Petrophysical Evaluation of Mishrif Formation in X oilfield, southeastern Iraq

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Abstract
Well logs data was analyzed and used to identify reservoir properties. The Mishrif Formation was subdivided into six units (MA, MB1, MB2, MC1, MC2 and MC3) with different potential characteristics. By using the MID method and M-N cross plots to determine the rock and mineral composition of the Mishrif Formation in the X oil field, it was found through the profiles that the Mishrif Formation consists largely of limestone, little dolomite and shale. Based on the CPI results of the two wells (XA and XB) it was noted that the units BM1, BM2 and MC1 reservoir units have good petrophysical properties as they had good porosity ranging from 0.1 to 0.19 with low values of water saturation (0.3-0.79) and shale volume (0.0295-0.070) respectively. Due to these characteristics these units are considered oil-bearing areas among the most important units in the Mishrif Formation in the X field, while the other units (MA, MC2 and MC3) are considered non-reservoir units due to It has poor petrophysical properties.

Keywords: Petrophysical Evaluation; Mishrif Formation; southeastern Iraq; Shale

1. Introduction
The Mishrif Formation a heterogeneous carbonate reservoir is one of southern Iraq's most important reservoirs. The Mishrif Formation which is part of the Wasia Group. During the Cretaceous period, it was deposited in the second sedimentary cycle (Cenomanian-Early Turonian) and is found all throughout the Arabian Gulf (Sadooni and Aqrawi, 2000). Despite the Khasib Formation being irregularly overlain, the Mishrif Formation is in gradational contact with the underlying Rumaila Formation (Al-Dabbas et al., 2010). The Mishrif Formation in central Iraq is the consequence of long-term shallow marine carbonate deposition as the main carbonate reservoirs in central and southeast Iraq throughout the Cretaceous epoch (Al-Dulaimy and Sa’ad, 2013) (Fig. 2). Well logging is the process of measuring physical parameters along a borehole (Well log data). The log data provide a continuous record of the entire profile and a physical characterization of the different layers and sections in terms of resistivity, nuclear radiation and etc. (Schon, 2015). As a result the stratigraphic column was divided into twenty stratigraphic zones: four for the Tanuma Formation, five for the Khasib Formation and eleven for the Mishrif Formation. Although there is controversy over the number of producing units and their stratigraphic intervals, the Mishrif Formation's bottom part is the main reservoir in the geological column (Al-Mimar et al., 2018). The Mishrif Formation is a significant reservoir in the Halfaya Oilfield.
and one of the most significant carbonate reservoirs in central and southeastern Iraq (Al-Baldawi, 2020). In this study, the velocity deviation log for the Mishrif carbonate reservoir in two wells in the Halfaya Oil Fields (HF-1 and HF-2) was calculated by converting porosity-log data into a synthetic velocity log using a time-average equation. A technique for gathering downhole information about the main pore types in carbonates is to create a velocity-deviation log by fusing a sonic log with a neutron-porosity or density log. Physical measurements from well logging are required to determine subsurface parameters. Log data is the kind of down-hole data that is most typically utilized for analyzing subsurface rocks and their physical characteristics. The basic goal of well log interpretation is to use drilling to assess the potential production of porous and permeable formations (Abdulrahman et al., 2020). Over 80% of Iraq’s oil reserves are found in the country’s most productive time period. The formation is composed of three reservoir units (MA,MB,MC). The MB unit has two secondary units (MB1 and MB2), while the MC unit has two secondary units as well (MC1 and MC2) (Fadel and Nasser, 2021). Logging tools are one of the most advanced methods in terms of precision and they are now playing a larger part in the geological decision-making process. The various well logging technologies are designed to produce measurements from which petrophysical features of reservoir rocks can be calculated or inferred. The goal of this study is evaluate the petrophysical characteristics of the reservoir units of the Mishrif Formation in the X oil field.

![Stratigraphic column of Mishrif Formation](M.O.C, 2013)

**Fig.1.** Stratigraphic column of Mishrif Formation (M.O.C, 2013)
2. Location of the Study Area

Iraq’s X Oilfield, a huge oilfield with bioclastic limestone as the principal producing zone, is situated in Missan Province in the country’s southeastern region (Fig. 2), about 400 kilometers from Baghdad. It occurs as a broad and somewhat long-axis anticline with NW-SE trends that was formed during Neogene Zagros orogenic activity in the foredeep region of the southern Mesopotamian Basin, according to the geological evidence (Aqrawi et al., 2010).

