Moveability and Nature of the Reservoir Hydrocarbons in the Lower Miocene Jeribe Formation in X-Oilfield, Northern Iraq

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Abstract
The flow capacity of the Lower Miocene Jeribe Formation was investigated in the two selected wells, A and B, of an oilfield northeast of Tikrit City. The available wireline logs and core test data are adapted for characterizing the reservoir potentiality of the formation. Three Hydraulic Flow Units was identified by calculating the values of the Flow Zone Indicators. Most parts of the formation parts have the lowest flow capacity among the three determined flow types. The Jeribe Formation contains hydrocarbons in various ratios in both wells of the study. The Reservoir Unit RUJ-1 at the upper part of the formation has the highest moveable hydrocarbon saturation, especially in the well A. Most hydrocarbons in the RUJ-3 at the lower part of the formation in both wells are immovable. The oil-water contact was expected within Dhiban Formation in the well B and was expected to be somewhere in the underlying Dhiban or Euphrates Formations in the well A. The nature of the hydrocarbons at the uppermost few meters of the formation consists of gas or light hydrocarbons and oil at the rest of the formation (residual and moveable oils).

Keywords: Jeribe Formation; Flow Zone Indicator; Hydraulic Flow Unit; Northern Iraq

1. Introduction

Recognition of reservoir quality is a crucial objective in reservoir characterization process. The reservoir quality is defined by its hydrocarbon storage capacity, and storage ability depends on porosity, whereas deliverability depends on permeability. Thus, both porosity and permeability are the main reservoir quality controlling factor (El Sharawy and Nabawy, 2019). These kinds of data ideally should be assessed together to detect and interpret correspondences between them (AHR, 2008). A reservoir zone with similar permeability, porosity, and bedding characteristics laterally and vertically continuous is referred to as the flow unit (Hearn et al., 1984).

The moveability of the hydrocarbons within the Jeribe Formation was investigated by Baban and Hussein (2016) in the Khabbaz Oilfield and Baban et al. (2018) in the Jambour Oilfield, depending on the techniques of the Flow Zone Indicator (FZI), Hydrocarbon Moveability Index, and other techniques. In this study, the movability of the reservoir hydrocarbons in the Lower Miocene carbonate Jeribe Formation from selected wells of X Oilfield was investigated by identifying the distinguished hydraulic flow units in the formation using different techniques to examine the hydrocarbon moveability.
Additionally, an attempt was done to determine the nature of the movable hydrocarbons depending on the available wireline log and core test data.

2. Geological Setting

The Northeast Tikrit Oilfield under investigation is located approximately 30km to the northeast of Tikrit City in the Salahaddin Governorate, Northern Iraq (Fig.1). Tectonically, the field is located very close to the western edge of the Zagros Foreland Low Folds Zone within Hamrin-Makhoul Subzone at the southwestern part of the central fault zone of the advanced basin of Mesopotamia. The structure of the field, which consists of an asymmetrical longitudinal anticline, is extended parallel to the southwest side of the Hamrin Oilfield. According to Bellen et al. (1959), the Jeribe Formation, in the type locality, is composed of limestone, recrystallized and dolomitized, generally massive, with beds of 3-6 feet in thickness. In terms of lithology and faunal assemblage, the Jeribe Formation is uniform. It reflects a restricted environment on marine platform, primarily of lagoonal facies, of calm, warm water, and a salinity that is relatively high (Henson, 1950; Bellen et al., 1959; Al-Hashimi and Amer, 1985). The Jeribe Formation is reported to contain Borelis melo curdica a Burdigalian marker (Bellen et al., 1959) in the study area. However, Jassim and Goff (2006) consider the Jeribe Formation to be of Langhian age (Middle Miocene), based on the co-occurrence of B. melo curdica and the so-called Orbulina datum.

3. Data and Methodology

The data used in this study are all records of wireline logging done for the selected Jeribe Formation in the two wells of A and B. The Jeribe Formation in the mentioned two wells lies between depths 1021m and 1065m and 1024m to 1067m, respectively. Depending on the following research methods, the logging data were from Gamma-ray, SP, Sonic, Density, Neutron, and Resistivity logs. The available
core test data, especially permeability values, were also used to identify the reservoir units and determine the distinguished FZI.

