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Study of hydraulic flow units using static modeling in upper Surmeh Formation (Arab) in one oil field in south of Iran

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Abstract

This study investigated the spatial distribution of an oil field's petrophysical parameters, including porosity and permeability, by determining and identifying the hydraulic flow units. By identifying hydraulic flow units as well as rock types and investigating the distribution of porosity and permeability variables, good quality and suitable areas of reservoir could be classified. Permeability relationships are noteworthy since they can be used to identify flow units for evaluation of reservoir quality. Therefore, in the present study, using results from six wells from the upper Surmeh formation in the subject oilfield, a 3D static model of a reservoir was developed. This was carried out after determining the Hydraulic Flow Units (HFU) by the probability diagram of the normal logarithm of Flow Zone Indicators (FZI) (based on the continuous variable of FZI). The Sequential Index Simulation (SIS) method was used for model development. As the result of this study and under the developed model, the probable distribution of these parameters for each cell in the reservoir were calculated, considering mean permeability and porosity. Different areas in the field with respect to reservoir quality were also determined, even for areas in which there was no sufficient core data. In summary, the HFU3 and HFU4 have the best reservoir quality, while the HFU1 and HFU5 have the lowest reservoir quality. This is of the most important issues for reservoir optimum production planning. The study provides deep understanding of how HFUs are spread. In addition, the results of this study can be used for the development of a dynamic model.

Keywords: Flow zone indicator; hydraulic flow units; sequential index simulation; static model.

1. Introduction

One of the important goals of hydrocarbon reservoir studies is the improvement of reservoir description and evaluation methods. Porosity and permeability are considered the most important parameter for describing a reservoir. Porosity and permeability relationships in heterogeneous hydrocarbon reservoirs have high dispersion and may show no correlation. Determination of Hydraulic Flow Units (HFU) based on permeability-porosity for reservoir zoning is a useful method for evaluating and describing hydrocarbon reservoirs. Determining these variable by conventional methods is difficult for a number of reasons. First is time and cost issues. Second, there are only a small number of wells. Third is a lack of sufficient cores. Finally, there is the problem of the alteration of rock along with the heterogeneity of the reservoir rock. Therefore, geologists and hydrocarbon reservoir engineers seek improved methods for estimating the spatial distribution of petrophysical parameters in the reservoir space (Amaefule *et al*., 1993; Ohen *et al*., 1995; Abbaszadeh *et al*., 1996; Al-Ajmi & Holditch, 2000; Svirsky *et al*., 2004; Jiang Xiang, 2006; Osorio, 2009; Tan Xuequan, 2013; Skalinski & Kenter, 2014). Recently with the advancement of new geostatistic methods (such as 3D modeling techniques for petrophysical properties combined with the development and extensive use of software packages such as Petrel and RMS), essential steps are taken to provide more accurate pictures of reservior behaviors. Using these models, different shapes of hydrocarbon fields are made. That includes the distribution of petrophysical properties in three dimensions, which can be used to study reservoir properties and factors that decrease or increase the quality of the reservoir more accurately.

2. Regional geology

The studied reservoir is located in a basin which is the world's richest region in terms of hydrocarbon resources, comprising approximately 57% of the world's oil and 45% of the world's gas reserves (Rabbani, 2013). The basin is located at the boundary of two separate plates for Eurasia and Saudi Arabia at the Mesozoic/Cenozoic boundary. This juncture produced the Zagros Fold Belt and the large Mesopotamian Foredeep (Konyuhov & Maleki, 2005).

During the Jurassic and most of the Cretaceous Periods, deposition in the south of Iran was characterized by platform carbonates. The history of these platforms is importance because of the remarkable richness of hydrocarbon in these horizons. The massive carbonate and dolomite of the Lower to Upper Surmeh Formation can be considered a source rock in the Basin. They also act as reservoir rocks in some parts. Hith evaporates, very effective seals, are the last major cycle of the Upper Jurassic in the basin. They have gradational contact with the underlying Surmeh Formation (Rabbani, 2013; Bordenave, 2014).

The Upper Surmeh Formation, which forms an important petroleum reservoir in a number of giant oil fields in south of Iran, is a classic carbonate sequence. It contains significant hydrocarbon deposits. This upper part, equivalent to Arab Formation in Arab countries with huge oil reservoirs, is an important exploratory formation, (Rabbani, 2013).

