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The Role of Effective Thickness of the Asmari Formation Zones on Oil Production

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Highlights

- Effective thickness is a term that includes the gross thickness of rocks by lithofacies for a selected wellbore;
- The adequate thickness of the reservoir formation zones plays a vital role in oil production in the carbonate oil field;
- The effective porosity plays an essential role in the production of hydrocarbons and has the most important relationship between the other petrophysical properties of the reservoir;
- Investigation of the adequate thickness of the reservoir formation zones leads to more reliable estimation of oil production;
- The proposed methodology illustrates the advantage of using adequate thickness and effective porosity for increasing oil production.

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Abstract

This paper investigates the role of the adequate thickness of the Asmari reservoir formation zones on oil production in one of the Iranian carbonate oil fields. Adequate thickness is a term that includes the total gross thickness of rocks by lithofacies for a selected wellbore. The lithology of the Asmari formation in the studied area consists of dolomite, sandstone, lime, dolomitic-lime, sandstone-shale, and shale limestone dolomites. Based on the existing well-logs, the average shale volume, the effective arithmetic means of porosity in the gross intervals, and average water saturation or hydrocarbon-bearing increments of the studied field are calculated using well-logs. In wellbore #A, a depth interval of 2214 to 2296 m shows 9.6% average shale volume, 27.2% average water saturation, and 20.9% average porosity. A depth interval of 2213 to 2280 m, in wellbore #B, shows 6% average shale volume, 21.25% average water saturation, and 28.5% average porosity. Based on our petrophysical assessments, we divide the Asmari reservoir in the studied field into eight zones. Zone 1 is made of carbonate (calcareous and dolomitic), and zones 2–5 are mainly sandstone; zones 7 and 8 are calcareous and shale, and zone 6 is a mixture of all the rocks mentioned above. Among these eight zones, there are two primary hydrocarbon productive zones. The numerical calculation of in situ oil volume showed that zone 2 contains 65% of oil volume in this reservoir. With more than 80% sand, this zone has the highest net hydrocarbon column.

Keywords: Asmari formation, Reservoir zones, Effective thickness, Oil production

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1. Introduction

Petrophysics is the study of the properties of rocks and their interaction with fluids (gases, liquid hydrocarbons, and aqueous solutions). Petrophysical assessment is the interpretation of information from well-log data. Today, well-log data help determine fluid reservoir properties. Well-logs are measurements of physical quantities of the formation, such as radioactive, electrical, and acoustic properties versus wellbore depth. Logs can be used to determine the parameters needed to evaluate properties such as shale volume, porosity, permeability, lithology, wellbore trajectory, layer thickness, total effective thickness, and in situ storage throughout the field, and to correlate these properties between adjacent wellbore. The cost of logging operation is much lower than that of coring, and continuous data are its advantage (Rezaee et al., 2006). In a thick reservoir containing oil and water, saturation can vary from 100% at the bottom hole to irreducible water to the upper layer of the wellbore. The primary purpose of reservoir assessments is to analyze the petrophysical properties of a hydrocarbon field (Schlumberger, 1989). Effective porosity plays an essential role in the production of hydrocarbons and has the most important relationship among the other petrophysical properties of the reservoir. Factors affecting oil production are effective thickness, arithmetic means of porosity, and average water saturation, *Sw*. Adequate thickness is a term that includes the total gross thickness of rocks by lithofacies for a selected well. Based on existing well-logs, average properties are calculated as arithmetic means of porosity in gross intervals. The productive porosity of the reservoir is defined as (Bulnes, A.C, 1946);

$$\tilde{f} = \left[\frac{f_p \times V_p}{\mathrm{V}}\right] \qquad (1)$$

Where $\tilde{f}$ is the productive porosity of the reservoir, f_p indicates the arithmetic mean porosity, V_p represents the permeable volume of the reservoir, and V denotes the total volume of the reservoir.

Average water saturation is the average *Sw* extrapolated for the entire lithofacies in an analyzed well, extrapolated from an equation based on porosity (Etnyre, L.M.,1989).

$$\tilde{S}_{\mathrm{w}} = \frac{\sum \emptyset_i S_W h_i}{\sum \emptyset_i h_i} \qquad (2)$$

Where $\tilde{S}w$ is the average water saturation of the reservoir, $\emptyset_i$ indicates the porosity of the *i*th zone, S_w is the water saturation of the zone, and h_i represents the thickness of the *i*th volume zone.

A higher adequate thickness and hydrocarbon column in a zone lead to more considerable oil in place in the wellbore. The raw thickness of the reservoir rock or formation is called gross, and evidently, the field development is subject to the net to gross increment in the wellbore's trajectory. To investigate the relation between petrophysical parameters and increasing hydrocarbon production, the adequate thickness, the net-to-gross ratio, and the oil volume produced from each zone are examined.

