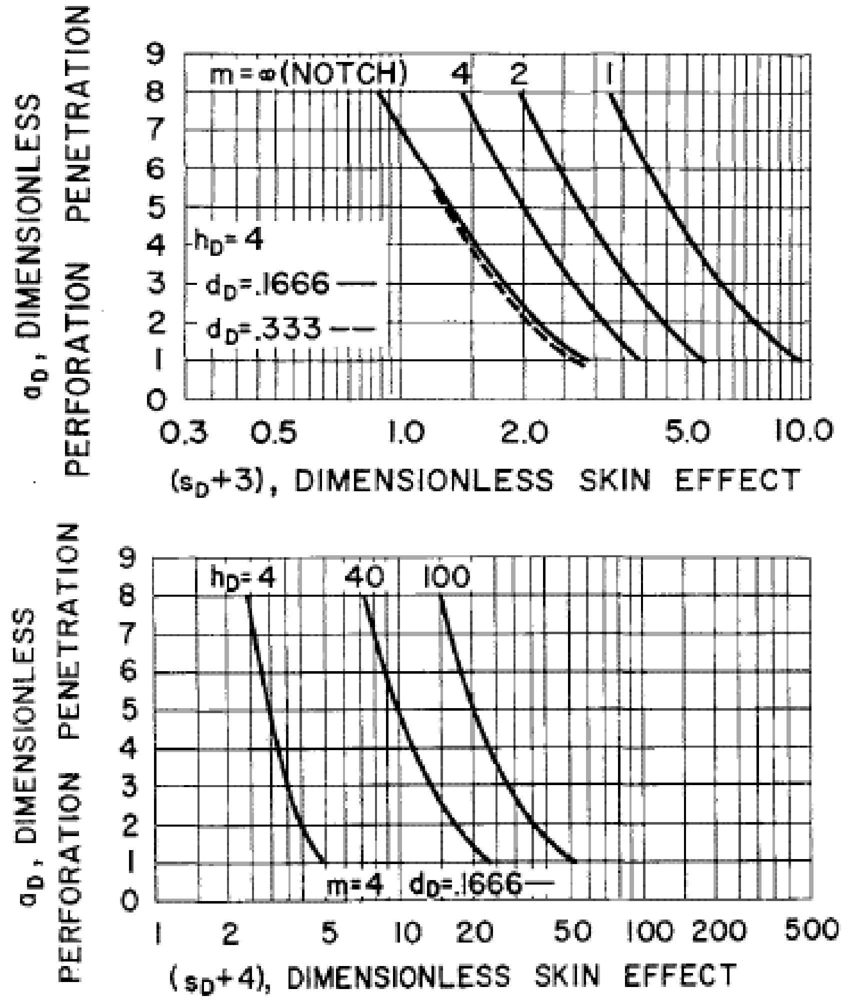

Figure (1) Dimensionless Skin Effect estimation chart [34].

Skin effect is related to the productivity ratio by:

$$\left[\frac{q_p}{q_r}\right]_{ss} = \frac{1\mathrm{n}\frac{r_e}{r_w}}{1\mathrm{n}\frac{r_e}{r_w} + (s_D)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (5)$$

Eq.5 for steady-state flow conditions, and

$$\left[\frac{q_p}{q_r}\right]_{qss} = \frac{1\mathrm{n}\frac{r_e}{r_w} - 0.75}{1\mathrm{n}\frac{r_e}{r_w} - 0.75 + (s_D)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (6)$$

Eq.6 for quasi steady-state flow conditions.

The steady-state and quasi-steady-state well productivity ratios are defined by Eq. 5 and 6. The absolute production rate q_p from a perforated well is calculated by multiplying the productivity ratio $\frac{q_p}{q_r}$ by the appropriate open hole flow rate. These flow rates are [14]:

$$[q_r]_{ss} = \frac{7.07 k h_t (\Delta p)}{\mu_0 \ln(r_e/r_w)} \qquad \text{.....................} (7)$$

Eq.7 for steady-state productivity, and

$$[q_r]_{qss} = \frac{7.07 k h_t (\Delta p)}{\mu_0 [\ln\left(\frac{r_e}{r_w}\right) - 0.75]} \qquad \text{.....................} (8)$$

Eq.8 for quasi-steady-state productivity.