The following methodology started with digitizing the original log sheets using NeuraLog software. Additional software, such as Techlog 2015.3, Grapher, and Excel are used to calculate the necessary parameters and to plot the curves, cross plots, and diagrams. The prepared log values were then adapted to calculate the shale volume and to correct the calculated and the recorded porosities from the shale impact. The studied section is then subdivided into different reservoir units depending on the shale content, porosity, and permeability. The Hydraulic Flow Units (HFU) are distinguished based on the variations in the calculated Reservoir Quality Index (RQI) and the Normalized Porosity Index (Øz). Water and hydrocarbon saturations, on the other hand, are calculated depending on the conventional Archie formula. In contrast, more than one technique is applied to identify the horizons containing moveable hydrocarbons with an attempt to recognize the nature of the existing hydrocarbons.

4. Result and Discussion

4.1. Flow Zone Indicator (FZI)

The FZI is a distinguished parameter in which several geological attributes such as texture and mineralogy contribute to form facies with distinct pore geometry known as a hydraulic unit (Amaefule et al. 1993).

\[ FZI = \frac{RQI}{\varnothing_z} \]  \hspace{1cm} (1)

\[ RQI = 0.0314 \sqrt[\frac{K}{\varnothing_e}} \]  \hspace{1cm} (2)

\[ \varnothing_z = \frac{\varnothing_e}{1-\varnothing_e} \]  \hspace{1cm} (3)

Where:
FZI: Flow Zone Indicator
RQI: Reservoir Quality Index
Øz: Normalized Porosity Index
Øe = Effective porosity in fraction
K = Permeability in Md

FZI mathematically represents the ratio of the RQI to Øz and can be calculated as shown below (Amaefule et al., 1993):

Normal probability analysis for the calculated FZI values (S-shaped curve) (Figs. 2 and 3) and an RQI versus Øz cross plot (Figs. 4 and 5) were used to identify the distinguished HFUs in the Jeribe Formation in both wells of the study. Three types of HFU with different flow capacities appeared to exist in the formation, with the minimum, maximum, and average values shown in Table 1.

The flow capacity of the Jeribe Formation in the well B is relatively higher than its capacity in the well A. It’s worth mentioning that the distribution of the sample points in Figures 2-5 indicates that only a few horizons in the formation have exceptionally high flow capacities (HFU-3), but most parts of the formation have the lowest flow capacities (HFU-1).

The low difference in the values of the identified HFUs at most parts of the formation indicates that the Jeribe Formation in both studied wells has less heterogeneous lithology.
Fig. 2. Normal probability analysis for the calculated Flow Zone Indicator values for the Jeribe Formation in the well A.

Fig. 3. Normal probability analysis for the calculated Flow Zone Indicator values for Jeribe Formation in the well B.
Fig. 4. The identified HFU values from RQI-Øz relationship for Jeribe Formation in the studied well A.

Fig. 5. The identified HFU values from RQI-Øz relationship for Jeribe Formation in the studied well B.

Table 1. Ranges and averages of the calculated FZI and HFU distinguished for the Jeribe Formation in both wells of the study wells A & B.

<table>
<thead>
<tr>
<th>Wells</th>
<th>FZI Range</th>
<th>Average FZI</th>
<th>Hydraulic Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.39-0.59</td>
<td>0.47</td>
<td>HU_1</td>
</tr>
<tr>
<td></td>
<td>0.59-0.99</td>
<td>0.70</td>
<td>HU_2</td>
</tr>
<tr>
<td></td>
<td>0.99-34.92</td>
<td>4.80</td>
<td>HU_3</td>
</tr>
<tr>
<td></td>
<td>1.0-1.96</td>
<td>1.48</td>
<td>HU_1</td>
</tr>
<tr>
<td>B</td>
<td>1.96-2.99</td>
<td>2.40</td>
<td>HU_2</td>
</tr>
<tr>
<td></td>
<td>2.99-16.3</td>
<td>5.20</td>
<td>HU_3</td>
</tr>
</tbody>
</table>
4.2. Water and Hydrocarbon Saturations