2. Field of study

The Asmari formation is located in the Zagros Basin and the Dezful embayment area, the shallowest oil production horizon in Southwestern Iran. This formation is the richest oil reservoir in the Middle

East. The Asmari formation is one of the richest carbonate reservoirs globally (Alavi). The carbonate reservoir in the study area consists of thick zones with high porosity, a good ratio of adequate thickness to total water saturation, and the highest amount of oil. The properties mentioned above of the Asmari formation are the reasons for good quality hydrocarbon reservoir in this area. In contrast, dolomitic and calcareous layers have reduced porosity, reducing the reservoir quality of the Asmari formation. The novelty of this study is to share the experience of new results in this area to find the role of effective thickness of the Asmari formation zones on oil production as new research.

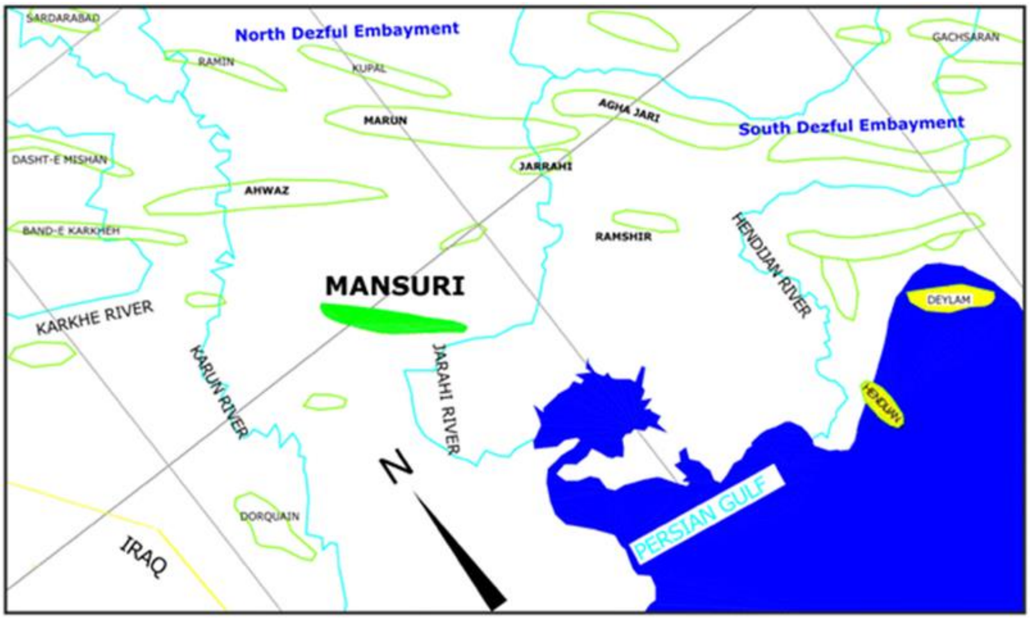

Figure 1
The geographical location of the studied area.

3. Materials and methods

The data used in this study are from two wells (A and B) in the study field. Different logs have been acquired for wells A and B, including GR, Sonic, BHC, LDT, MSFL, and DLL.

3.1. Wellbore #A

a. Quality of logs taken in well #A

According to the caliper log in this wellbore, except for the shale downfall in some wellbore intervals in the Asmari formation and some tight and dense rocks in the Sarvak formation, the wellbore wall in deeper depths are stable, and the driven logs have good quality data.

b. Quality of logs measured in well #B

The first series of measured logs
Due to the presence of barite in the drilling mud, the measurement of the photoelectric (PEF) log shows a higher value than the actual value. Log measurements along the washout intervals are also affected by the presence of barite in the drilling mud. However, logs measured in well #B are generally of good quality for further analysis.

The second series of measured logs

The drilling mud affected the neutron tools because it was driven through the wellbore without a bow spring. Still, an attempt has been made to minimize the impact of the drilling mud by applying environmental corrections. The PEF logs were corrected in terms of the presence of barite in the drilling mud in most of the logging intervals. In general, except for the mentioned cases like the presence of barite in the drilling mud and lack of bow spring, the logs are of good quality for further analysis.

The third series of measured well-logs

The measurement of the PEF logs is affected by the presence of barite in the drilling mud and shows a higher value than the actual value, but in general, the rest of the logs are of good quality for further analysis.

