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Geological Model for Mauddud Reservoir in Khabaz Oil Field, Kirkuk, northern Iraq

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Abstract

The Mauddud reservoir, Khabaz oil field which is considered one of the main carbonate reservoirs in the north of Iraq. Recognizing carbonate reservoirs represents challenges to engineers because reservoirs almost tend to be tight and overall heterogeneous. The current study concerns with geological modeling of the reservoir is an oil-bearing with the original gas cap. The geological model is establishing for the reservoir by identifying the facies and evaluating the petrophysical properties of this complex reservoir, and calculate the amount of hydrocarbon. When completed the processing of data by IP interactive petrophysics software, and the permeability of a reservoir was calculated using the concept of hydraulic units then, there are three basic steps to construct the geological model, starts with creating a structural, facies and property models. The reservoirs were divided into four zones depending on the variation of petrophysical properties (porosity and permeability). Nine wells that penetrate the Cretaceous Formation (Mauddud reservoir) are included to construct the geological model. Zone number three characterized as the most important due to its large thickness which is about 108 m and good petrophysical properties are about 13%, 55 md, 41% and 38% for porosity, permeability, water saturation and net to gross respectively. The initial oil and gas in place are evaluated to be about 981×10^6 STB and 400×10^9 SCF.

Keywords: Geological model; Petrel software; Mauddud Reservoir; Khabaz oil field

1. Introduction

Khabaz field is located in Kirkuk, which is located 23 Km to the southwest of Kirkuk City, the dimensions of the Khabaz field are nearly 18 km long and 4 km width. Khabaz oil field is described as a subsurface asymmetrical anticline, and the northeast limb dipper than the southwest limb, Khabaz oil field has more than one formation (reservoir). The Upper Qamchuqa (Mauddud) Formation with a thickness of about 172 m is one of the reservoirs of the khabaz oil field (Qadir, 2008), which is a goal of this study. The Qamchuqa Formation was defined as comprising the neritic limestones. in the contact sections, the formation below is Sarmord, whereas, the upper Kometan Formation. The reservoirs may be heterogeneous with limited information; thus, describing and evaluating their petrophysical characteristics might need exceptional approaches and techniques (Al-Beyati et al., 2021). The aims of the study are to establish a geological model for the reservoir by identifying the facies and evaluating the petrophysical properties of this heterogeneous reservoir due to depositional and diagenetic processes, then calculate the amount of hydrocarbon. A geological model is known as an applied knowledge that

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computerized representation for partitions of earth crust depends on geological observations, and it is a numerical equivalent for a 3D geological map (Mallet, 2008). The 3D geological models show a better mechanism for combining all the available data (Mehdi, 2011). Nine wells were selected for the study reservoir of Mauddud, as their coordinates and total depths are shown in Table 1 (North Oil Company, 1989).

Table 1. Locations of studied wells in Khabbaz Oil Field

Well name	Coordinates		Well depth (m)
	Easting	Northing	
Kz-1	422 190	3929 342	3414
Kz-4	417 650	3932 200	3350
Kz-7	425 502	3927 730	3120
Kz-13	420 345	3930 275	3210
Kz-14	424 685	3927 939	3294
Kz-16	423 850	3929 471	3100
Kz-21	422 167	3930 712	2992
Kz-23	418 457	3930 597	2957
Kz-29	421 259	3931 541	3443

2. Methodology

Available data well logs, as well as field maps and reports have been used in this study. Available data have been processed by petrophysical interactive (IP) and Diger softwares were employed to use in petrel software. Petrel software was used in turn created the geological model. The petrel software, which in turn creates the structural and property models. So, several steps that must be followed in order to reach the goal.

2.1. Structural Contour Maps Modeling

Structure contour maps link the characteristics of reservoir structure as different rock layers and features on well tops as well as well paths and zone logs (Engheim, 2018). The structural model was created based on the contour map of the reservoir, which was digitized by the Diger software, then data was transferred to the petrel software, which created the model as shown in Fig. 1, that reveals the Mauddud structure in the Khabbaz oil field is composed of subsurface asymmetrical anticline dome. Mauddud reservoir is one of the most prolific Khabbaz reservoirs that is 155m to 177m thickness.