Fig. 2. (a) Location and regional structure of the study area in Iraq (Al-Ameri et al., 2015); (b) Enlarged of the study area in a; (c) Structure contour map shows the selected wells in MA unit of X oilfield.
3. Materials and Methods

Full set logs (Caliper log, Gamma rey log, Neutron log, Density log, sonic Log and Resistivity log) were used to investigate two wells. Interactive Petrophysics software (IP) version 4.5 and Techlog 2015 were used to interpret well logs.

4. Results

4.1. The Petrophysical Parameters

4.1.1. Porosity logs

- Neutron log

The concentration of hydrogen ions in a formation is measured using neutron logs. The neutron on log determines liquid-filled porosity in clean strata. Different detector types, separation between source and detector and lithologies affect its reactions (Asquith and Gibson, 1982).

- Density log

The density log measures the formation’s bulk density. The value of bulk density obtained from the density correction curve ($\Delta \rho$ in g/cm$^3$). calculate porosity for clean depth intervals ($V_{sh} < 0.1$) using equation (1) (Dresser, 1979), whereas unclean depth intervals ($V_{sh} > 0.1$) were calculated using equations (2) or (3) (Dewan, 1983).

$$\phi_D = \left( \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_{fl}} \right)$$  \hspace{1cm} (1)

$$\phi_{De} = \left[ \left( \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_{fl}} \right) - \left( \frac{\rho_{ma} - \rho_{sh}}{\rho_{ma} - \rho_{fl}} \right) \right] \times V_{sh}$$  \hspace{1cm} (2)

$$\phi_{De} = \phi_D - V_{sh} \times \phi_{D_{sh}}$$  \hspace{1cm} (3)

Where

$\phi_D$ = density derived porosity
$\phi_{De}$ = Shale-corrected density porosity
$\rho_{ma}$ = matrix density (2.71 gm / cm$^3$)
$\rho_b$ = formation bulk density (the log reading)
$\rho_{fl}$ = fluid density
$\rho_{sh}$ = density of nearby shale
$V_{sh}$ = shale volume
$\phi_{D_{sh}}$ = Density porosity of a nearby shale

- sonic Log

The time-average equation (Wyllie et al., 1958) can be used to find porosity that should exist to derive sonic porosity (Asquith and Krygowski, 2004):

$$\phi_{S} = \frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_{f} - \Delta t_{ma}}$$  \hspace{1cm} (4)
Where:
\( \Phi_s \) = Sonic derived porosity.
\( \Delta t = \log \) = Time of Interval transit measured via log.
\( \Delta t_f \) = Time of Interval transit in pore fluid (185 μsec/ft in the saltwater mud, but 189 μsec/ft in the fresh water mud).
\( \Delta t_{ma} \) = Time of Interval transit to matrix.

### 4.2. Determination of Porosity

#### 4.2.1. Total porosity (\( \Phi_t \))

The total porosity of a rock is defined as the volume ratio of all pores in the rock to the overall volume of the substance, and these pores are not always related (Bowen, 2003). (Al-Baldawi, 2016) suggested the following equation to determine (\( \Phi_t \)) by combining density and neutron log data:

\[
\Phi_t = \frac{\Phi_N + \Phi_D}{2}
\]  
(5)

Where:
\( \Phi_t \) = total porosity (Neutron-Density log).
\( \Phi_N \) = neutron porosity.
\( \Phi_D \) = density porosity.

#### 4.2.2. Effective Porosity (\( \Phi_e \))

Effective porosity is defined as the relationship between the volume of connected pores and the total volume of reservoir rock. To calculate (\( \Phi_e \)), (Schlumberger, 1998) used the following equation:

\[
\Phi_e = \Phi_t \times (1 - V_{sh})
\]  
(6)

Where:
\( \Phi_t \) = Total porosity (Neutron-Density log).
\( \Phi_s \) = Porosity from sonic log.
Each of the three porosity indices is computed, as indicated in Fig. 3 for well XA and XB for the Mishrif Formation.