In this study, the petrophysical properties of the reservoir are determined and investigated using well-logging data. This work aims to initially evaluate and enter information into the static model to prepare the petrophysical model. The ratio of effective thickness to total and water saturation for each zone will lead to a relation between effective thickness, porosity, and oil production, which is the goal of this study.

c. Analysis of the results obtained from wellbore #A

Obtaining lithology using neutron-density (PEF) cross-plot

As mentioned earlier, the matrix line shown in the cross-plot (Figure 2) is used to identify minerals and different lithologies. According to this cross-plot, dolomitic limestone, shaly limestone, and shaly sandstone are separated. In Figure 2, Neutron–density cross-plot and PEF log were used to identify the type of mineral (Schlumberger, 5). In this cross-plot, different colors are dedicated to each mineral. For example, limestone is approximately 5.1 and almost green, sandstone is approximately 3.2 and almost blue, and shale is approximately 4 and black.

Obtaining lithology using neutron–density (CGR) cross-plot

In this cross plot, the presence of gas in the formation has caused the points to be transferred to the northwest of the cross plot, which causes errors in determining lithology. This cross-plot shows that points related to gas in the formation are not seen. However, in general, it is necessary to correct the neutron and density graphs for hydrocarbons and shale before using this cross-plot (Figure 3).

d. Evaluations of complete set well-logs

Evaluation is known as explaining the meaning of something. Evaluation of diagrams means describing the meanings of diagrams such as RHOB, PEF, and GR to obtain information about different parts of the well and the reservoir parameters.

e. Results of petrophysical evaluation in wellbore #A

This formation has oil hydrocarbon potential, and information about the average porosity and water saturation of the intervals with hydrocarbons is given in Table 1. The depth interval of 2214 to 2296 m, which has been determined in the petrophysical evaluation and according to the obtained model as the oil zone of the Asmari formation in this well, includes thick sandy and dolomitic layers, dolomitic lime, and lime due to high porosity of sandstones. As shown in the obtained model, the most considerable amount of oil is distributed in the sand layers. Lime layers, located between layers and veins with sandstones, do not have good reservoir properties due to their low porosity. In this well, dolomitic layers have reduced porosity, but the saturation of the hydrocarbon fluid in this well is high.

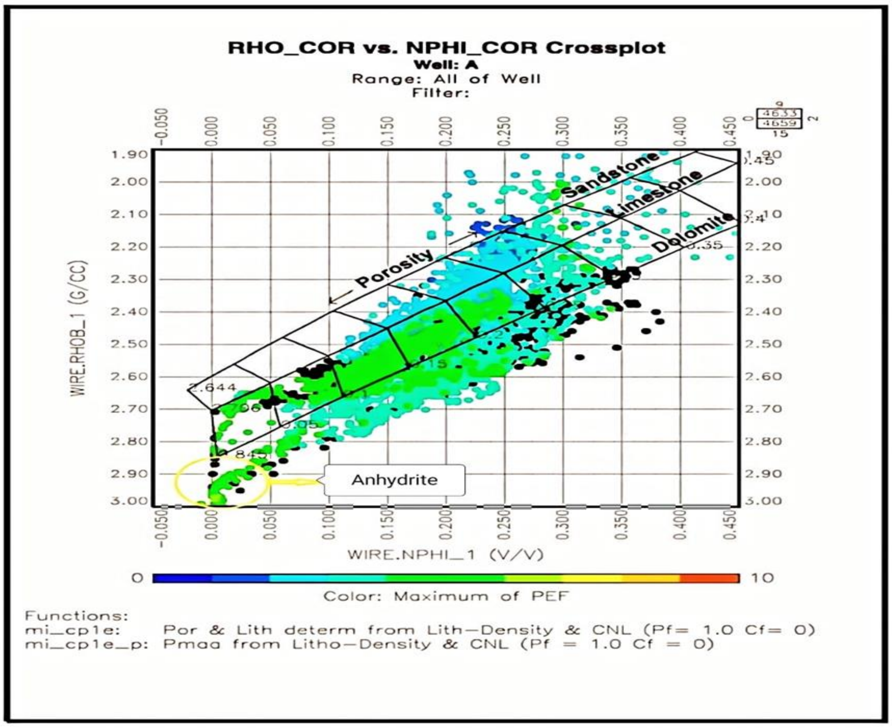

Figure 2

PEF density–neutron cross plot (wellbore # A) according to which the Asmari formation in this well is composed of dolomitic limestone, shaly limestone, and shale.