The conventional equation suggested by Archie in the 1950s is still the common equation that is relied on by log analysts for calculating water saturation in both the uninvaded zone of the reservoirs (Eq. 4) and within the invaded zone of the reservoirs flushed by the drilling mud filtrate (Eq. 5).

\[
S_W = \frac{n \left( \frac{F \times Rw}{Rt} \right)}{\left( \frac{Rw}{Rt} \right)^1}^{1/n} \quad (4)
\]

\[
S_{xo} = \frac{n \left( F + Rmf \right)}{Rxo} \quad (5)
\]

Where:
- \( S_W \): Water saturation in the uninvaded zone.
- \( F \): Formation resistivity factor.
- \( Rw \): Formation water resistivity at formation temperature (\( \Omega.m \)).
- \( Rt \): True resistivity of the formation (\( \Omega.m \)).
- \( n \): Saturation exponent, which varies from 1.8 to 2.5 but normally the value 2.0 is used when no laboratory test done for this exponent (the case of this study).
- \( S_{xo} \): Water saturation in the flushed zone.
- \( Rmf \): Resistivity of mud filtrates (\( \Omega.m \)).
- \( Rxo \): Resistivity of the flushed zone (\( \Omega.m \)).

The hydrocarbon saturation (\( S_h \)), with both types of residuals (\( S_{hr} \)) and moveable (\( S_{hm} \)), has been determined using the simple equations 6–8:

\[
\text{Hydrocarbon saturation} = 1.0 - S_w. \quad (6)
\]

\[
\text{Moveable hydrocarbon saturation} (S_{hm}) = S_{xo} - S_w \quad (7)
\]

\[
\text{Residual hydrocarbon saturation} (S_{hr}) = 1.0 - S_{xo} \quad (8)
\]

Where:
- \( S_h \): Total oil saturation.
- \( S_w \): Water saturation in the uninvaded zone.
- \( S_{hr} \): Residual hydrocarbon saturation.
- \( S_{xo} \): Water saturation in the flushed zone.
- \( S_{hm} \): Moveable hydrocarbon saturation.

The relative distribution of the three different saturations of \( S_w \), \( S_{hr} \), and \( S_{hm} \) within the pore spaces of the Jeribe Formation is shown in Figs. 6 and 7 for both wells of the study. The distribution of the water and hydrocarbon saturations in Figs. 6 and 7 is plotted with regard to the previously identified reservoir units in the formation based on the variations in the shale content, porosity, and permeability.

In both wells of the study, the entire studied section of the Jeribe Formation contains hydrocarbons in varying ratios interspersed by thin horizons of full water saturation at different depth intervals. Although the porosity and permeability of the formation in the well A is less than that in the well B, the ratio of the moveable hydrocarbons looks higher in the well A, especially in the Reservoir Unit-1 (RUJ-1) at the upper part of the formation. The formation in the well B contains a higher ratio of hydrocarbons, but most of them are residual with no noticeable moveability.
Fig. 6. Water saturation and Hydrocarbon saturation (Residual and Moveable) for the studied Jeribe Formation in the wells A and B.

4.3 Moveable Hydrocarbon Index (MHI)

One of the Quick Look Methods (QLM) is used to estimate the moveability of the hydrocarbons and is called the Moveable Hydrocarbon Index (MHI). When the value of $S_{xo}$ is greater than $S_w$, then the hydrocarbons in the flushed zone have possibly been moved or flushed out of the zone nearest the borehole by the invading drilling fluids (Shahab, 2019).