### 4.3. Gamma Ray Log

Gamma ray logs are used to determine the natural radioactivity of a formation; the logs are typically used to determine the shale content of a formation since radioactive elements tend to cluster in clays and shales (Peters, 2006).

#### 4.3.1. Volume of shale from GR log

Shale rock, or its volume, has a significant impact on the interpretation of porosity and water saturation in a formation, which can influence hydrocarbon saturation (Bassiouni, 1994). The volume of shale can be determined by measuring the radioactivity of the minerals that make up the formation rocks using the GR log (Asquith and Gibson, 1982), as the clay contains a high concentration of radioactive elements, particularly potassium. Because the Mishrif Formation is one of the old rocks from the Cretaceous period, so that, the volume of shale formula it must be modeled using Larionov’s (1969) equation (7) for old rocks (Asquith and Krygowski, 2004).

\[
V_{sh} = 0.33 \times 2^{(2 \times IG_R)} - 1
\]  
(7)
Where:

Vsh = volume shale.

IGR = index of gamma ray.

The results for the wells XA and XB are shown in Fig. 4.

Fig. 3. Wells XA and XB were studied for their effective porosity (PHIE) and the relationship between total porosity (PHIT) and secondary porosity (SPI), as well as the impacts of the GR log.
4.4. Determination of Lithology and Mineralogy

4.4.1. Neutron-density cross plot for lithology determination

It is one of the most important quantitative interpretation tools for determining the lithology and matrix of a formation. The matrix density changes between the three main rock types (sandstone, limestone, and dolomite) benefit the basic layout (Ellis and Singer, 2007). Finally, the limestone line runs through the Mishrif formation units, unit A and B points nevertheless disperse near the limestone-
sandstone line, while some points of units C scatter toward the dolomite line. Fig. 5 shows a crossplot for two wells.

4.4.2. M-N Cross-Plot for mineral determination

Because M-N values rely on the formation’s porosity, this approach employs porosity logs data to determine mineral mixes. M and N values are defined using the following equations (Schlumberger, 1972): 

\[ M = \frac{\Delta t_f - \Delta t \log \rho_b - \rho_f}{0.01} \]  
\[ N = \frac{\Phi N_f - \Phi N}{\rho_b - \rho_f} \]

Where:
\( \Delta t_f \) = time of interval transit in (185 μsec/ft for the salt water mud, and 189 μsec/ft for the fresh water mud).
\( \Delta t \log \) = time of interval transit.
\( \rho_b \) = density of bulk formation.
\( \rho_f \) = fluid density (for the fresh water = 1 (g/cm³) and for the salt mud = 1.1 (g/cm³)). 
\( \Phi N_f \) = neutron porosity for fluid = 1.
\( \Phi N \) = neutron porosity.

According to the cross plot of two wells in this research, almost all Mishrif formation units are found on calcite mineral (dominant), with few MA and MB units spread near secondary porosity and MC units scattered toward dolomite. Fig. 6 shows a crossplot for two wells.

Fig. 5. The Mishrif Formation in wells XA and XB was studied using a density-neutron cross plot.
Fig. 6. M-N cross plot for the Mishrif Formation in wells XA and XB

4.4.3. Matrix Identification (MID) Cross Plot

To depict a link between apparent-matrix density (RhoMatrix) (g/cc) and apparent-matrix transit time (DTMatrix) (s/ft) in a reservoir (Fig. 7), this plot requires the availability of porosity logs data. Where the (RhoMatrix) and (DTmatrix) are obtained by calculating the apparent total porosity ($\phi_{ta}$) as determined by the computed neutron density value using the formulae below (Schlumberger, 1998):

$$
\Delta t_{maa} = \frac{\Delta t_{log} - \Delta t_{f}}{1 - \phi_{ta}} \quad (10)
$$

$$
R_{maa} = \frac{\rho_b - \phi_{ta} \cdot \rho_f}{1 - \phi_{ta}} \quad (11)
$$

Where:

$\Delta t_{maa}$, = apparent transit time in the rock matrix ($\mu$sec/ft).