Fig. 1. 2D Cross section model for structure contour map of Mauddud reservoir

2.2. Pillar Gridding

It is the step of generating a grid depending on fault description (Petrel – petrofaq, 2009). The grid, used in Mauddud reservoir, was represented as 100m grid for x-axis and $\times 100$ m grid for y-axis. The total number of cells is 443520, which divided the reservoir into three skeletons on top, mid and base skeletons as shown in Fig. 2.

Fig. 2. 3D model for Pillar Gridding of the Mauddud Reservoir

2.3. Make Horizons and Zones

This step includes inserting the main reservoir horizons into the grid. The isochores can be inserted above, below, and between the major horizons to produce the isolated reservoir zones (Shepherd, 2009), as shown in the Fig. 3. Four horizons (zones) have been built for the Mauddud reservoir based on the porosity values obtained from the well logs. The zones, respectively, were divided into layers, as illustrated in table 2, depending on the variation of porosity.

Table 2. The number of layers for each zone of Mauddud reservoir

Zone	Average Layers thickness(m)	no. of Layers
1	11.4	5
2	34.2	10
3	108.5	20
4	22.8	5

2.4. Scale up Well Logs

Well log data must be adjusted to treat the complication of the properties being heterogeneous by scaled up that is because every petrophysical quantity is used at a scale lesser than the one which was recorded (Lake and Srinivasan, 2004). There is more than one method used to scale up well logs, as arithmetic, geometric and harmonic. The arithmetic method was used to scale up porosity, water saturation and net to cross values, while the geometric method is used for distributing permeability.

2.5. Property Modeling

It is the process of filling the cells of the grid with individual continuous properties (i.e. porosity, permeability and water saturation), which is carried out by Petrel software. Petrel supposes that the layer geometry given to the grid depends on the geological layering in the model scope (Schlumberger, 2009).

Fig. 3. 3D Model for zones of Mauddud Reservoir

2.6. Facies Modeling

Petrel Facies modeling is utilized to integrate geocellular grids with values of discrete property for a reservoir characterization. Properties are distributed into the remaining 3D grid volume by using a set of algorithms (Schlumberger, 2009). The lithology of the reservoir was determined by M-N cross plot, which used in the petrel software. Fig. 4 shows that the facies of the dolomite with blue and the dolomitic-limestone in the light blue are mostly prevailing on the Mauddud reservoir.

Fig. 4 2D Cross section facies distribution of Mauddud reservoir

2.7. Petrophysical Modeling

Petrophysical modeling is the operation of distributing the complete set of continuous log properties to the whole reservoir. More than one different algorithm can be used to create these parameters (Bellorini et al., 2003). Three-dimensional property modeling process based on well logs data the properties were distributed between the wells of study. Consequently, it realistically conserves reservoir heterogeneity and matches the well information (Schlumberger, 2010a). Geostatistical methods were employed to create petrophysical model.

2.8. Porosity Model

This model was built by petrel based on the porosity results that obtained from the well logs (density, neutron and sonic) which was conducted using Interactive Petrophysics software. Statistical Sequential Gaussian simulation algorithm was employed as a statistical method (Schlumberger, 2010b). Fig. 5 shows the general 2D porosity model for the Mauddud reservoir of Khabaz oil field. It was noted that the porosity within the reservoir is high, where the zone1 is about 26%, but this zone is not thick relative to the zone 3. However, a more suitable zone is 3; that is largest zone, its average porosity about 13%. Fig. 6 shows a 2D model for porosity distribution of Mauddud reservoir in zone 3. The reservoir's average porosity value is 16.9%.

Fig. 5. 2D model for porosity distribution of Mauddud reservoir

2.9. Permeability Model

Permeability model depends widely on the porosity model, considering that a relationship between porosity and permeability is a perfect way to construct the model. Depending on the generalized Flow zone indicator FZI method and the equations that appear as a result of the statistical analysis used to predict permeability, where, FZI represents similar or close values for some properties of rock (surface area and flow path), a 2D Permeability Model was constructed for 9 selected wells in the Mauddud reservoir. Consequently, the different FZI values for core data that lie on the same straight line have similar pore throat attributes (Ezekwe, 2011). There are four groups of FZI depending on field

data of porosity and permeability, Fig. 7 shows the relationship between properties. The relationship was cross-plotted between permeability–porosity, Fig. 8 then permeability correlations were generalized on un-cored wells by statistical analysis. Equations used for calculation are as follows:

$$RQI = 0.0314 \times \sqrt{\frac{K}{\Phi}} \quad (1)$$

$$FZI = \frac{RQI}{\Phi_z} \quad (2)$$

$$\Phi_z = \frac{\Phi_e}{1 - \Phi_e} \quad (3) \text{ (Ezekwe, 2011)}$$

Where RQI is reservoir quality index, Φ_z is pore volume-to-grain volume ratio, and Φ_e is effective porosity (fraction).