The Arab Formation is divided into two sections: the upper and lower Arab. These are then divided into several sub-sections. The upper part of the Arab Formation consists of brown dolomite with white and clear anhydrite. It is divided into nine layers of oil, namely U1, U2, U2-A, U3, U4, U5, U6, U7 and U8 (Amirkafee, 2014), (Figure 1).

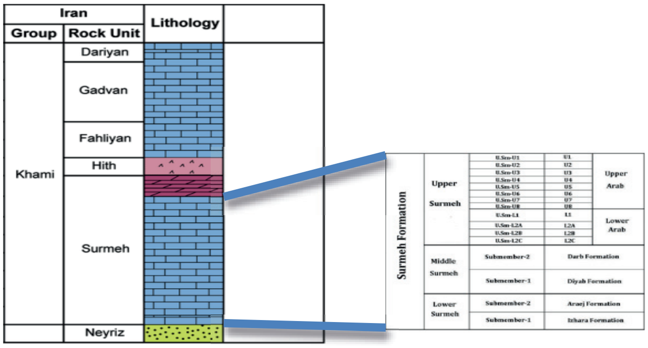


Fig. 1. Surmeh Formation distribution during Jurassic in Iran.

3. Methodology

3.1 Data and study method

The hydraulic flow units and discrete rock typing of the reservoir were determined using the results of core samples in terms of porosity and permeability of six wells. With the probability of normal occurrence of the flow zone indicator, hydraulic flow units and rock types were specified. Using geostatistic methods, the distribution of these petrophysical parameters was investigated by applying the software in three dimensions.

3.2 Hydraulic flow units

Understanding and recognizing flow units is a very important issue in the modeling and simulation of hydrocarbon reservoirs. Hydraulic flow units have the following characteristics (See the definition from Ebanks, 1987; Ameafule *et al*., 1993; Abbaszadeh *et al*., 1996; Gunter, *et al*., 1997; Tiab & Donaldson, (2012):

1- Hydraulic flow units are the volume of reservoir rock in which the geological and petrophysical properties affecting the flow of the fluid are the same.

2- A hydraulic flow unit is sequentially dependent, map-able and is predictably different from the other volume of the reservoir rock.

3- A hydraulic flow unit is a volume of reservoir rock that is vertically and laterally continuous and predictable.

4- Zoning of a hydraulic flow unit is recognizable on well logs.

Hydraulic flow units are related to geological distribution, but they do not necessarily follow the boundaries of the facies. Therefore, hydraulic flow units may not be vertically continuous (Abbaszadeh *et al*., 1996).

The basis of hydraulic flow units is porosity and permeability. Permeability not only depends on porosity. It also depends on factors such as free space geometry, grain size dispersion, specific surface area, spatial coefficient, fluid saturation, etc.. Each flow unit is characterized by a flow zone indicator (FZI) as per the following formula (Ameafule *et al*., 1993; Osorio, 2009):

$$\mathrm{FZI} = \frac{\mathrm{RQI}}{\varphi_z}\,, \tag{1}$$

where, RQI (Reservoir Quality Index) is:

$$\mathrm{RQI} = 0.0314\sqrt{\frac{\mathrm{k}}{\varphi}}\ . \qquad (2)$$

k is permeability in md (*millidarcy)*, and φ is the fractional porosity. φ_z (the normalized porosity index) is:

$$\varphi_z = \frac{\varphi}{1-\varphi} \qquad (3)$$

The porosity, permeability relationship on the plot can be uniquely defined for each hydraulic unit (Kadkhodaie & Amini, 2009).

Hydraulic flow units are related to geological distribution, but they do not necessarily follow the boundaries of the facies. Thus, hydraulic flow units may not be continuous vertically (Abbaszadeh *et al*., 1996).

3.3 3D modeling of hydraulic flow units

Geomodeling is refers to the process of making a mathematical model of the Earth's layers. Since the final result of the geological model is the formation of a 3D volume of the reservoir building, which is usually of a fixed shape and does not change over time, it is also referred to as static model. There is also the reservoir model based on how the fluid flows inside the reservoir over time through its production period. This is known as the dynamic model (Aminzadeh *et al*., 2013).

There are different methods for 3D modeling of the reservoir. In each of these methods, geological information is combined with statistics. Several software programs are also employed to model reservoir properties (Aminzadeh *et al*., 2013)., Geostatistics is a powerful tool in modeling (Deutsch, 2002).