3. Results and Discussion

Determination of the perforation interval is a very important task to complete the well for production successfully. the perforation interval will determine based on several data which can be summarized as below:

3.1. Geological data

Estimating the well location on the contour map is very important Because it affects the determination of the perforation interval. A 2D cross section of WOC has been built using Petrel Software showing the depth of WOC and the well location in the structure (Figure 2). The results show that the depth of WOC is 3915m, so this depth should be avoided when selecting the perforation interval (Figure 2). In addition, our results indicate that the well is located in the flank of structure and this will affect the estimation of the perforated interval. This is because WOC will influence the perforated interval from bottom and edge so this will cause restriction or no flexibility in determining the perforation interval.

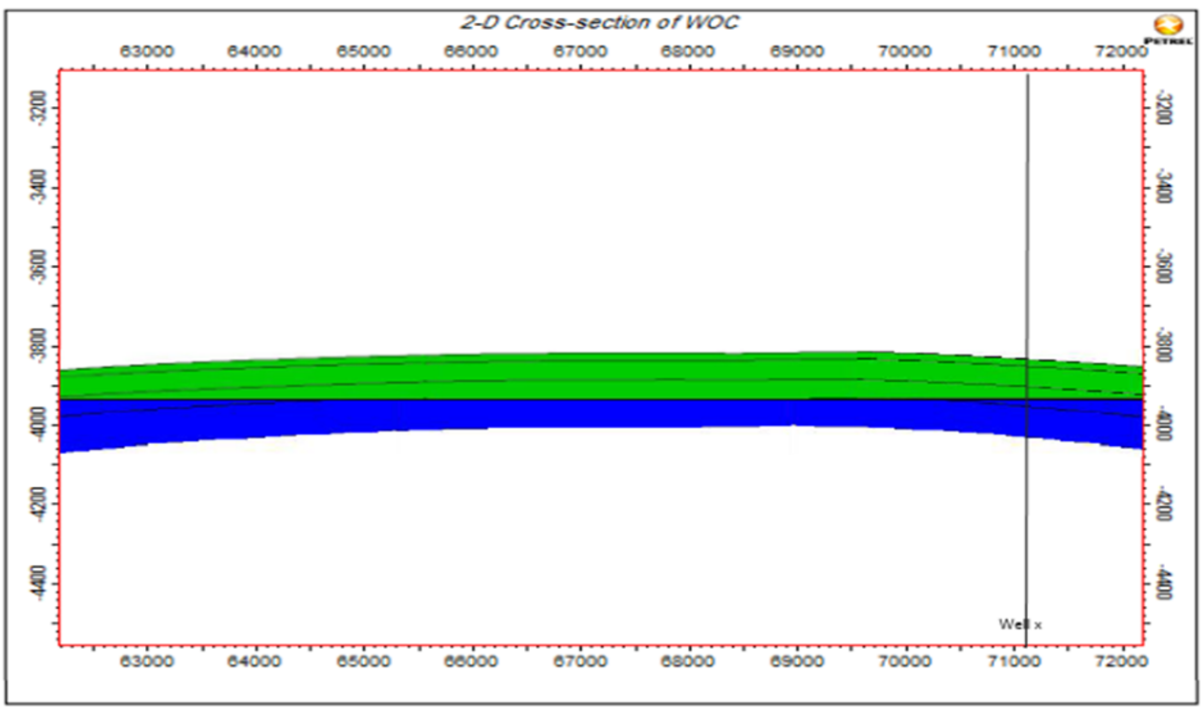

Figure (2) 2D Cross section of WOC showing well location and depth

It is important to mention that the well geological data of the well indicate that there is a tight zone in the zone at a depth of 3865.5 m with underlying limestone.

3.2. Drilling history data

Drilling history data is used to make the environmental correction for well logs device because some well logs device is affected by some factors such as hydrostatic pressure, hole size, mud resistivity, weight and type of mud. Table 1 shows the drilling history data that have been used, in this paper, to perform the environmental corrections. Performing the environmental correction is necessary for compensating the differences between the actual condition in a borehole and the calibration of the test pit tool to obtain more accurate readings.

