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Reservoirs Type Classification Using Hydraulic Flow Units Approach With An Application To Pivnichno-Korobochkynska Area (Dnipro-Donetsk Depression)

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SUMMARY

When improving the reservoir characterization techniques, it very important to give better description of the storage, flow capacities of a petroleum reservoir.

Using the core data and the statistics approach the authors have used the HFU method to classify the reservoir rocks of the Pivnichno-Korobochkynska area. For each of the unit the Reservoir Quality Index (RQI) and Flow Zone Indicators (FZI) were calculated. The paper shows that four hydraulic flow units were distinguished. Each of the unit has its own equation that allows calculating the permeability very precisely.

Key words: reservoir rocks, porosity, permeability, reservoir quality index, hydraulic flow units.

Introduction

One of the most important existing challenges for geoscientists and petroleum engineers is to improve reservoir characterization techniques. They are very valuable as they provide a better description of the storage, flow capacities of a petroleum reservoir and, most importantly, reduce the amount of hydrocarbon left behind pipe.

This paper introduces the concept of Hydraulic Flow Unit (HFU) on the basis of Flow Zone Indicator (FZI) and its application to sandstone formations of Pivnichno-Korobochkynska area located in Dnipro-Donetsk Depression.

The purpose of this paper is to use the HFU methodology to classify the reservoir rocks from the wells №1-6 (depth interval 1254.3- 2798.5 m) as well as determining permeability equations per each rock class.

Examined samples. According to the drilling data, statistical, and core analysis data, the authors have previously identified rock intervals with reservoir properties. There were 101 rock samples used for the survey. All these rocks are sandstones with porosity varying from 0.04 to 0.25 fractions and permeability varying from 0.01 to 1940 mD.

The previous studies stated that the selected reservoir rocks are represented by fine and middle-grained sandstones that have bedded structure, mica, and clay mineral layers in their composition, as well as carbonaceous-clay matter. The bedding and fracturing in the samples are oriented at an angle of 75-90° to the well axis (which means in the horizontal direction).

Theory

Permeability is one of the most important parameters used in reserves estimation as well as in modelling and oil and gas production. Knowledge of permeability gives an understanding of the flow mechanism in oil and gas reservoirs. Usually, the permeability is estimated based on the simple logarithmic regression (1):

$$\log k = a\varphi + b \qquad (1)$$

where a and b are constants (Sokhal et al, 2016).

Permeability and permeability distribution are usually determined from core data. Although, this method is taking into account only the porosity of the rock and it does not include any geological settings, which makes a drawback in this methodology. What is more, the relationship between porosity and permeability is not casual. The porosity is generally independent of the grain size, whereas the permeability is strongly dependent on the grain size. For instance, in a reservoir, porosity and permeability may, in general, be directly proportional. Yet, in the same reservoir, there may be both high and low permeability zones with equal porosity values. Therefore, this traditional plot cannot be used reliably to estimate accurate permeability from porosity data (Amaefule et al, 1993).

This way several geoscientists (Amaefule et al., 1993; Tiab & Donaldson, 2015) have noted the drawback of this approach and have proposed alternative methods for determining permeability and relating porosity and permeability. Considering the classical approach, it can be marked that different porosity-permeability relationships evidence the existence of different hydraulic units.

Considering the typical Kozeny and Carmen equation (2) Amaefule et al. deduced parameter that is named the mean hydraulic radius $\sqrt{\dfrac{k}{\varphi_e}}$ (3).

$$k = \frac{\phi^3}{(1-\phi)^2}\left[\frac{1}{F_{ps}\tau^2 S_{gv}{}^2}\right] \tag{2}$$

where k is the helium permeability (in μm^2), φ is the effective porosity (fractions), F_{ps} is the form-factor of the voids, τ is tortuosity of the filtration channels, S_{gv} is the specific surface area of the voids.

Dividing both sides of Eq. 2 by porosity (φ_e) and taking the square root of both sides results in:

$$\sqrt{\frac{k}{\varphi_e}} = \frac{\varphi_e}{1-\varphi_e}\left[\frac{1}{\sqrt{F_{ps}}\tau S_{gv}}\right] \tag{3}$$

where k is in μm^2. The same interval can be characterized by close value of porosity but different values of permeability. This is due to the different structure of pore system and the secondary porosity. To address the classification of reservoirs by productivity Amaefule et al. (1993) presented the parameter – Reservoir Quality Index (RQI):

$$RQI = 0,0314\sqrt{\frac{k}{\varphi_e}} \tag{4}$$

The other coefficient that was presented by the authors (Amaefule et al.) is Flow Zone Indicator (FZI). This is a unique parameter that includes the geological settings of the texture and mineralogical composition of the reservoir as well as pore geometry. FZI was defined using the following equation:

$$FZI = \frac{1}{\sqrt{F_{ps}}\tau S_{gv}} = \frac{RQI}{\varphi_z} \tag{5}$$

where $\varphi_z = \dfrac{\varphi_e}{1-\varphi_e}$ and FZI is given in μm. Substituting these variables into equation 5 and taking the logarithm of both sides results in:

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

On a log-log plot of RQI versus φ_z all samples with similar FZl values will lie on a straight line with unit slope. Samples with different FZI values will lie on other parallel lines. What is more, samples that lie on the same straight line have similar pore throat attributes and constitute a hydraulic unit.

Results

For the reservoir rock classification (101 sandstone sample) Interactive Petrophysics software was used. The first step in the verification of the hydraulic unit zonation method was to compare the crossplot of log permeability versus porosity (Fig. 1). The log of permeability/porosity crossplot shows wide dispersion. Therefore, it can't be approximated using only one equation and requires using the HFU methodology for rock classification.
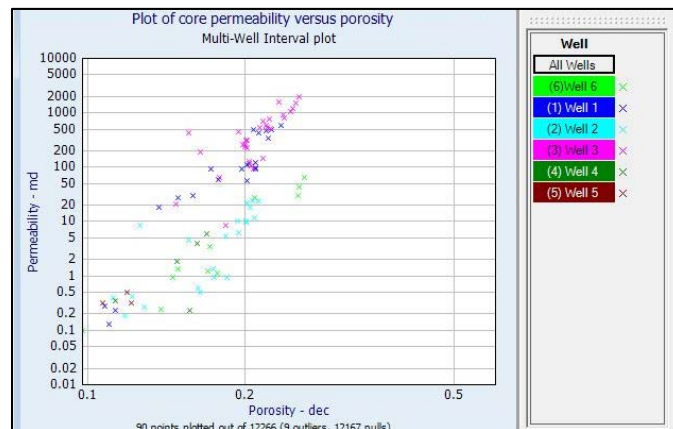

Figure 1 *Plot of core permeability versus porosity*

The analysis was done in two parts, firstly the selection of flow unit boundaries and secondly, using these flow units' boundaries, the creation of hydraulic flow units. Firstly, the selection of the flow units using the RQI method was done from the Flow Zone Indicator (FZI) output curve. The module has created three new curves from the input porosity and permeability data using the Equations 4 and 5. The boundaries were selected using cluster analysis resulting in the data of the FZI as a histogram. Authors distinguished four HFU based on the analysis of the histogram (Fig. 2).
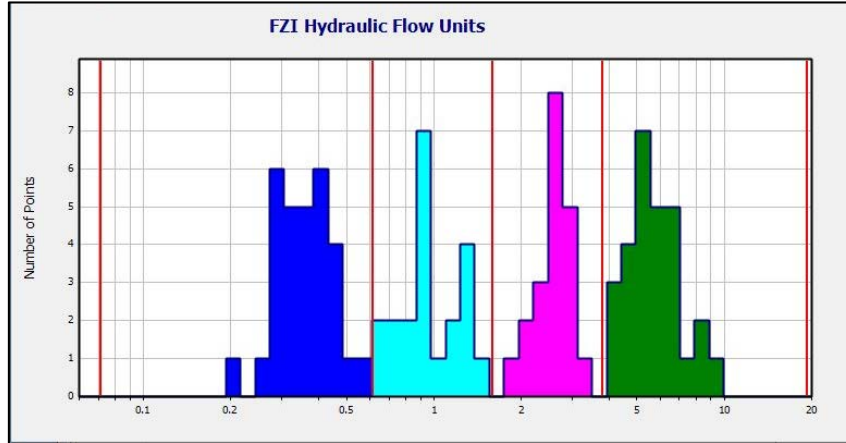
Figure 2 FZI histogram analysis, the X axis is Log (FZI) and the Y axis is the frequency