Geostatistics is based on the variogram. Applied modeling based on the variogram is divided into two main categories. The first group is Deterministic Models, definite models that include estimating methods such as kriging, and so on. In these estimation methods, a model is obtained for each variography.

The second group is Stochastic Models. The basis of these models is simulation methods. In simulation methods, several models are obtained with a variogram (Dubrule, 2003). In Stochastic modeling, various realizations are performed to determine the possible range of results for the model's suitability. This type of modeling can also include a wide range of data. Some examples are petrophysical and seismic data for generating various realizations (Soleimani & Jodeiri, 2015).

With the use of geostatistics methods, extracted data from cores, well-shaped and seismic diagrams can be optimally integrated to build the static model of the reservoir (Deutsch, 2002).

New geostatistics methods (i.e., 3D-modeling methods of petrophysical properties) are presented in the form of various software packages such as Petrel and RMS. The software enables a more precise study of hydrocarbon reservoirs.

Using these methods, different shapes of hydrocarbon fields can be constructed. From them, the distribution of petrophysical properties in three dimensions can be referred and then used for a precise study of factors. This reduces or increases the quality of the reservoir (Payamani *et al*., 2013).

In this study, one of the most popular software tools in the upstream of oil fields, PETREL (2009), has been used. Three-dimensional modeling of the geology was done as follows:

- Definition of the model (Define Model) as the first stage of construction modeling.
- Pillar Gridding: At this stage, the grid dimensions (x,y) and the upper and lower bounds of the range are specified.
- Making Horizons: Define the up and down horizons for the construction of the model. In this study, the upper and lower Arabs are these horizons.
- Layering: According to the average thickness of each zone, the number of layers of each zone is determined (Figure 2).

Three-dimensional modeling of hydraulic flow units can be performed by using the output of variogram stage. To simulate discrete variables, the sequential simulation method is employed (Sequential Indicator Simulation or SIS method) because it is simple and flexible,. One feature of the SIS method is that it maintains the distribution of data after initial modeling in the initial distribution of data, which is more consistent with reality.

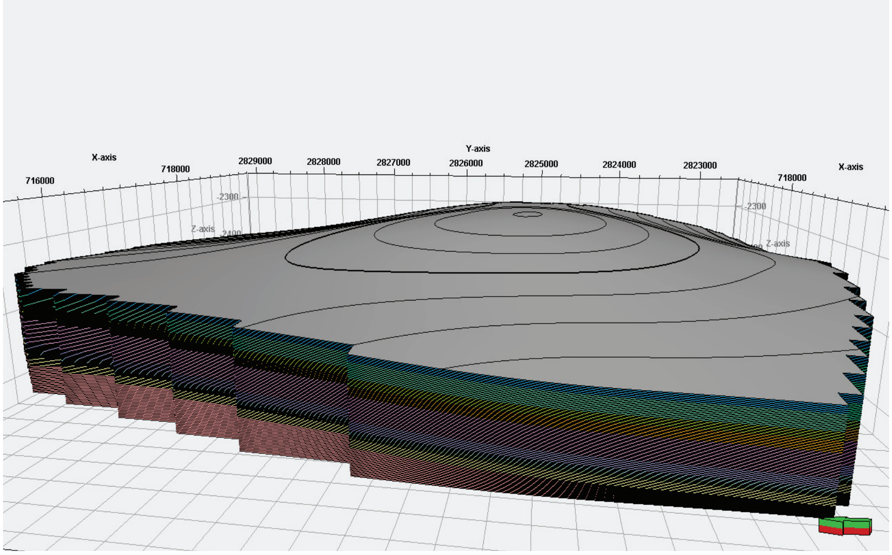


Fig. 2. Horizons and layering of the reservoir studied.

4. Result and discussions

For determining the hydraulic flow units, a normal logarithmic diagram was used to designate the flow zone calculated for porosity and permeability data for the six reservoirs' wells. By specifying the fracture points, measured as the boundaries of hydraulic flow units, five hydraulic flow units were identified (Figure 3). Porosity and Permeability cross-plots for these hydraulic flow units are shown in Figure 4.

The values of the flow zone indicator for each of the hydraulic flow units are shown in Table 1.