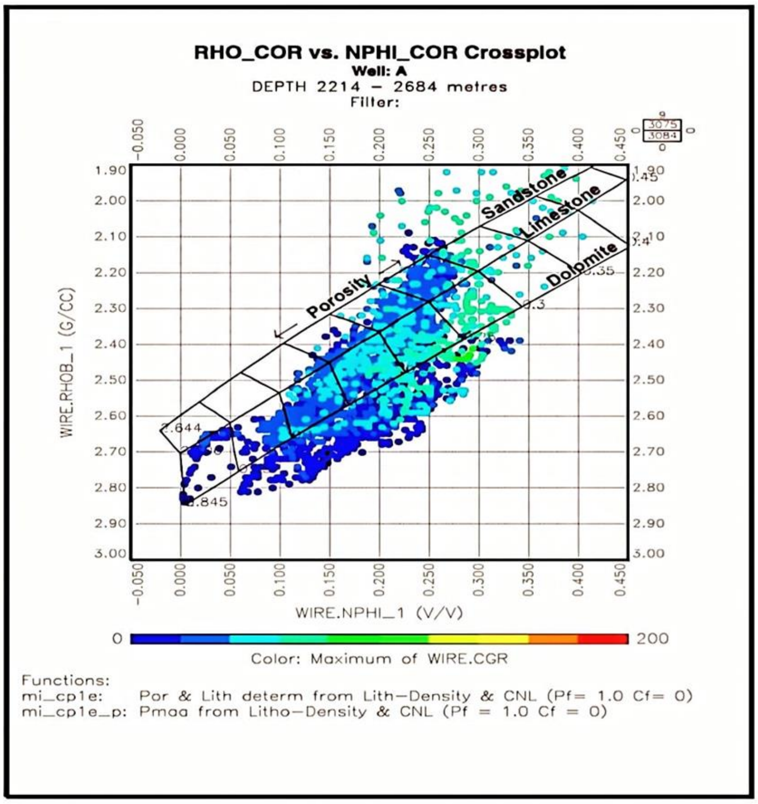

Figure 3

CGR density–neutron cross plot (wellbore #A) according to which gas points are not seen in the formation.

Table 1
The results of petrophysical evaluation in wellbore #A.

Average shale volume (%)	Average water saturation (%)	Average porosity (%)	Depth interval(m)	Studied location	Formation
10	37.2	17.7	2214–2240	Wellbore #A	Asmari
8	22.5	26.3	2240–2265		
11	32	18.9	2265–2300		
9.6	27.2	20.9	2214–2296	Oil zone	

From a depth of 2300 m to the bottom hole of the Asmari formation in this well, the porosity changes were not studied due to the absence of significant hydrocarbon, according to the obtained model. In terms of porosity, high porosity values are seen in many parts of deeper intervals.

f. Results of petrophysical evaluation in wellbore #B

This formation has hydrocarbon potential of oil type, and information about the average porosity and water saturation of the intervals with hydrocarbons is given in Table 2. The depth interval of 2213 to 2280 m, determined in the petrophysical evaluation and according to the obtained model as the oil zone of the Asmari formation in this well, includes thick layers of sand, dolomitic lime, and lime. The oil is distributed in the sand layers. Lime layers with sandstones do not have good reservoir properties due to their low porosity. As can be seen in the obtained model, dolomitic layers and reducing the porosity also decrease the saturation of the hydrocarbon fluid.

Table 2
The results of petrophysical evaluation in wellbore #B.

Average shale volume (%)	Average water saturation (%)	Average porosity (%)	Depth interval (m)	Studied location	Formation
5	15	31	2200–2225	Wellbore #B	Asmari
4	15	32	2225–2250		
8	35	24	2250–2275		
7	30	27	2275–2300		
6	21.25	28.5	2213–2280	Oil zone	

4. Petrophysical study of the Asmari formation in the study field

Petrophysical studies and graph studies indicate that the Asmari reservoir comprises lime, dolomite, sandstone, and shale in this periodic field. Figure 4 shows the percentage of sand, dolomite, lime, and clay in different zones. Moreover, the ratio of effective thickness to total thickness, average porosity, water saturation, and hydrocarbon can be observed for the Asmari reservoir zones in this oil field.

Evaluations show that the zone is one of the highest parts of the Asmari reservoir and consists mainly of dolomitic limestone and calcareous dolomites, limestone, and a layer of Chilean lime. The average porosity of this zone ranges from 17% to 18%, which increases from the west to east of the field, and the percentage of water saturation is 49%. The amount of adequate thickness in this zone varies from less than 1 m to 21 m, and the amount of effective thickness in the central parts of the anticline is more than the edges and nostrils of the anticline. The maximum ratio of the effective thickness to the total thickness of whole zones reaches 0.9 in the northeastern part of the oil field.

