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Hydraulic flow units, depositional facies and pore type of Kangan and Dalan Formations, South Pars Gas Field, Iran

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ABSTRACT

It is highly essential to characterize the reservoir as rigorously as possible to implement enhanced oil recovery operations and field development scenarios. In this scope, use of novel concepts and techniques for classification of reservoir rocks and definition of producing and non-producing zones will be greatly helpful. In the current research, hierarchical clustering is employed to characterize hydraulic flow units of four wells of South Pars Gas Field using core data. Studying the clustering tree, also known as dendrogram, it is proved that six is the optimal number of flow units for reservoir zonation. Cross plot of porosity versus permeability for each flow unit shows high cross correlation value, which confirmed the accuracy of employed technique for grouping the FZI data. The available core data were studied to identify the possible microfacies. Ten micofacies are distinguished including massive to laminated anhydrite, evaporite bearing fenestral dolomudstone, pellet grainstone, pellet wackestone to packstone, bioclastic wackestone to packstone/mudstone, bioclastic wackestone to mudstone, bioclastic ooid grainstone, ooid grainstone, intraclastic grainstone, and thrombolite boundstone. The frequency of each facies for each hydraulic flow units was investigated. The results indicate that presence of anhydrate severely reduced reservoir quality. According to thin section and core slab analyses results, high quality flow units mainly consist of bioclastic ooid grainstone, ooid grainstone, and intraclastic grainstone and thrombolite boundstone, which are associated with shoal facies. Finally, thin section and scanning electron microscope (SEM) analysis was done to recognize pore types of each flow unit.

1. Introduction

Hydrocarbon production from oil and gas reservoirs and also the volume of the fluid contained in the pore spaces depend on reservoir rock characteristics. Therefore, extensive studies have been carried out since the last few decades on better characterization and recognition of carbonate reservoir rocks which have an intricate environment with heterogeneous reservoir properties. The respective studies have been aimed at devising more suitable enhanced oil recovery methods and reducing production costs.

Archie (1952) studied the carbonate rocks based on rock texture features and analyzed the size of pore spaces of rocks in terms of their genesis and depositional environment conditions. Lucia (1983) estimated the reservoir properties by apparent description of carbonate rocks and classified the pore spaces. Numerous research works have been done concerning diagenetic environments in carbonate rocks and also factors such as rock texture identification, effective porosity value, diameter of interstitial pathways (pore throats), and distribution and scatter of porosity values as well as capillary pressure curves in carbonate formations for comparison and categorization of facies (Moore, 1989; Longman, 1982; Kopaska-Merkel and Friedman, 1989).

In most cases, the conventional zonation methods using geological data and even the common petrophysical zonation techniques are not capable of providing a realistic image of varying and heterogeneous conditions of the reservoir. Accordingly, more meticulous zonation is needed with taking into account the fluid production conditions for better understanding of reservoir with regard to hydrocarbon recovery. Deployment of such HFU technique for reservoir zonation leads to division of rock unit into different zones based on the parameters affecting fluid flow, which is a significant factor in comparison of different zones in terms of reservoir properties. This method is superior to geological and

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facies-based classifications which merely consider the rock fabric. In addition to reservoir zonation, the hydraulic flow units can be also used for predicting permeability in different points along the well where cores are unavailable or the data quality is not favorable. Amaefule et al. (1994) used a hydraulic (flow) units-based approach for predicting formation damage in uncored interval. Ohen et al. (1995) determined petrophysical properties from NMR relaxation measurements using a hydraulic (flow) unit based model. For these reasons, great deal of attention have been devoted to the concept of hydraulic flow units during the recent years and the technique has been applied as one of most common tools in reservoir characterization and zonation.

Relatively similar definitions have been proposed for flow units, all of which are based on reservoir rock classification in terms of geological and petrophysical parameters.

Bear (1972) defined the hydraulic flow unit as representing a volume of the rock in which the petrophysical and geological properties of the rock are the same. Based on the definition offered by Hearn et al. (1984) hydraulic flow unit is a vertically and laterally continuous part of reservoir zone where porosity, permeability and bedding characteristics are the same. Ebanks (1987) defined hydraulic flow units represent the zones of the reservoir rock that can be mapped and correlated and have constant petrophysical and geological properties affecting the fluid flow; these zones or units are predictably different from other parts of the reservoir rock. Amaefule et al. (1993) and Abbaszadeh et al. (1996) proposed definitions nearly analogous to Ebanks' definition and defined hydraulic flow unit as a representable initial volume of the whole reservoir rock in which geological and petrophysical properties affecting fluid flow are constant and predictable with respect to the rest of rock volume. In Gunter et al.'s definition (1997), flow unit is a stratigraphically continuous thickness in which the reservoir and diagenetic processes are similar. As a result, the geological frame and rock type is the same in the respective thickness. Flow units can be also mapped and correlated in the inter-well space. A flow unit might consist of one or several reservoir or non-reservoir lithologies. Also, reservoir and non-reservoir fluids may exist in a single flow unit (Slatt, 2006). In fact, rock-typing based on flow unit is independent of fluid type and is made solely as a function of characteristics of fluid flow through the rock sample.