MHI represents the ratio of the water saturation in the uninvaded part of the formation ($S_w$) to the water saturation in the flushed zone ($S_{xo}$) (Eq. 9).

$$\text{MHI} = \frac{S_w}{S_{xo}} = \sqrt{\frac{S_{xo}}{R_t \left( \frac{R_o}{R_w} \right)}}$$  \hspace{1cm} (9)
Where:

$S_{xo}$: water saturation in the flushed zone
$S_w$: water saturation in the uninvaded zone
$R_t$: resistivity of the uninvaded zone
$R_{xo}$: resistivity of the flushed zone
$R_{mf}$: resistivity of the mud filtrate
$R_w$: resistivity of the formation water

According to Schlumberger (1972), if the ratio of $S_w / S_{xo}$ (MHI) is (1.0) or greater, then no movable hydrocarbon occurs during an invasion, and this is true regardless of whether or not the zone contains hydrocarbon, and if the ratio of $S_w / S_{xo}$ is less than (0.7) for sandstone and less than (0.6) for limestone, then moveable hydrocarbon is detected. Reservoirs with MHI less than 0.6 are of sufficient porosity and permeability and are containing moveable hydrocarbons (Asquith, 1985).

The use of a cutoff of 0.6 to separate the non-moveable from the moveable hydrocarbon zones in carbonate reservoirs makes the MHI method more confident than the Archie method. It is important to mention that the FZI method leads to recognizing flow ability in a reservoir without giving an idea about the nature of the flowed fluids (Shahab, 2019).

In order to connect between the ability to flow and the nature of the flowed fluid (water, oil, or gas) in the carbonate Jeribe Formation; both MHI and FZI values are correlated as shown in the Fig. 7.

Best productive zones should be those intervals in which low MHI values (lower than 0.6) are coupled with high FZI values (Shahab, 2019).

The RUJ-1 and RUJ-2 in both wells of the study contain almost continuous productive zones with different efficiencies (as appears in the FZI values). This case continued to the RUJ-3 in the well A, whereas a lot of non-moveable hydrocarbon horizons were observed in the RUJ-3 in the well B and are likely to be within the transition zone of the reservoir.

The alternative appearance of the non-moveable and the moveable hydrocarbons in the RUJ-3 in the well A indicates that this reservoir unit is also part of the transition zone above the oil-water contact. Accordingly, the oil-water contact is expected to be somewhere in the underlain Dhiban or Euphrates Formations in the well A and within the Dhiban Formation in the well B. The difference in the position of the O/W contact is expected to be due the locations of the both drilled wells related to the structure of the field (well A is located at the northwest plunge and well B is located at the southeast plunge).

### 4.4. Hydrocarbon Moveability Scenarios

Hamada (2004) showed the nature of the fluid distribution in the uninvaded virgin reservoir zone and the flushed zone in different water and hydrocarbon bearing cases. Although the principle on which Hamada (2004) relied in his conclusions is not too far from the basis of Archie’s formula, an attempt is made in this study to take advantage of this proposed method.

Hamada (2004) mentioned that in clean formation, water saturation ($S_w$) and flushed zone saturation ($S_{xo}$) are determined from clean formation water saturation model, Archie formula (Eqs. 4 and 5). In case of fully water saturated formation, formation resistivity factor ($F$) is a rock property; relates rock electrical property to its porosity and cementation factor.
Fig. 7. MHI and FZI for the studied Jeribe Formation in the wells A and B.

\[ F = \frac{a}{\Theta^m} = \frac{R_o}{R_w} \]  

(10)

\[ (R_o \text{ is rock resistivity fully saturated with formation water}) \]

In uninvaded zone, formation factor (Fd) can be represented as:

\[ F_d = \frac{R_t}{R_w} \]  

(11)

While in flushed zone, formation factor (Fs) can be represented as shown in Eq. 12.

\[ F_s = \frac{R_w}{R_{mf}} \]  

(12)

According to Hamada (2004), in water zones, it is found that \( F = F_s = F_d \). This is based on the fact in water zone Rt may be considered equal to Ro.

If \( F < F_s \) and \( F_s = F_d \), it is hydrocarbon section, but it is immoveable.

If \( F < F_s \) and \( F_d > F_s \), it is hydrocarbon section and it is moveable.