Table 1. Flow Zone Indicator Value

HFU	Log (FZI)
HFU1	Log FZI<-0.28
HFU2	-0.28<Log FZI<0.08
HFU3	0.08<Log FZI<0.41
HFU4	041<Log FZI<1.500
HFU5	Log FZI>1.500

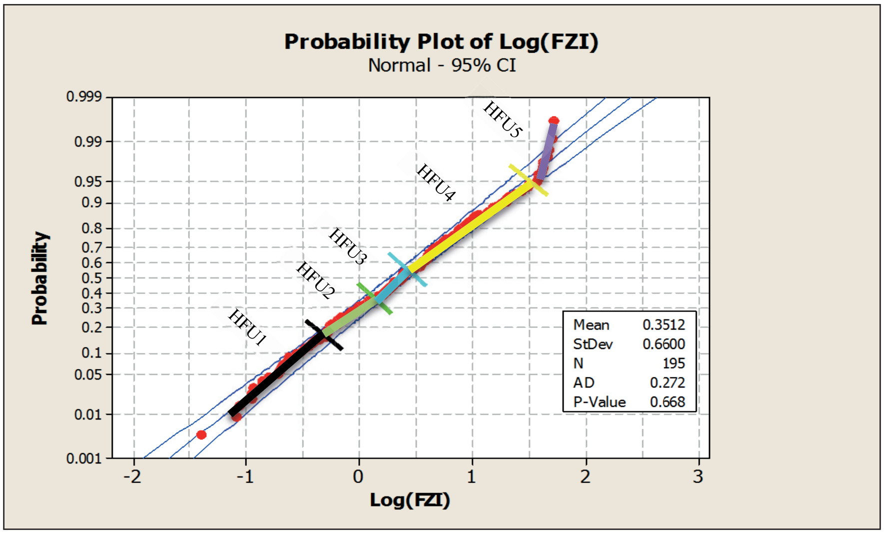


Fig. 3. Normal probability chart shows current flow and separation of hydraulic units.

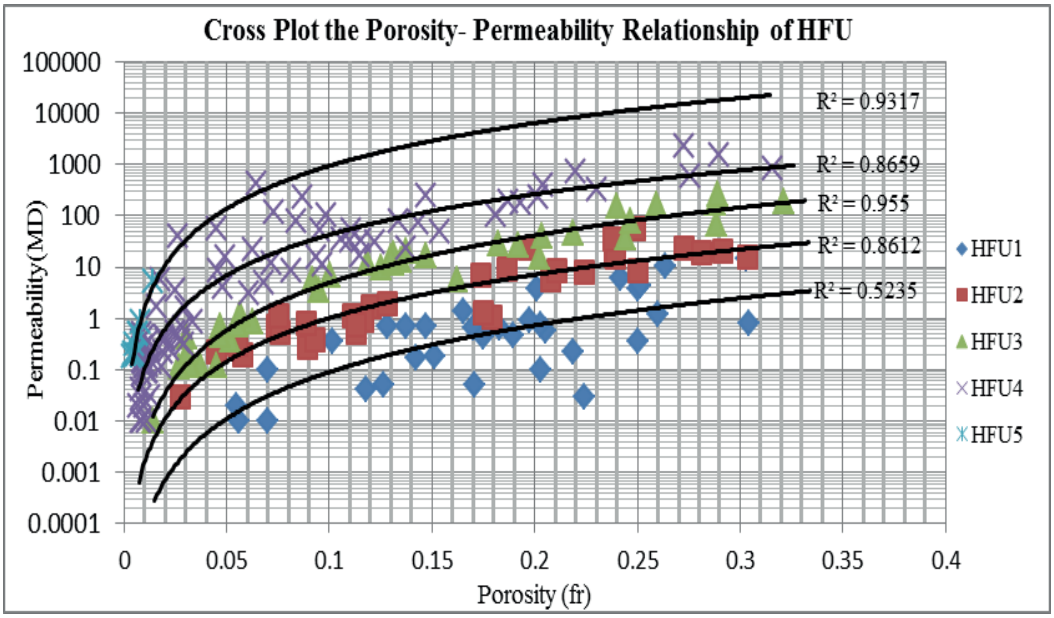


Fig. 4. Permeability-porosity distribution diagram for five current units related to the upper reservoir.