Several studies have been conducted on the HFUs and facies in South Pars Gas Field. Ghiasi-Freez et al. (2012) used committee machines based on intelligent models to make a quantitative formulation between flow units and conventional log responses. Aghchelou et al. (2012) used multi-resolution graph-based clustering technique to determine lithofacies based on well log data. Insalaco et al. (2006) analyzed outcrop and subsurface data for identification of the depositional facies of Upper Dalan Member and Kangan Formation. Mardani et al. (2013) defined NMR facies for Kangan/Dalan carbonate formation using core/log and pore-scale measurements. All of these studies have focused either on identification of facies of South Pars reservoir formations or on determination hydraulic flow units of this huge reservoir. As mentioned above some studies investigate the methods for prediction of facies or hydraulic flow units using well logs. In the current study, after determining of the hydraulic flow units and core facies the results are integrated and analyzed to examine the frequency of each facies in each flow units. This work gives many valuable information about this heterogeneous reservoir.

In the present study, concept of hydraulic flow is first presented in terms of reservoir quality index (RQI) and flow zone indicator (FZI). Subsequently, the techniques of determining flow units including graphical methods (histogram, and probability plot) and hierarchical clustering will be discussed, and, the best option will be selected for clustering the flow units in four wells of Iran's South Pars Gas Filed via comparing the cophenetic coefficients between distance and linkage functions. To assess the quality of clustering and optimal number of clusters, permeability in each flow unit will be estimated using the mean FZI value corresponding to the flow unit. Ultimately, reservoir quality will be studied through comparison and correlation of flow units to geological facies acquired from analyses of thin sections, scanning electron microscope (SEM) images, and core slabs.

2. Concept of flow units

Amaefule et al. (1993) introduced reservoir quality index (RQI) using Kozeny–Carman formula, in which factors like pore and throat size, pore and grain size distributions and other microscopic parameters are involved. Dividing sides of Kozeny–Carman equation by porosity and taking square root of both sides, the following equality will be obtained:

$$\sqrt{\frac{k}{\varphi}} = \frac{1}{s_{Vgr}\sqrt{K_T}}\left(\frac{\varphi_e}{1-\varphi_e}\right) \tag{1}$$

where (k) is the permeability in μm^2, (ϕ) is the total porosity in fraction, (ϕ_e) is the effective porosity in fraction, (S_{Vgr}) is the specific surface area of the grain in μm^{-1} and (K_T) is Kozeny constant.

If permeability and porosity are respectively expressed in mildarcy (mD) and fraction, then:

$$RQI = 0.0314\sqrt{\frac{k}{\varphi_e}} \tag{2}$$

Using the above equation, reservoir quality index (RQI) is derived in micrometers.

Each hydraulic flow unit is represented by a flow zone indicator (FZI) (Abbaszadeh et al., 1996). The points with similar FZI are placed in the same flow unit. FZI, which is in fact the factor determining the flow units, do not necessary depend on facies and different facies can be located in a single hydraulic flow unit.

FZI value is defined via the following equation:

$$FZI = \frac{1}{s_{Vgr}\sqrt{K_T}} \tag{3}$$

Equation (2) can be written as:

$$RQI = FZI(\varphi_z) \tag{4}$$

where; φ_z (normalized porosity) denotes ratio of the pore space volume to the grain volume:

$$\varphi_z = \frac{\varphi_e}{1-\varphi_e} \tag{5}$$

Taking logarithms from each side of Equation (4):

$$\log(RQI) = \log(\varphi_z) + \log(FZI) \tag{6}$$

This equation indicates that a straight line with unity slope will be achieved by plotting log (RQI) versus log (φ_z). The RQI value would equal the FZI value at $\varphi_z = 1$ (y-intercept of the line). As observed in Fig. 1, samples with different FZI values will lie on other lines parallel to this line. The samples lying on this line have identical pore throat size properties, and therefore, are classified in one hydraulic flow unit. However, lines with unity slope belong to clean sandstone formation whereas slopes greater than 1 are expected for shaly formations which alter the equations to some extent.

Permeability can be evaluated using Equation (7) and mean FZI values of each flow unit (FZI_{mean}) and the porosity of the corresponding sample.