In Zone 2, in the carbonate subunit of zone 1, a thickness of siliceous-detrital sediments is observed, mainly composed of sandstone with the interlayers of limestone shale.

The thickness of this zone has been about 30 m, and the ratio of adequate thickness to total thickness in most parts of the field has been calculated. The average effective porosity and water saturation in different field parts are 25% and 10%, respectively. These petrophysical properties indicate that this zone can have outstanding reservoir quality. Further, these reservoir properties are improved from the west to the east of the field so that the maximum effective porosity of this zone in the east of the field reaches 32%.

Zone 3, below zone 2, has an alternation of thick layers of red sand and marl, which on average is about 50 m thick. The average effective porosity is 25%, and water saturation is 65%. The ratio of effective thickness to total in some parts reaches 0.6.

Zone 4 comprises limestone sandstone and sandy limestone with inter-shaly layers. Although the porosity in this zone is more than 20%, the water saturation is very high. In some parts, the percentage of water saturation reaches 90%. This zone is below the water–oil contact, which has led to a net hydrocarbon column and caused the ratio of the effective thickness to the entire zone to be negligible.

5. Identification of lithofacies of the Asmari reservoir in the study area

The Asmari formation, the youngest and most crucial hydrocarbon reservoir in the Middle East, is of great importance in this oilfield with two sections of sandstone and carbonate (Motiei H., 1993).

The sandstone section, which is a continuation of the sandstone section of Ahvaz, is mainly composed of detrital siliceous sediments, quartz grains, calcareous sandstones, and sandy limestone with inter-shaly layers. Sandstones are generally angular to semi-angular and contain calcite cement (Moradi et al., 1394). The method of Pettijohn and Potter (1987) has been used to classify sandstone. Evaluations indicate that the lithofacies of the sandstone section of the Asmari formation in the study field include quartz-arenite, sub-arkose, and sublitharenite (Hosseini-Barzi et al., 2008). In the carbonate part of the Asmari formation, cream-to-brown colored limestone with mountainous morphology are mountainous. The Asmari limestone is the essential reservoir rock in the Zagros sedimentary basin of the Middle East (Esrafili-Dizaji et al., 2011). Dunham classification is used in naming carbonate rocks (Dunham R J., 1962). This limestone has wackestone and packstone textures and sometimes appears as dolomitization. The dolomitization process has mainly affected this formation and caused a change in its porosity. Since the dolomite has more stability and resistance during burial than limestone and retains its permeability and porosity better, it can play a more effective role in increasing the quality of the reservoir (Jardine et al., 1987; Sun, 1995). The dolomites of the Asmari formation in the study field are composed of different types. They are divided into dolomites, dolomicrosparsite, granular dolomites, and dolomitic cement based on the fabric and according to the size distribution of crystals and the shape of the crystal border (flat or non-flat) (see Table 3).

The different diversity of dolomites can reflect the time of formation, origin, or composition of the early limestone (Adabi, 2004; Ado, 2020; Rezaie Faramani et al., 2019; Amirshahrami et al., 2007). The dolomitization process has mainly affected this formation and caused a change in its porosity. The distribution of porosity percentage for each lithofacies is shown in Figure 4.

Table 3
Three lithofacies of the Asmari formation in the studied field.

Lithofacies	Informal name	Age	Lithologies
I	Limestone	Early Oligocene to Early Miocene	Limestone is composed of packstone tissues with intergranular and intercrystalline porosity, wackestone, and sometimes dolomitization (porosity up to 15%).
II	Sandstones	Early to Late Oligocene	Detrital siliceous sediments are mainly from quartz grains, quartzarnite, subarkose, and sublitharnite.
III	Dolomites	Early Miocene	Early and late digenetic dolomites, calcareous dolomitic, dolomicrite, dolomicrisparite, sucrosic dolomite, and dolomite cement