$R_{maa}$, = apparent density of the matrix (gm/cc).

$\phi_{ta}$, = total porosity apparent.

$\Delta t_f$, = time of interval transit in (185 $\mu$sec/ft = in the salt water mud, 189 $\mu$sec/ft = in the fresh water mud.

$\Delta t_{log}$, = time of interval transit .

$P_b$ & $P_f$ mentioned in the equations (8&9)
Fig. 7. MID cross plot for the Mishrif Formation in wells XA and XB

4.5. Water and Hydrocarbon Saturation

Water saturation is the quantity of water contained in the rock pores, while hydrocarbon saturation is one minus water saturation and denotes the amount of hydrocarbons present, respectively (Sw, and Shr) (Bowen, 2003). In order to calculate the water saturation levels in both the uninvaded (Sw) and invaded (Sxo) zones, the following equations were utilized.

\[ SW = \left( F \cdot \frac{RW}{Rt} \right)^{1/n} \]  
\[ Sxo = \left( F \cdot \frac{Rmf}{Rxo} \right)^{1/n} \]

Where:
- \( F \) = Factor of formation.
- \( RW \) = Resistivity of water formation.
- \( Rt \) = True formation resistivity.
- \( n \) = Saturation exponent (assumed to be 2.0).
- \( Rmf \) = Resistivity of mud filtrate at formation temperature.
- \( Rxo \) = Resistivity of invaded zone.

The following equations (Asquith and Krygowski, 2004) can be used to compute movable (Shm) and residual hydrocarbon saturations (Shr) from the findings of the previous for values of water saturation in flushed zone (Sxo) and un-invaded zone (Sw):

\[ Shm = S_{xo} - S_{w} \]
Then, using the equation (Schlumberger, 1987 in Abdulrahman et al., 2020), determine hydrocarbon saturation (Sh), which is defined as the portion of the pores that is not filled with water:

\[ S_h = (1 - S_w) \]  \tag{16}

### 4.6. Analysis of Bulk Volume

BVW and BVXO are the formation water saturation (Sw) and porosity outputs that may be determined using the equation below: (Asquith and Gibson, 1982)

\[
\begin{align*}
BVW &= Sw \times \Phi \\
BVXO &= Sxo \times \Phi
\end{align*}
\]  \tag{17} \tag{18}

Where:
- BVW = bulk volume water for un-invaded zone.
- BVXO = bulk volume water for invaded zone.
- \( \Phi \) = porosity.

The following equation can be used to calculate the bulk volume of hydrocarbon:

\[
Bvo = S_h \times \Phi
\]  \tag{19}

Where:
- Bvo = bulk volume of hydrocarbon
- \( S_h \) = hydrocarbon saturation.
- \( \Phi \) = porosity.

Figs. 8 & 9 explain the Computer Processes Interpretation (CPI) for wells (XA and XB), CPI consists of several tracks including (The lithology track and Fluid analysis)

### 4.7. Evaluation of Reservoir Units

The Mishrif Formation consist from mainly limestone, some dolomite and shale, and can be divided to three main zones through all wells, depending on the heterogeneity of the petrophysical properties. We analyzing these units using the Interactive Petrophysics application (IP) and the Techlog program:

- **(MA) Reservoir Unit**: A unit is uppermost reservoir unit, the average of water saturation value ranging from (0.26-0.54) while effective porosity ranging from (0.1-0.14), shale volume where ranging (0.008-0.057).

- **(MB) Reservoir Unit**: A unit is an important reservoir unit, it is divided into two units. Which has good petrophysical property.

- **(MB1) Reservoir Unite**: This unit has good reservoir properties because has good petrophysical properties, the average of water saturation value ranging from (0.33-0.5) while effective porosity ranging from (0.11-0.13) with decrease in shale volume where ranging (0.03-0.056). Therefore, this unit is interpreted as an oil-bearing zone.

- **(MB2) Reservoir Unite**: The average of water saturation value ranging from (0.3-0.38) while effective porosity ranging from (0.19-0.22) with decrease in shale volume where ranging (0.07-0.0998). Therefore, this unit is interpreted as an oil-bearing zone.

- **(MC) Reservoir Unit**: It is divided into three unites.