Fig. 6. 2D Cross section model for porosity distribution of Maudud reservoir in zone 3

Fig. 7. Cross plot RQI vs. PHZ from core data in Maudud reservoir, Khabaz oil field

Fig. 8. Permeability vs. porosity Cross plot for certain FZI values Mauddud reservoir, Khabaz oil field

Fig. 9 shows the 2D permeability model for the Mauddud reservoir of Khabaz oil field. Permeability model shows that the good average permeability value at zone 1 is about 230 md Fig. 10, and it is decreased to 1 md in the zone 4. However, the average permeability value is 86 md for all reservoirs, so it can be recommended as good permeability.

Fig. 9. 2D Cross Section model for permeability distribution of Mauddud reservoir

Fig. 10. 2D Cross Section model for Permeability distribution of Maaddud reservoir in zone 1

2.10. Water Saturation Model

The same geostatistical method used in porosity and permeability models was employed to create water saturation model (Schlumberger, 2010a). Archie (1942) formula was used to calculate of water saturation, where the data was transferred from the interactive petrophysics program after it has been processed (Archie, 1942).

$$S_w = \left(\frac{a}{\phi^m} \times \frac{R_w}{R_t} \right)^{\frac{1}{n}} \quad (4)$$

where (m, n, a) are parameters of Archie, m is cementation exponent, n is saturation exponent, a is tortuosity factor, R_w is formation water resistivity and R_t is formation resistivity. Fig. 11 illustrates a 2D water saturation modeling distribution for Maaddud reservoir. It was noted that the water Saturation within zone 1 is characterized by almost low and low to moderate values within zone 3. The majority of the beneficial hydrocarbon accumulation is found in zone 3 Fig. 12. However, the mean water saturation for Maaddud reservoir is nearly 39%.

2.11. Fault Construction Model

Faults and fractures components are essential factors affecting production performance (fluid flow patterns) (Shepherd, 2009). Based on the field data and structural contour map a major fault intersects the structure in its southeastern nose in Khabaz Field. Well (Kz-7) intersects the fault with around one-hundred-meter displacement to top of Maaddud reservoir (North Oil Company, 1989), as shown in Fig. 13.

Fig. 11. 2D Cross Section model for water saturation distribution of Mauddud reservoir

Fig. 12. 2D Cross Section model for water saturation distribution of Mauddud reservoir in zone No.3

2.12. Fluid Contact Model

The Mauddud reservoir information shows that two interfaces levels (fluid contacts) for separated fluids were located within the reservoir. Gas-oil contact is at (2564m) MSL Mean sea level and oil-water contact is at (2782m) MSL depending on field reports during drilling.

Fig. 13. 2D Cross Section fault model illustration for Maaddud reservoir

2.13. Net to Gross Reservoir Estimation

Net to Gross is a measure of the quantity of production in the overall reservoir and is focused upon to assess reservoir quality and the economics associated with reservoir development (Inichinobia et al. 2014). Net to Gross zones could be evaluated by using results of cut-offs criteria on petrophysical well log data. Interactive Petrophysics Software (V3.5) was utilized to determine cutoff value. Permeability cutoff equals 0.1 md, was chosen for Maaddud reservoir to find porosity cutoff. From cross-plot porosity cutoff was identified and its value is about 6%. The net to gross average value for Maaddud reservoir was 43.2%. The best values of NTG are in zone 1, about 70, Fig. 14 illustrates the 2D net to gross model for reservoir, while Fig. 15 shows net to gross for zone 1.