Figure 3 shows the division of the hydraulic flow units of the Upper Surmeh Formation. Five systems with different petrophysical properties having a strong relationship between porosity and permeability are recognized. Each of the hydraulic flow units has a good correlation coefficient.

After designing the reservoir structure model, the calculated parameters of hydraulic flow units (HFU), reservoir quality index (RQI) and flow zone index (FZI) were introduced (Figure 5). To do this, information about these parameters in the form of discrete data was used. Important to note it that petrophysical data, obtained in the form of a data log during drilling of the wells, were averaged in correspondence with the dimensions of the cells defined in the reservoir. Therefore, for each cell, a unique number of different parameters can be considered. For determining the averages, arithmetic method was used.

By performing the above (zones as per Table 2), The results for calculations are presented in Figure 6. It shall be mentioned that the distribution of flow units (HFUs) can be separately considered in each zone (Figure 7).

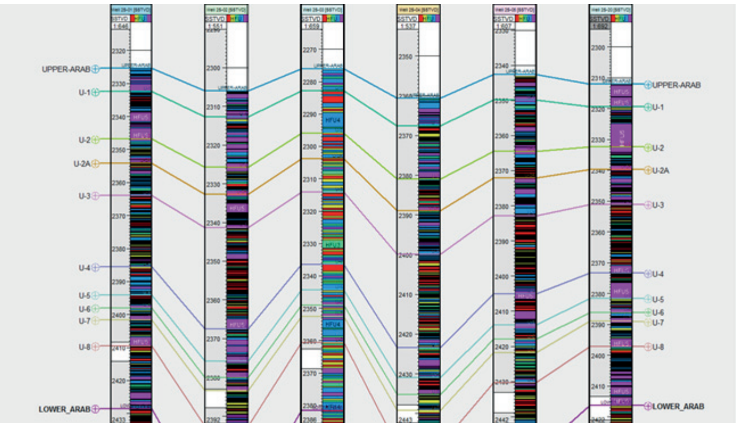


Fig. 5. Distribution of hydraulic flow units in the reservoir wells.

Table 2. Zones in the subject reservoir.

Zone	Formation
Zone 1	Upper Arab – U1
Zone 2	U1 – U2
Zone 3	U2 - U2A
Zone 4	U2A – U3
Zone 5	U3 – U4
Zone 6	U4 – U5
Zone 7	U5 – U6
Zone 8	U6 – U7
Zone 9	U7 – U8
Zone 10	U8 – Lower Arab

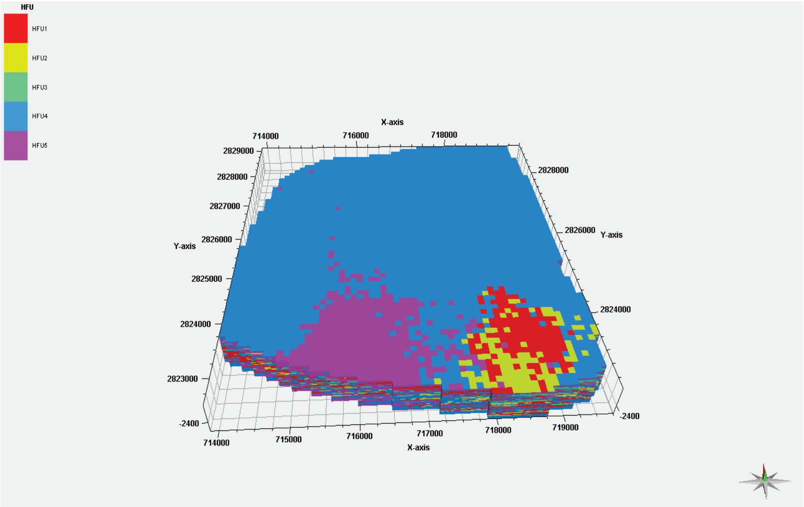
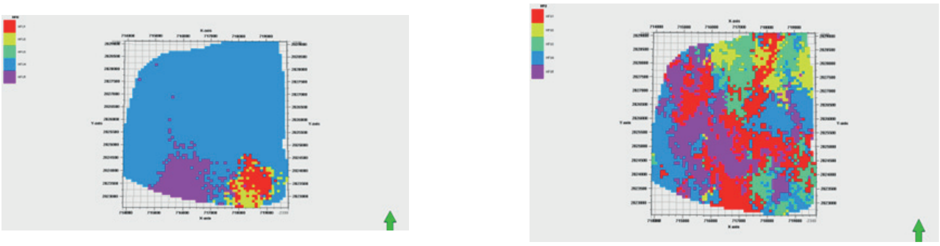
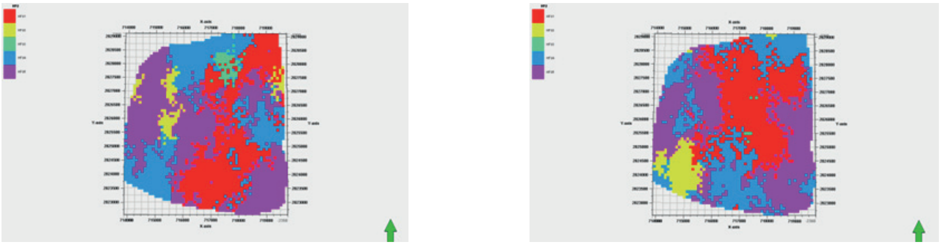