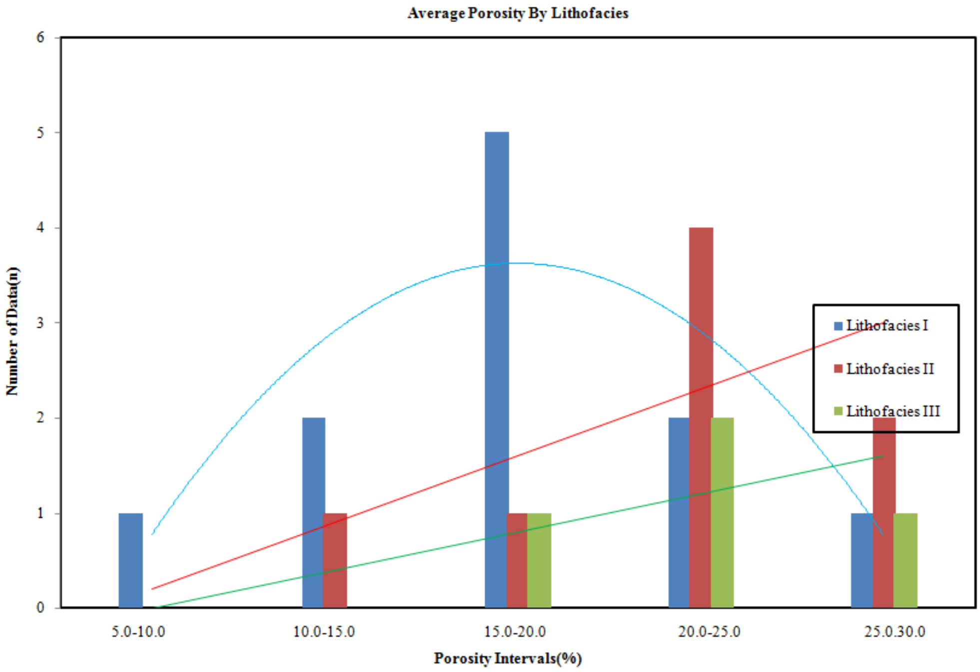

Figure 4
Distribution of porosity percentage for each lithofacies based on statistical data.

Based on the data obtained from petrophysical assessments of the Asmari formation in the study field and study of parameters such as water–oil contact surface, porosity, hydrocarbon saturation, and water saturation, a diagram of adequate total thickness and hydrocarbon column thickness is depicted for each zone in Figure 5.

Finally, the amount of oil in place of the reservoir for each zone was calculated according to the following equation.

$$\mathrm{N} = 7758 \times \left[\frac{V_r \emptyset_e (1 - S_{Wi})}{B_0}\right] \quad (3)$$

where N is oil in place in terms of oil storage barrels (STB), V_r indicates the reservoir rock mass volume in acre-feet (ac-ft), $\emptyset_e$ represents the effective porosity (%), S_{wi} is the primary water saturation (%), and B_o is the volume coefficient of oil formation (Rb/STB).

Table 4 presents the numerical calculations of the oil volume for the studied reservoir in the Asmari formation.

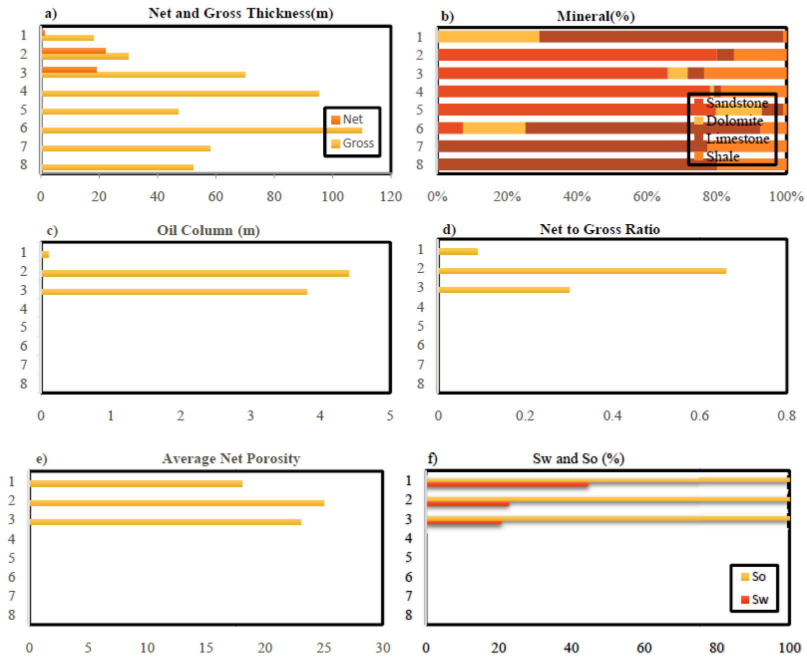

Figure 5

Petrophysical parameters calculated for the Asmari reservoir zones in the study field; vertical axis numbers are related to the number of zones (Alizadeh Pir Zaman, 2005).

Table 4

Numerical calculation of oil volume in the Asmari formation reservoir in the study field.

