PRACTICAL APPLICATION OF HYDRAULIC FLOW UNITS IN PETROLEUM ENGINEERING

Kononov V. S.
Scientific advisor professor Chernova O. S.
National Research Tomsk Polytechnic University, Tomsk, Russia

Oil and gas reservoir description nowadays incorporates both geological and petrophysical rock assessment. The main parameters, which define reservoir filtration characteristics are permeability and porosity. Equations which comprise both these characteristics were derived by Josef Kozeny (1927) [8] and Philipp Carmen (1956) [5]. In 1970 s with sharp rising of oil prices secondary recovery methods began to develop simultaneously geological models appeared. [6] Thus, it became necessary to know more about inherent reservoir architecture. In 1987 William J. Ebanks Jr. defined Hydraulic Flow Unit as: "…a volume of the total reservoir rock within which geological and petrophysical properties that affect fluid flow are internally consistent and predictably different from properties of other rock volumes" [7]. This definition integrated such reservoir properties as structure, texture, mineral composition and capillary effects.

In 1993 Amaefule et al [2] introduced practical method to define Hydraulic Flow Units. Kozeny-Carmen equation was written as follows:

$$k = \frac{\varphi_e^3}{(1-\varphi_e)^2}\left(\frac{1}{F_s\tau^2 S_{gv}^2}\right) \quad (1)$$

where, k is permeability, μm², φ_e — effective porosity (from core analysis), fraction unit, F_s — shape factor, τ — tortuosity, S_{gv} — specific area of the grain, μm^{-1}.

Then both sides of the equation (1) were divided by φ_e and square root was taken, which resulted in:

$$\sqrt{\frac{k}{\varphi_e}} = \left(\frac{\varphi_e}{1-\varphi_e}\right)\left(\frac{1}{\sqrt{F_s}\tau S_{gv}}\right) \quad (2)$$

LHS was denoted as Reservoir Quality Index:

$$RQI = 0.0314\sqrt{\frac{k}{\varphi_e}} \quad (3)$$

where, 0.0314 is multiplier if permeability is in mD. In the RHS of equation (2) $\varphi_e/(1-\varphi_e)$ was denoted as φ_z. Finally, Flow Zone Indicator was denoted as:

$$FZI = \frac{1}{\sqrt{F_s}\tau S_{gv}} \quad (4)$$

As a result, equation for Reservoir Quality Index can be written as:

$$RQI = \varphi_z FZI \quad (5)$$

It can be seen, that all the above equations comprise geological and petrophysical parameters.

Optimal number of HFU (Hydraulic Flow Units) can be determined with the help of graph analysis (cumulative probability plot) or with the help of cluster analysis. [1] Amaefule et al [2] suggested to use the new application of HFU described above to predict permeability values in uncored wells, to predict the distribution of those values in adjacent wells and to predict permeability values in interwell space. Usability of the concept was shown on different clastic and carbonate reservoirs with different geographical locations: West Africa, South-East Asia, Canada, East and West Texas. On the example of South-East Asia with the help of Spearman Rho Statistical Technique GR, Sonic and Resistivity wellogs were selected as environmentally corrected. This was done because individual log responses should not be correlated directly with pore area parameters and statistical correlation was necessary. With the usage of Bayes Theorem values of HFU were predicted in uncored intervals of two wells. Excellent correlation was achieved between predicted permeability values and actually measured ones.

Hydraulic Flow Unit concept is used globally in abroad reservoir description practice. For prediction of permeability values except Bayes Theorem it is possible to use neural networks. In 2001 R. Soto B. et al [9] introduced the way to use such approach. Core and log data from two wells of Colombian basin was used (412 core samples) in this work.
Normal probability plot of log (FZI) was created, and then clustering analysis with Ward's algorithm was performed to identify five HFU. For each HFU equation (6) was used to calculate permeability values:

$$k = 1014 * (FZI_{mean})^2 * \left(\frac{\varphi_{core}^3}{(1-\varphi_{core})^2}\right) \quad (6)$$

After that Adaptive-Network-based Fuzzy Inherence System (ANFIS) was used to predict FZI values. The authors noted good correlation between FZI values obtained from the core data and FZI values generated with ANFIS tool.