Table 4-1: Drilling history information

Mud type	Bentonite Fresh water
Mud weight	9.841 Ib/gal
Bit size	7.875 in
Pressure	6780 psi
Mud cake res.	0.07 ohm

3.2. Well logging data

Interactive petrophysical software IP (3.5V) used for the environmental correction, lithology identification and logs interpretation, the results can be shown in the **Figure (4-2).**

Figure (4-2) shows that at depth 3865.5 m there is a tight zone, it can be seen that in tracks 6,7, and 10 the effective porosity and permeability is very low. The correlations with geological data confirm this availability of this tight zone at a depth of 3865.5 m. However, the resistivity logs and neutron-density logs behaviours give indicator for a gas zone due to the high readings of resistivity. This high reading of resistivity usually suggested either there is a hydrocarbon or a compacted zone.

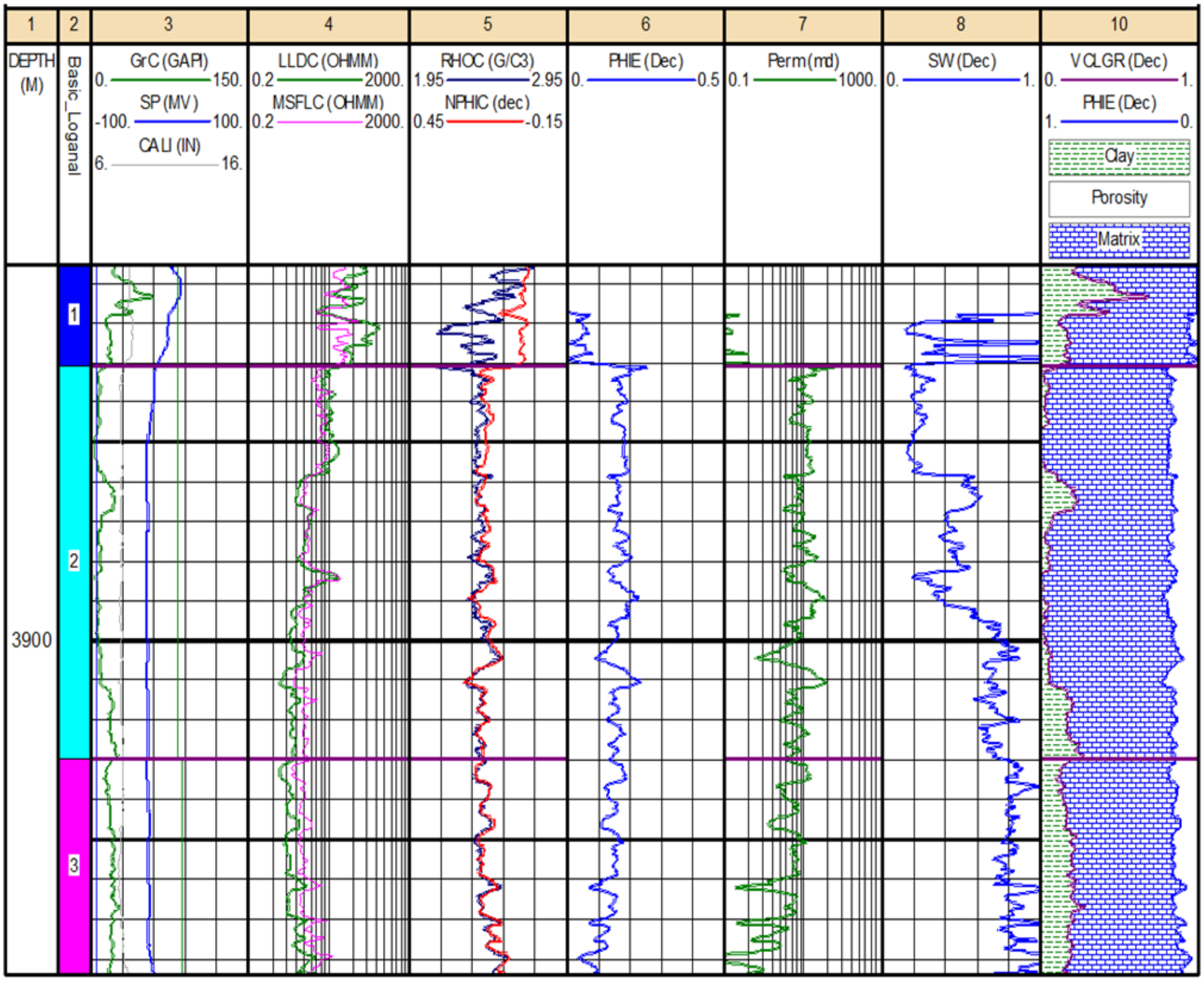

Figure (3) Well logs data interpretation by IP software

To understand the main reason of the high resistivity log reading, a cross plot M - N has been made to an adjacent well to the well under study.