Producible hydrocarbon volume (barrel)	Hydrocarbon oil in place volume (barrel)	Net porosity volume of total zones (m^3)	The total volume of the effective thickness (m^3)	Total reservoir volume (m^3)	Zone
304.302.752	371.259.128	597.596.955	420.131.419.2	934.248.159.6	**1**
164.283.638.7	200.426.044.9	248.790.019.9	103.016.931.44	122.893.079.17	**2**
554.696.385	676.729.609	918.873.799	475.543.492.3	101.790.090.02	**3**
438.421.0	534.873.6	933.547.2	465.950.56	136.821.111	**4**
250.622.773.3	305.759.792.2	401.370.642.4	1930.503.731.5	319.876.196.27	**Total**

As can be seen, zone 2 has the highest volume of oil in the reservoir and has the best reservoir quality. In terms of water saturation, as we move deeper in the reservoir (from zone 1 to zone 8), the percentage of water saturation increases, indicating the normal state of the reservoir. In addition, the amount of water saturation in the eastern part of the field is less than in other parts of the field. In other words, the quality of the reservoir in the eastern part is better than in other parts of the field. Despite the relatively high porosity percentage, the high water saturation percentage makes the wells drilled in this area not very profitable to the west and northwest of the field.

Figure 6 shows the relationship between the effective thickness, porosity, oil production, and water saturation for four reservoir zones of the Asmari formation in the study field.

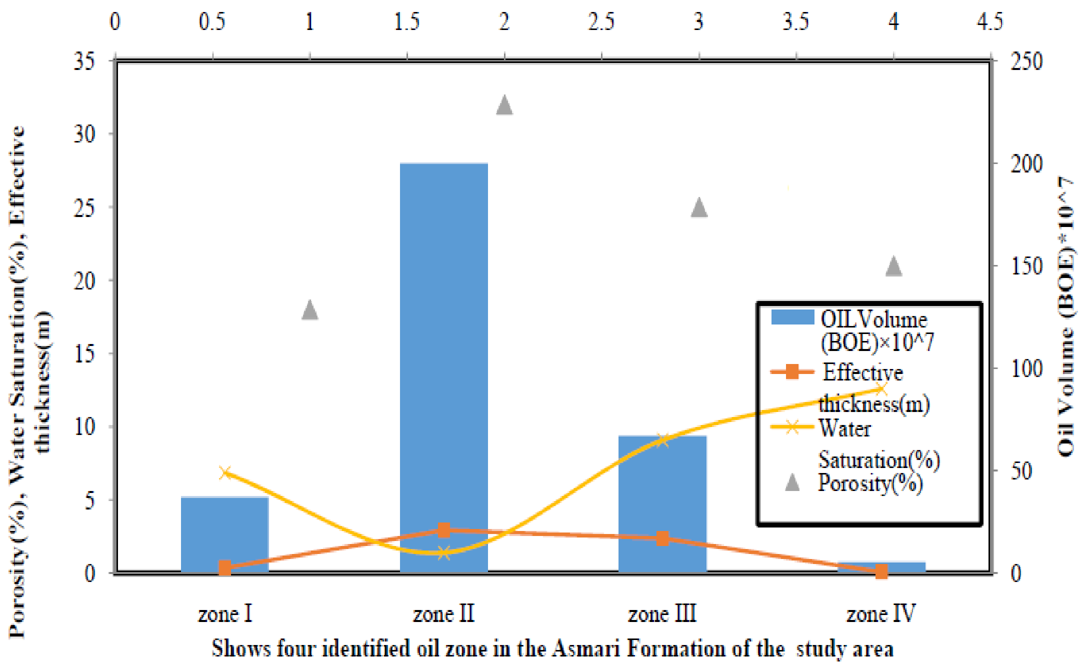

Figure 6
Relationship between the effective thickness, porosity, oil production, and water saturation in zones 1, 2, 3, and 4 in the Asmari reservoir of the study field.

The iso-depth maps for zone 2 are shown in Figure 7 for a closer look.

a) b)