The more recent example contains the work of Ayhan Sengel and Gulcan Turkarslan (2020) [4]. HFU concept was used on carbonate reservoir of Germik field in Turkey. Five Hydraulic Flow Units were identified with RQI (φ_z) plot. For prediction of permeability values from wireline logs Artificial Neural Network (ANN) was used. The results were used to calculate FZI logs and apply derived HFU spatial distribution to build 3D permeability model. After that dynamic model was history matched and authors noted good collaboration of obtained results with history production rates and static bottomhole pressures. Some uncertainties, though were met due to the impact of natural fractures in the reservoir. Authors are planning to improve the simulation model by integrating image logs and seismic attributes.

Amanat Ali Bhatti et al (2020) [3] used HFU approach together with Electrofacies analysis on the Sawan Gas field in Pakistan. Five HFU were identified by calculating RQI (φ_z) plot, which gives mean FZI values for every Hydraulic Flow Unit. The results were used to determine permeability in Sawan-7 well. After that electrofacies (EF) analysis was used on Sawan-7, Sawan-01, Sawan-09 and Sawan-3B wells. EF analysis was performed using k-mean clustering method. Values of permeability were also estimated in the wells Sawan-07, Sawan-02 and Sawan-3B. The authors note, that results obtained on the well Sawan-3B are doubtful, because of lack of core data to validate them. However, authors conclude that applied techniques were useful in estimating reliable permeability values on the Sawan Gas field in circumstances of limited data.

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RESERVOIR DRIVE MECHANISM AS A GEOLOGICAL PARAMETER: FURTHER PROSPECTS OF ITS STUDY AND APPLICATION

Kornev A. I.

Scientific advisor associate professor Pozdeeva G. P.

National Research Tomsk Polytechnic University, Tomsk, Russia

The relevance of studying the parameter "reservoir drive mechanism" in terms of energy state is the key parameter in the reservoir development.

The production conditions of petroleum deposit is the expression of the driving forces that ensure the fluids movement to the bottom of producing wells. The reservoir drive is determined primarily by reservoir pressure determining the prevailing type of reservoir energy. For this purpose, reservoir pressure is compared with the hydrostatic pressure (normal). [2]

Indicators forming the basic concept of the production reservoir drive are abnormal high reservoir pressure, interaction of filtration-volumetric parameters and energy reservoir characteristics, and interference between the wells (exemplified by the Yamburg gas condensate field and the Urengoy oil and gas condensate field).

Various fluid systems determine reservoir pressure values. The hydrocarbons and groundwater movement under the formation pressure conditions cause Elysian Fluid Systems (EFS). Typically, this pressure exceeds hydrostatic one. The rock pressure is an acting force in an elision fluid system. In addition, the overlying layers weight, elision processes, and rock compaction rate predetermine the value of reservoir pressure. In geodynamic fluid systems (GFS), formation pressure is not equal and dependable on hydrostatic pressure. Therefore, the main factors determining the pressure are resonance wave processes in the geological medium, caused by deformation, microseismic, electric and magnetic fields. Earth Stresses specify pressure in geodynamic fluid systems. Stresses form deformation-stress zones. Abnormally high formation pressure is characterized by these zones. [3] Reservoir pressure is formed due by overlaying deformation and high frequency wave fields. In addition, there are distinguished closed, semi-closed and open fluid systems characterized by abnormally high reservoir pressure. Such systems with reservoir pressure exceeding rock pressure are termed endogenous systems. The peculiarity of such systems is the overlaying of two anomalies: pressure and temperature.

The object of the given /present study is the Urengoy field. The deposit of this field is not an endogenous. System, as the temperature in some areas decreases (is not anomalous) and refers to the semi-closed geostatic elision fluid systems. The pressure depends on the consolidation degree of the adjacent reservoir rocks and the displaced water volume into the sandstones.