Fig. 6. Three-dimensional model of hydraulic flow units (HFU) in the reservoir studied.



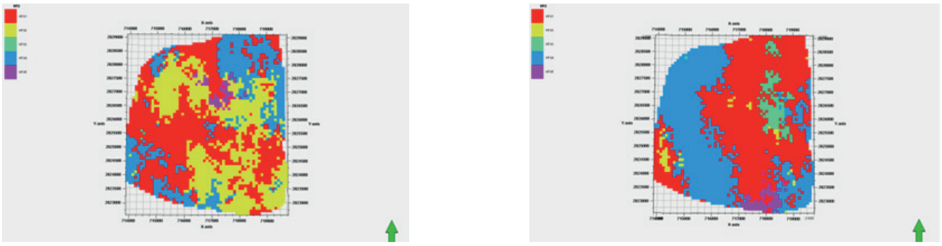
Zone 1

Zone 2



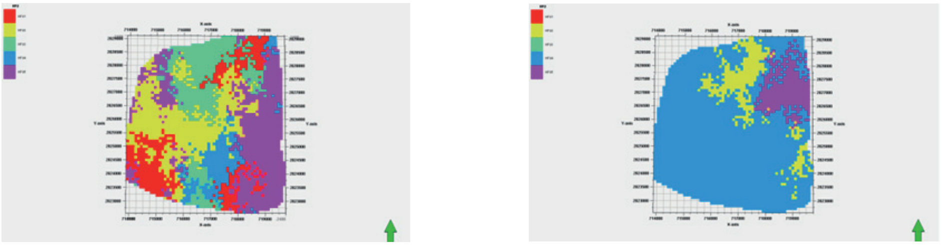
Zone 3

Zone 4



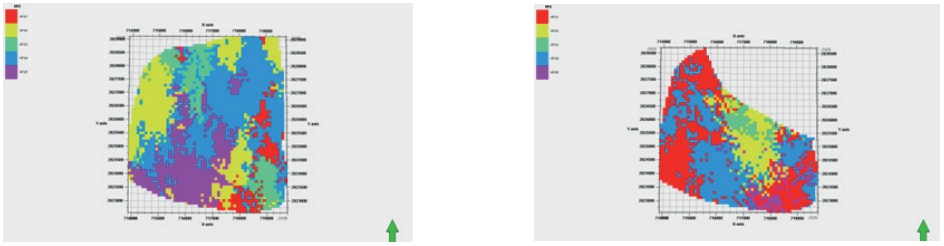
Zone 5

Zone 6



Zone 7

Zone 8



Zone 9

Zone 10

Fig. 7. Three-dimensional model of hydraulic flow units (HFU) in each zone separately (zone1 to zone10).

It is important to note that different facies can be seen inside a hydraulic flow unit because the diagnosis processes sometimes have such an effect on the hydrocarbon reservoir that a facies can exhibit any porosity and permeability (Kadkhodaie & Amini, 2009). In other words, separated hydraulic flow units, more than dependent on sedimentary facies, depend on reservoir potential based on porosity and permeability data (Noorian, *et al*., 2015).

Additionally, according to the average permeability and porosity obtained for each hydraulic flow unit (Table 3), it can be said that the HFU3 and HFU4 flow units have the best reservoir quality and the HFU1 and HFU5 flow units have the lowest reservoir quality.