Fig. 14 2D cross section model of Net to Gross for Maaddud Reservoir

Fig. 15 2D Cross Section Model for Net to Gross Percentage Distribution of Mauddud Reservoir in Zone 1

2.14. Well Correlation

Correlation is a main part for most geologists, especially in petroleum industry (Luthi, 2001). Peterl software were used to visualize the well correlation to display the petrophysical properties (porosity and water saturation)

2.15. Hydrocarbon Volume Calculations

There are some properties required to evaluate the hydrocarbon stored in a reservoir, for example, determination of these properties "porosity, water saturation and the bulk volume of the reservoir" lead to the calculation of the original amount of hydrocarbon in Mauddud reservoir.

Calculations are done by using the following formula

$$OIIP = \frac{A \times h \times \phi \times (1 - S_w)}{Bo_i} \frac{Net}{Gross} \quad (5)$$

$$GIIP = \frac{A \times h \times \phi \times (1 - S_w - S_{or})}{Bg_i} \frac{Net}{Gross} \quad (6)$$

Where, OIIP is oil initially volume in place (OOIP), GIIP is gas initially volume in place, A is area of reservoir, h is thickness of pay zone, ϕ is porosity (decimal) from log and/or core data, S_w is connate water saturation (decimal) from log and/or core data, Bo_i is formation volume factor for oil at initial conditions, Bg_i is formation volume factor for gas at initial conditions. Calculation with a volumetric method is depending on cell value of porosity and water saturation of the petrophysical model estimated from well logs and distributed overall the reservoir with Geostatistics methods. The reservoir is divided into four zones. The zone number three that is the largest and is about 109 m thickness. The reservoir average values were about 16.9%, 86 md, 39% and 43.2% for porosity, permeability, water saturation and net to gross respectively. The volume of initial oil in place of Mauddud reservoir in Khabaz oil field was estimated by 981 million stock tank barrels and the volume of initial gas in place of Mauddud reservoir was estimated by 400×10^9 standard cubic feet.

3. Results and Discussion

Khabaz oil field represents a asymmetrical subsurface anticline that is affected by faults. The reservoir is divided into four zones depending on the petrophysical properties. The focus is on zone 3 which is the largest one and is about 109 m thickness. The reservoir properties average values shown in Table number 3, based on these results, the petrophysical properties of the Mauddud reservoir are good. The best averages porosity and permeability at zone 1 can be about 26% and 230 md. However, the thick of zone one is about 11 m. While the thickness of the zone 3 is more than 108 m, that reason considered zone 3 is the most important. The Mauddud reservoir is characterized by relatively good porosity and permeability values. Depending on realization of lithology, the dolomitic limestone is widespread and affects most of the reservoir zones. The correlation of well sections extends from the northwest to the southeast for wells Kz-4, Kz-1 and Kz-14 as shows in Fig. 16 the petrophysical properties were improving smoothly along the axis of fold directions when comper with structure model Fig 1. It is possible to notic that, the thickness increasing from the SE at Kh-14 to NW at Kh-4 direction. The best value of NTG is in zone 1, which is about 70%. OOIP of the Mauddud reservoir in Khabaz oil field was estimated by 981 million stock tank barrels and OGIP of Mauddud reservoir was estimated by 400×10^9 standard cubic feet. This is considered a large quantity encouraging production.

Fig. 16. SE-NW correlation section of Mauddud reservoir for wells Kz-14, Kz-1 and Kz-4

Table 3. Porosity, Permeability, Water Saturation and Net to Gross Average Values for Each Zone in Maaddud Reservoir

Type of properties	Reservoir				
	Mean values	Average value for each zone			
Zones	All reservoir	1	2	3	4
Ø, %	16.9	26.5	21	13.3	13.8
K md	86	230	120	55	1
S _w , %	39	28	40	41	38
N/G %	43	70	45	38	30

3. Conclusions

Maaddud reservoir is classified into four zones. The study shows that zone 3 is the largest with good petrophysical characteristics (porosity and permeability) so, it is regarded as the best in the reservoir. The average porosity, permeability, water saturation and net-gross values through the study were about 16.9%, 86 md, 39% and 43.2% respectively, for the Maaddud reservoir. Finally, the potential hydrocarbon volume in the reservoir is estimated by (981 million stock tank barrels) and (400×10⁹ standard cubic feet) for oil and gas respectively.

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