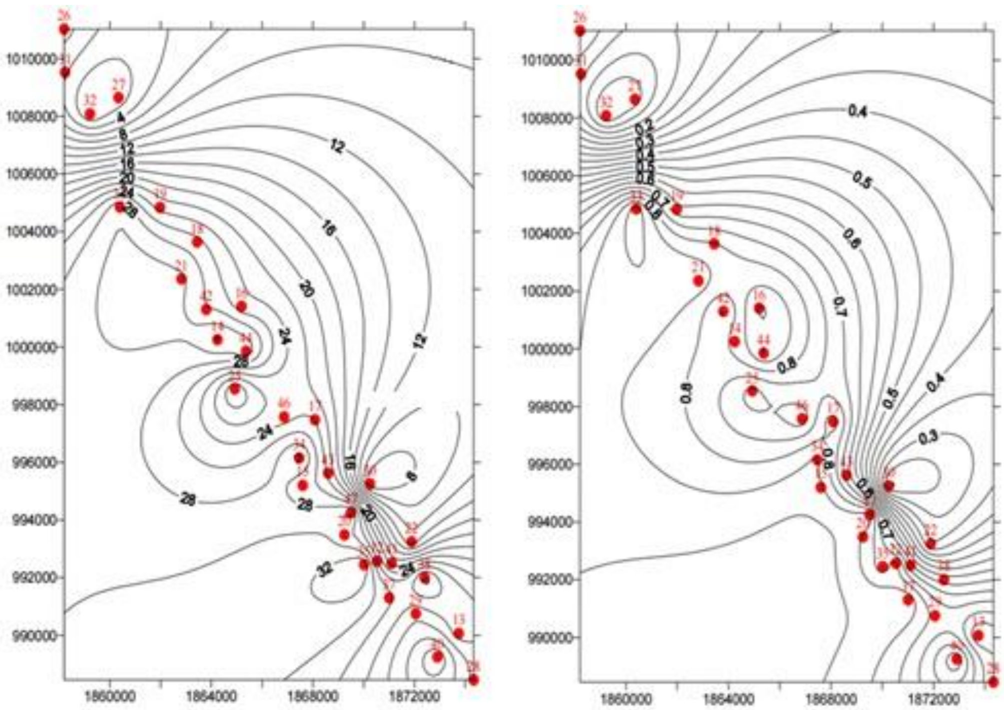

Figure 7
The iso-depth maps of zone 2 of the Asmari reservoir in the study field. a) the adequate thickness of hydrocarbons; b) the ratio of the effective thickness to the total thickness (Alizadeh Pir Zaman, 2005).

The results show that zones 1, 2, and 3 contain hydrocarbons out of these eight zones, and the rest are almost saturated with water. Since zone 2 has the highest effective thickness, this has caused this zone to have the largest oil reserves in the reservoir so that 65% of the oil in the Asmari formation reservoir located in the study field has been allocated to it.

6. Conclusions

Based on the existing petrophysical assessments, the Asmari reservoir in the studied field is divided into eight zones (layers) which differ in their lithological and petrophysical characteristics. Zone 1 is made of carbonate (calcareous and dolomitic), and zones 2–5 are mainly sandstone; zones 7 and 8 are calcareous and shale, and zone 6 is a mixture of all the rocks mentioned above. The Asmari formation oil reserves mainly accumulate in the sandstone layers, while the scattered calcareous layers do not have good reservoir properties. The studied Asmari sandstones are mainly quartz, with few limestone, dolomite, anhydrite, and gypsum grains. Based on our assessments, zones 1–3 have the most desirable porosity. From zone 1 to zone 8, the water saturation increases, which indicates the normal state of the reservoir. Moreover, the water saturation in the eastern part of the field is less than in the other parts. Changes in the percentage of water and oil saturation in the reservoir indicate lithological control of oil distribution. The examination of acoustic diagrams shows that the cementation situation in the western areas of the Asmari reservoir is the best. The analysis of practical thickness diagrams, the study of oil column in the studied field, and the numerical calculation of in situ oil volume show that zone 2 has 65% of oil volume in this reservoir. With more than 80% sand, this zone has the highest net hydrocarbon column.

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Nomenclature

B_o	Volume coefficient of oil formation (Rb/STB)
BHC	Bore hole compensated: The sonic tool measured the time required for a compressional sound wave to travel through one foot of formation. The sonic transit time can compute porosity using the appropriate transform and estimate fracture porosity in carbonates.
BOE	Barrels of oil equivalent
CGR	Computed gamma-ray (SGR minus uranium contribution)
DLL	Dual laterolog: providing two resistivity measurements with different depths of the investigation into the formation: deep (LLd) and shallow (LLs)
f_p	Arithmetic mean porosity
h_i	Thickness of the *i*th volume zone
LDT	Litho-density log: a new form of the formation density log with added features. It is typified by Schlumberger's litho-density tool (LDT). These tools have a cesium-137 source emitting gamma rays at 0.662 MeV and a short-spaced and a long-spaced detector in the same way as the essential formation density tool.
MSFL	A measurement of the flushed zone resistivity (Rxo)
N	Oil in place in terms of oil storage barrels (STB)

S_{wi}	Primary water saturation (%)
S_w	Water saturation of the zone
V	The total volume of the reservoir
V_p	The permeable volume of the reservoir
Vr	Reservoir rock mass volume in acre-feet (ac-ft)
$\tilde{f}$	Productive porosity of the reservoir
$\tilde{S}w$	Average water saturation of the reservoir
$\emptyset_i$	The porosity of the *i*th zone
$\emptyset$	Effective porosity (%)

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