The RQI was plotted as a function of the void fraction (PhiZ) in log-log scale. Samples that are on the same straight line have similar Pore Throat, and thus constitute a single HFU (Fig. 3). Each line represents an HFU and the intersection with the line value PhiZ = 1 is the FZI mean for this HFU (Al-Ajmi et al, 2000).
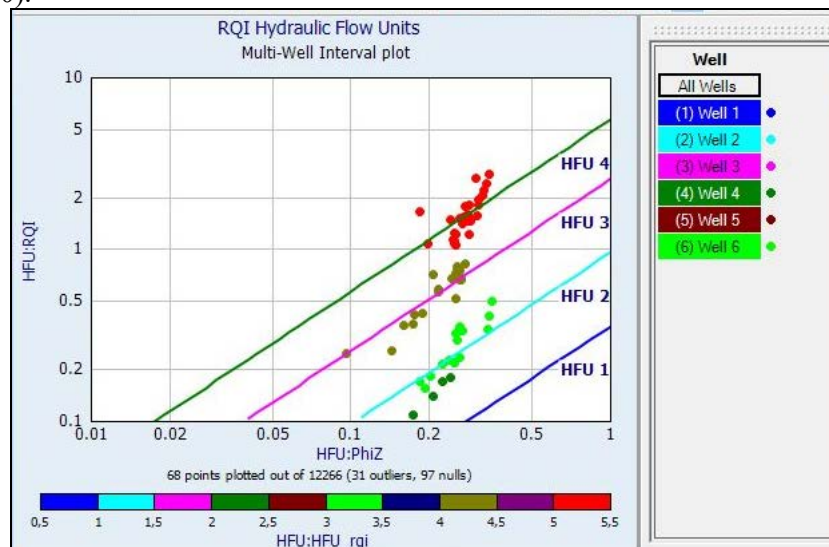
*Figure 3 Plot of RQI versus PhiZ*

After determining 4 HFU from the histogram, we can predict permeability with good accuracy by using the average value of the corresponding FZI and porosity. (Al-Ajmi et al, 2000). The equations for each HFU are shown in Equations 7-10. Figure 4 shows the permeability calculated in relation to the core permeability using the four HFU hydraulic flow units.

$$HFU1 : k = \varphi^3 \cdot \left(\frac{0.36}{(0.0314 \cdot (1 - \varphi))} \right)^2 \tag{7}$$

$$HFU2 : k = \varphi^3 \cdot \left(\frac{0.969}{(0.0314 \cdot (1 - \varphi))} \right)^2 \tag{8}$$

$$HFU\,3 : k = \varphi^3 \cdot \left(\frac{2.598}{(0.0314 \cdot (1 - \varphi))} \right)^2 \tag{9}$$

$$HFU\,4 : k = \varphi^3 \cdot \left(\frac{5.733}{(0.0314 \cdot (1 - \varphi))} \right)^2 \tag{10}$$
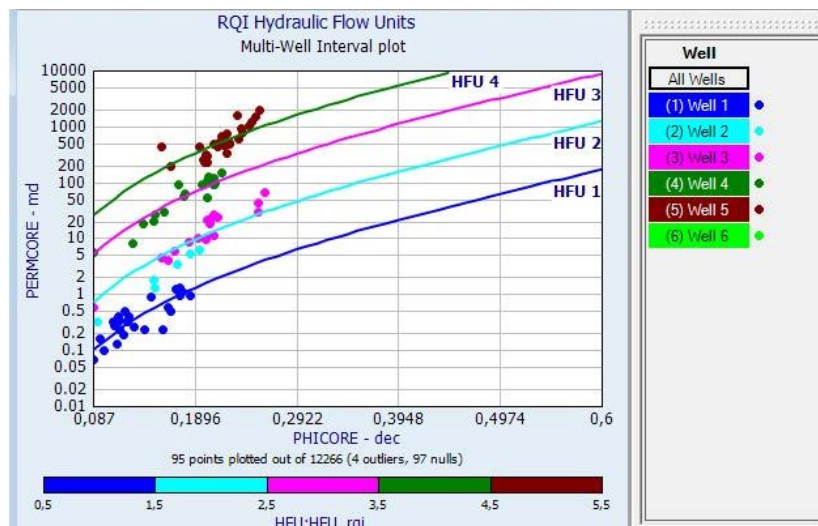
Figure 4 *Permeability calculated in relation to the core permeability using the four HFU*

Conclusions

Using the core data and the statistics approach the authors have used the HFU method to classify the reservoir rocks of the Pivnichno-Korobochkynska area. The analysis of the porosity-permeability relation for the selected samples was done. With the use of the HFU methodology, four hydraulic units were distinguished. For each of the unit, the unique equation was established. These equations allow determining the permeability of the units much more precisely than using the classical approach.

In the future works, the authors plan to use and confirm the obtained results to predict the permeability for the un-cored intervals of the wells in the area using linear regression and neural networks methods.

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