The M - N cross plot as shown in the ***Figure (4)*** is made for the interval 3864- 3954.3 that represents the extended of the interested layer in the adjacent well (well x2) plus 13.3 m above the interested layer to investigate the availability a gas zone in this interval. The distribution of carbonate formation, secondary porosity, sulfur, gypsum, anhydrite, and gas can be indicated from this plot. The M - N cross-plot illustrates that formation consists mainly of limestone when the blue points accumulate in the carbonate zone. Also, Figure 4 shows that there is no reasonable gas in the target reservoir; this confirm the availability of a tight zone at depth of 3865.5m.

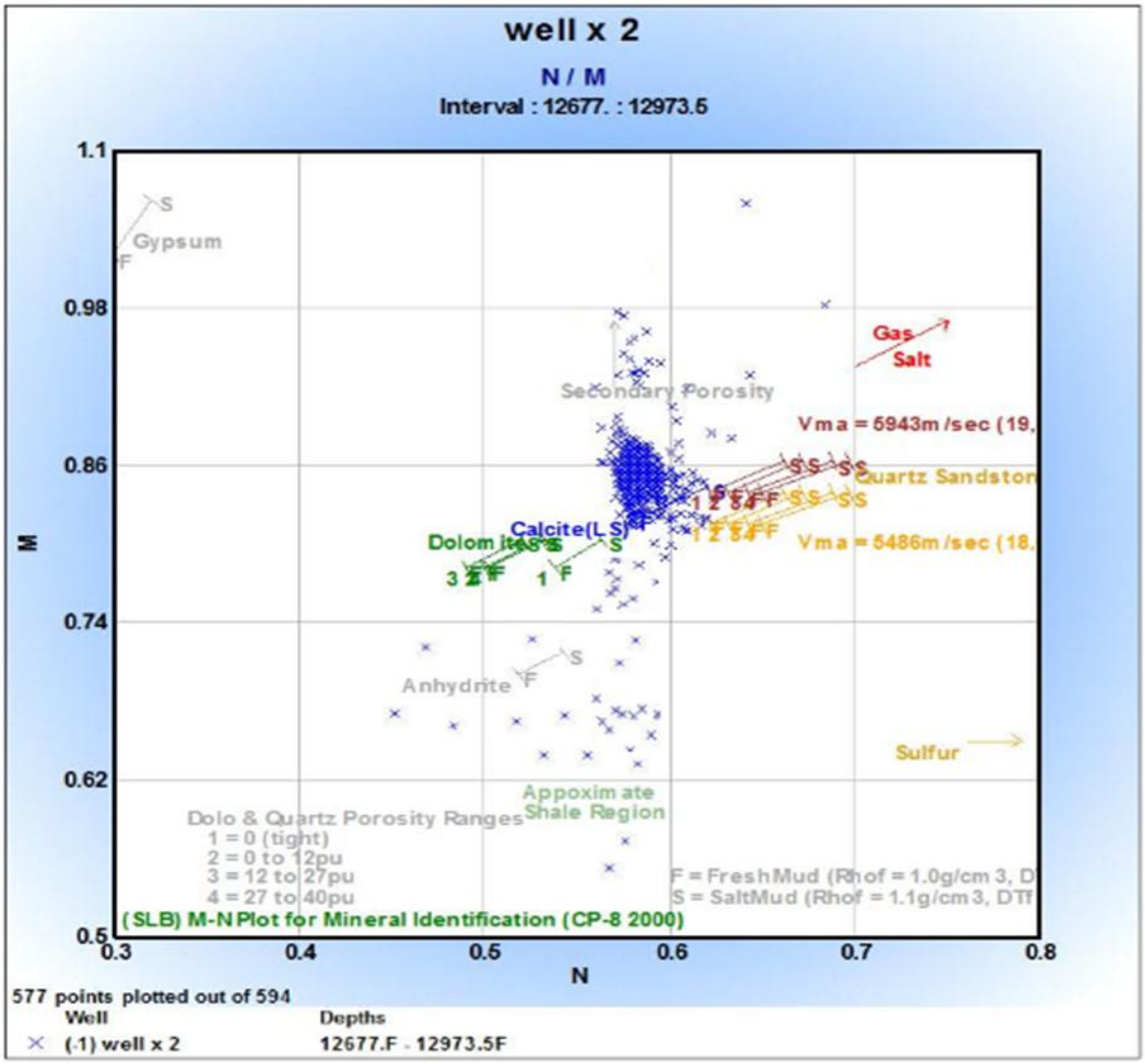

Figure (4) M – N cross plot for an adjacent well

Regarding to WOC, the geological data state that the WOC in depth 3915 m as shown in the **Figure (2)**. Furthermore, Figure (3**)** shows that the water saturation values are very high in at a depth of 3915 m and the resistivity logs reading are recorded to be the lowest below the depth of 3915 m. In addition, Figure (3) shows no separation between neutron-density curve, that is indicating to water zone.

After determining the tight zone and WOC, our results indicate that the oil zone is in a range of 3865.5 – 3915 m with thickness of 49.5 m. where from the behaviour of the resistivity log that gives high reading value in permeable zone (limestone), that indicating to the presence of oil, also from neutron-density curves that separate (reflection of density-neutron curve in which the neutron curve will cross over the density curve and vice versa) during pass through limestone containing oil.

Now the perforation interval can be determined considering high porosity and permeability, high oil saturation, and avoiding shale zone and water zones.

Our results indicate that the optimum perforation interval is in a range of 3865.5-3874 m because this interval has highest effective porosity and permeability with lower water saturation. As a result of the high effective porosity in the oil zone (see track 6 and 10 Figure 3), and the well location (in the flank of structure), the perforation interval is selected to be away from WOC by 41 m to avoid water production in the beginning life of the well. After completing the perforation process the oil well (well x) properties can be shown in the Table 4-2**:**

Table 4-2: Perforations and oil well properties