This technique, known as Hydrocarbon Moveability Factor (HCM), was applied in this study to examine the movability of the hydrocarbons in the Jeribe reservoir in the wells A and B. The measured F, Fs, and Fd values are plotted as curves on the same track (Fig. 8).
Water-bearing zones are characterized by tracking the curves with nearly the same values, whereas the separation between the curves means the existence of hydrocarbons. The separation between the curves and the widening of the space between them indicates the ratio of the immovable and moveable hydrocarbons. The wider the space between F and Fs, the higher the ratio of the immovable hydrocarbons; the same is true for the space between Fs and Fd curves for the ratio of the moveable hydrocarbons.

As noticed from Figure 8, the RUJ-1 in both wells of the study has a noticeable ratio of moveable hydrocarbons, especially in the well A, where there are different horizons in which all of their reservoired hydrocarbons are moveable. The existence of zones with moveable hydrocarbons in the RUJ-3 of the formation in the well B that are separated by water-bearing zones can also be observed through the separation and tracking of the three F curves. The oil-water contact that expected previously to be within Dhiban Formation in the well B is also supported by this HCM method, and the tracking of the three plotted curves can be clearly observed. In addition to identifying moveable hydrocarbon bearing zones, the HCM method can also help define the nature of the moveable hydrocarbons via the \((Fs/Fd)^{0.5}\) ratio. According to Hamada (2004), this ratio goes from 0.0 to 1.0. It is found that if the ratio is less than 0.75, the hydrocarbon is moveable, and if the ratio is less than 0.25, the moveable hydrocarbon is either gas or a light hydrocarbon. In cases where the Fs/Fd value is between 0.25 and less than 0.75, the moving hydrocarbon is oil, and when the ratio is greater than or equal to 0.75, the existing oil is immovable.

Fig. 9 shows the values of the calculated HCM or the \((Fs/Fd)^{0.5}\) for the Jeribe Formation in both wells of the study. Except for the uppermost part of the formation, where indications of light oil or gas can be seen, the formation appears to contain oil as hydrocarbons.

The obvious difference between this method and the MHI method can be noticed, especially for the well A, where all the reservoired hydrocarbons were identified as moveable. This difference between the two methods is mainly due to the selected cutoff value for differentiating between immovable and moveable hydrocarbons. The higher selected cutoff of 0.75 in this method compared to the specified cutoff of 0.6 in the MHI method led to variations in the results. According to Hamada (2004), the selected 0.75 and other cutoffs are based on field experience.

The calibration of the results obtained from this study with the information recorded in the internal reports of the operator company indicates that the used cutoff of 0.6 (MHI method) is more likely to be of higher reliability.
Fig.8. The used F, Fs, and Fd parameters for detecting water, immoveable, and moveable hydrocarbon zones in the Jeribe Formation at the two wells of A and B.
5. Conclusions

Based on the techniques used in identifying the moveability of the hydrocarbons in the Jeribe Formation, and through the comparison done between them, the following are concluded:

- Jeribe Formation has three levels of flow capacity as noticed from the identified FZI and HFUs and most parts of the formation have the lowest flow efficiency.
- The difference between the three flow capacities in the formation is not so great indicating the low heterogeneity nature of the formation’s lithology.
• The entire Jeribe Formation in both wells of the study contains hydrocarbons with different ratios. The RUJ-1 at the upper part of the formation has the highest ratio of moveable hydrocarbons especially in the well A.
• The oil-water contact is expected to be within the underlain Dhiban or Euphrates Formations in the well A and it’s within Dhiban Formation in the well B.
• The nature of the hydrocarbons in the Jeribe Formation is likely to be gas or light oil at the top 2-4m of the formation and oil at its rest parts.
• The difference in the selected cutoffs for distinguishing moveable and immoveable hydrocarbons causes kind of confusion when applying Archie and Hamada methods.
• The results obtained by Archie formula and cutoffs proposed by Schlumberger (1972) in this study look to have more reality than the results obtained through applying the proposed cutoff value by Hamada (2004).

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References