  - **(MC1) Unit**: The average of water saturation value ranging from (0.68-0.79) while effective porosity ranging from (0.17-0.186) with decrease in shale volume where ranging (0.0295-0.056). Good reservoir unit because which has good petrophysical property.

  - **(MC2) Unit**: The average of water saturation value ranging from (0.85-0.93) while effective porosity
ranging from (0.12-0.15) with decrease in shale volume where ranging (0.0298-0.08).

- (MC3) Unit: the average of water saturation value ranging from (0.89-0.97) while effective porosity ranging from (0.2-0.22) with decrease in shale volume where ranging (0.015-0.056).

Table 1. Average of petrophysical properties($\Phi$ef, Sw and $V_{Shl}$ %) of units for two wells.

<table>
<thead>
<tr>
<th>Wells</th>
<th>XA</th>
<th>Units</th>
<th>$\Phi$ef</th>
<th>Sw</th>
<th>$V_{Shl}$ %</th>
<th>Thick (m)</th>
<th>XB</th>
<th>Units</th>
<th>$\Phi$ef</th>
<th>Sw</th>
<th>$V_{Shl}$ %</th>
<th>Thick (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA</td>
<td>0.1</td>
<td>0.54</td>
<td>0.008</td>
<td>41</td>
<td></td>
<td></td>
<td>0.14</td>
<td>0.26</td>
<td>0.057</td>
<td>30.96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MB1</td>
<td>0.11</td>
<td>0.5</td>
<td>0.056</td>
<td>118</td>
<td></td>
<td></td>
<td>0.13</td>
<td>0.33</td>
<td>0.03</td>
<td>119.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MB2</td>
<td>0.19</td>
<td>0.38</td>
<td>0.070</td>
<td>46</td>
<td></td>
<td></td>
<td>0.22</td>
<td>0.3</td>
<td>0.0998</td>
<td>46.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC1</td>
<td>0.17</td>
<td>0.68</td>
<td>0.056</td>
<td>77</td>
<td></td>
<td></td>
<td>0.186</td>
<td>0.79</td>
<td>0.0295</td>
<td>74.58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC2</td>
<td>1.15</td>
<td>0.85</td>
<td>0.08</td>
<td>79</td>
<td></td>
<td></td>
<td>0.12</td>
<td>0.93</td>
<td>0.0298</td>
<td>69.78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC3</td>
<td>0.2</td>
<td>0.89</td>
<td>0.056</td>
<td>54</td>
<td></td>
<td></td>
<td>0.22</td>
<td>0.97</td>
<td>0.015</td>
<td>63.38</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig.8. CPI of the Mishrif Formation in well XA
5. Discussion

Through a logs for the two wells and the processing of this data (CPI) by software, it was possible to identify the petrophysical properties of the formation in the study area of lithology, porosity and water saturation. Where it was possible to divide the composition into units due to variation in the petrophysical properties, which included the reservoir units for having good petrophysical properties and the non-reservoir units based on previous studies. As a result, it was possible to identify the oil areas, Excluding
units that are considered economically unviable areas, and the prospects for this study are to search for hydrocarbon aggregates to make maximum economic use of these units.

6. Conclusions

The Mishrif formation is mainly composed of limestone, which was determined using the neutron-density and M-N cross plots. It was found that the formation consisted of calcite and a little bit of dolomite, it was possible to divide the formation into six reservoir units (MA, MB1, MB2, MC1, MC2 and MC3) using CPI through various physical properties such as shale volume, water saturation and effective porosity. Where the volume of the shale reaches 0.08 in unit MC2 and to 0.0295 in unit MC1, while the water saturation increases in units MA, MC2 and MC3 to reach 0.97 in unit MC3 and decreases to 0.3 in unit MB2. The porosity is effective which has a significant effect in the petrophysical evaluation, as it increases significantly in units MB1, MB2 and MC1 up to 0.22 in unit MB2 and decreases to 0.1 in unit MA. Finally, the units MB1, MB2 and MC1 are among the most important reservoir units because of their good physical properties. There is a large percentage of shale in units MA, MC2 and MC3, in addition to a high percentage of water saturation and therefore it is considered as non-reservoir units within the wells studied.

References