Drainage radius	660 ft
Wellbore radius	0.33 ft
Net pay thickness	168 ft
Oil viscosity	0.953 cp
Permeability	50 md
Perforations diameter	0.65 in
Average penetration depth	14 in
Shot density	4 shots/ ft
Reservoir pressure	6260 psi
Bottom hole pressure	6000 psi

The production rate of the perforations of this well has been calculated as follows:

The dimensionless ratios calculated from Eq. 1 through Eq.3:

$$d_D = \frac{0.65}{3.9375}\sqrt{1} = 0.1666$$
$$a_D = \frac{14.0}{3.9375} = 3.555$$
$$h_D = \frac{1.0}{0.33}\sqrt{1} = 3.03$$

Values of s_D for $h_D = 3.03$ and $m = 4$, **(Figure 1)**

$(s_D + 4) = 3$ for $d_D = 0.1666$

and $a_D = 3.555. s_D = 3 - 4 = -1.$

Quasi-steady-state conditions prevail since the well has been drilled on a developed spacing pattern.

$$\left[\frac{q_p}{q_s}\right]_{qss} = \frac{7.6 - 0.75}{7.6 - 0.75 - 1} = 1.1709$$

Open hole flow rate is:

$$[q_r]_{qss} = \frac{(7.07)(168)(0.05)(260)}{0.953(7.6 - 0.75)} = 2365.31 \text{ BOPD}$$

The production rate from the perforation will be

$$[q_p]_{\text{qss}} = (1.1709)(2365.31) = 2769.54\text{BOPD}$$

It can be seen that the production rate from perforations is high compared with the open hole flow rate because the calculation neglects the skin due to the crushed zone, also the perforation depth is high and it may be exceeding the effects of the drilling damage zone and thus it provides high cross-section area open to flow so the productivity ratio increase and this reflects on production rate.

4. Conclusions

This paper focused on the detection of perforation interval of oil well based on geological, drilling and well logs data. The main conclusions that may be constructed from the study results are:

1. The petrophysical properties results show that the effective porosity in the perforated zone is 18%, Permeability is 50 md, water saturation is 18.1 % and clay volume is 1.82% so these properties can give a good indicator of the quality of perforated interval that has been selected.

2. The 2D cross sectional of WOC shows that the WOC in 3915 m depth and the well located in the flank of the structure.

3. The perforated interval located in depth ranging 3865.5-3874m with a thickness 8.5 m with a number of perforation equal to 112 perforations.

4. The perforation calculation shows that the productivity ratio equal to 1.1709 and the flow rate through perforations equal to 2769.54 7 BOPD.

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