Table 3. Permeation and porosity average for five units of hydraulic flow.

HFU	Log(FZI)	Perm(mD)	Porosity (%)
HFU1	Log (FZI) <-0.28	4.607	14.436
HFU2	-0.28 < Log (FZI) < 0.08	10.650	10.159
HFU3	0.08 < Log (FZI) < 0.41	17.381	10.379
HFU4	0.41 < Log (FZI) < 1.500	54.610	6.636
HFU5	Log (FZI) > 1.500	17.921	0.447

5. Conclusion

In this research three-dimensional modeling of the reservoir by using geostatistical methods, of the most efficient methods to describe the reservoir due the possibility of creating multiple realization of the reservoir in which heterogeneities and range of variations of variables are well represented, is done. Hydraulic flow units are powerful tools for separating reservoir segments from non-reservoir ones at different depth. Using the flow zone indicators (FZI), and by plotting a normal probability chart for the logarithm of FZI, five hydraulic flow units were detected. The model, which was constructed by sequential simulation methods with high accuracy, shows the distribution of hydraulic flow units in the reservoir. Understanding the distribution of hydraulic flow units in a reservoir can be useful in separating the reservoir into different units with different reservoir qualities and conditions. Finally, considering the mean permeability and porosity, it can be said that HFU3 and HFU4 have the best reservoir quality, whereas the HFU1 and HFU5 have the lowest reservoir quality.

To summarize, the data show the

- distribution of HFUs in the reservoir
- distribution of HFUs in each reservoir zone, and
- estimation of reservoir properties in areas that there is no sufficient core data.

These finding are the most important issues regarding optimum production planning and for providinga deeper understanding of how HFUs are spread. In addition, they can be used to construct a dynamic model for reservoir zoning in terms of reservoir quality and potential. Lastly, using the constructed models, the average yield for each reservoir variable can be determined by the superior reservoir area in the field.

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دراسة وحدات التدفق الهيدروليكي باستخدام النمذجة الساكنة في تكوين Surmeh العلوي (العربي) في أحد حقول النفط، في جنوب إيران

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الملخص

الغرض الرئيسي من هذه الدراسة هو تحديد التوزيع المكاني لمعلمات الحقل البتروفيزيائية، بما في ذلك المسامية والنفاذية عن طريق تحديد وتعريف وحدات التدفق الهيدروليكي. فمن خلال تحديد وحدات التدفق الهيدروليكي وكذلك أنواع الصخور ودراسة توزيع متغيرات المسامية والنفاذية، يمكن تصنيف مناطق ذات جودة عالية ومناسبة للمكمن. وتجدر الإشارة إلى أنه يمكن استخدام العلاقة بين المسامية والنفاذية لتحديد وحدات التدفق لتقييم جودة المكامن. لذلك في هذه الدراسة، وبعد تحديد وحدات التدفق الهيدروليكي (HFU) من خلال مخطط الاحتمال للوغاريتم الطبيعي لمؤشرات منطقة التدفق (FZI)، استناداً إلى المتغير المستمر لـ FZI، واستخدام نتائج ستة آبار من تكوين Surmeh العلوي في حقل النفط المعني، تم تطوير نموذج ثابت ثلاثي الأبعاد للخزان. أثناء تطوير هذا النموذج، تم استخدام طريقة محاكاة الفهرس المتسلسل (SIS). نتيجة لهذه الدراسة ووفقاً للنموذج المُطوّر، تم حساب التوزيع المُحتمل لهذه المعلمات لكل خلية في المكمن، ومع مراعاة متوسط النفاذية والمسامية، تم تحديد مساحات مختلفة في الحقل تتعلق بجودة المكمن، حتى بالنسبة لتلك المناطق التي لا تتوفر عنها بيانات أساسية كافية. وباختصار، يمكن القول أن HFU3 و HFU4 تتمتعان بأفضل جودة للمكمن وأن HFU1 و HFU5 لديهما أدنى جودة للمكمن. وهذا يُعتبر من أهم القضايا لتخطيط الإنتاج الأمثل للمكمن في حين أن نتيجة هذه الدراسة توفر فهماً عميقاً لكيفية انتشار HFUs. كذلك يمكن استخدام نتيجة هذه الدراسة لتطوير نموذج ديناميكي أو أنشطة مماثلة.