Arctic Environmental Research

Arctic Environmental Research 19(3): 93–98
UDC 550.8.023:519.223.4
DOI 10.3897/issn2541-8416.2019.19.3.93

Research Article

Scale effect on the reservoir permeability and porosity over a wide range of void structure (example of the Tedinskoye oil field)

IS Putilov[1], AV Yuriev[1], NA Popov[1], DB Chizhov[1]

1 *Perm Oil Research and Planning Institute, Perm Branch of LLC "LUKOIL-Engineering" (Perm, Russian Federation)*

Corresponding author: *Alexander Yuriev* (Aleksandr.Yuriev@pnn.lukoil.com)

Academic editor: *Aleksandr I. Malov* ♦ **Received** 2 September 2019 ♦ **Accepted** 17 September 2019 ♦ **Published** 15 November 2019

Citation: Putilov IS, Yuriev AV, Popov NA, Chizhov DB (2019) Scale effect on the reservoir permeability and porosity over a wide range of void structure (example of the Tedinskoye oil field). Arctic Environmental Research 19(3): 93–98. https://doi.org/10.3897/issn2541-8416.2019.19.3.93

Abstract

A study of the scale effect on the reservoir permeability and porosity over a wide range of the void structure appears to be a significant research task. In this work, we aimed to investigate the scale effect over a wide range of alternating reservoir properties, depending on changes in the void structure, as well as to assess the feasibility of using a whole core with a retained drilling diameter in determining the permeability and porosity of complex reservoirs. For the first time, core samples are proposed to be selected on the basis of space zoning, which takes into consideration the void structure and the scale effect. Filtration studies using such samples are expected to correctly reflect the physical and hydrodynamic characteristics of the reservoir, thus being valuable for calculating reserves and designing project documentation. Based on the performed linear discriminant analysis, the practical problem of dividing the D_3fm object of the Tedinskoye oil field by the type of productive sediment reservoir is solved. In addition, an analysis of the results of physical and hydrodynamic studies confirmed the significance of the scale effect when studying the porosity and permeability properties of complex reservoirs. A significant effect of the void structure on the value of residual water-oil saturation is demonstrated. The feasibility of using whole core samples is substantiated, taking into account the quantitative measure of the scale effect differentiated over a wide range of porosity and permeability when determining the boundary values of porosity for carbonate deposits of the D_3fm object of the Tedinskoye oil field. The obtained results show that the calculation of geological and recoverable reserves should take into account both the scale effect and the structural features of the void.

Keywords

scale effect, permeability and porosity properties, whole core, physical and hydrodynamic studies, complex reservoirs, dynamic porosity coefficient

Introduction

A detailed study of the physical properties of rocks facilitates prediction of oil and gas accumulations, evaluation of the porosity and permeability properties (PPP) of the reservoir and selection of optimal methods for completion and production of the stratum. The reliability of such studies depends largely on the availability of petrophysical information (Gurbatova et al. 2010, Gubaidullin et al. 2017, Petersilier et al. 1980), which can exclusively be obtained through laboratory core studies (Aleksin et al. 1982).

In this work, we aimed to study the scale effect across a wide range of alternating reservoir properties, depending on changes in the void structure. In addition, we set out to assess the feasibility of using a native-state core with a retained drilling diameter for determining the permeability and porosity properties of complex reservoirs.

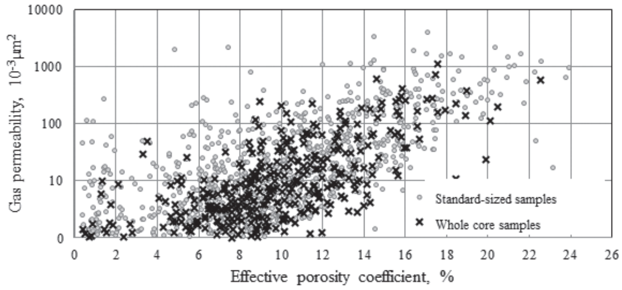

Fig. 1. The dependence of gas permeability on porosity

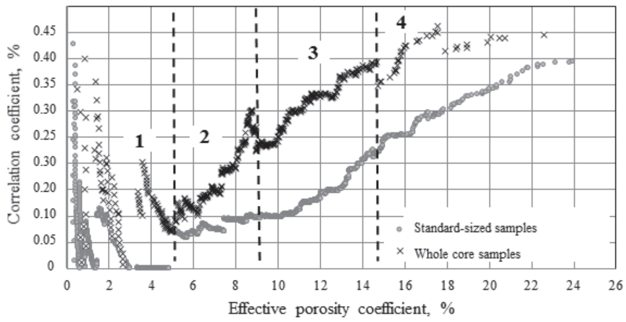

Fig. 2. Correlation coefficient plotted against porosity

Materials and methods

During physical and hydrodynamic studies, we used 2075 core samples (1532 samples of standard size and 543 whole core samples) taken from six wells of the D_3fm object of the Tedinskoye field (Fig. 1).

As can be seen from Figure 1, the correlation fields in the two batches of samples overlap, although the points of standard-sized samples demonstrate a significant level of scattering.

At the first stage, the accumulated correlation between the coefficient of effective porosity and the coefficient of gas permeability over the entire batch of samples was calculated. Correlation plots were constructed separately for standard-sized and whole core samples (Fig. 2).

The plots of the accumulated correlation characterise the relationship between the coefficient of effective porosity and gas permeability across different ranges of porosity. Gaps, breaks and curvature of the plots for whole core and standard-sized samples reflect a change in the structure of the pore space over different ranges. The area between the plots of the standard-sized and the whole core samples presents a measure of the scale effect over the entire range of reservoir permeability and porosity properties of the studied field. The distance between the individual points of the plot across a narrow range of gas permeability coefficient values quantitatively characterises the scale effect attributed to this range. Such measures of accounting the scale effect are proposed for the first time. Using this plot, boundary values can be evaluated independently of the calculated ones and used to estimate reserves and allocate reservoirs.

Let us consider the change in the slope and other effects in the plots of the accumulated correlation in greater detail. The plot highlights Zone 1, which is characterised by the absence of effective void space and an increased value of the permeability coefficient caused by induced fractures formed during the core drilling. This is confirmed by the absence of correlation relationships, i.e. the samples are arranged non-linearly. According to the plot, it is possible to clearly identify the boundary values consistent with the calculated ones selected on the basis of using correlation relationships between permeability and effective porosity. Thus, using this approach, independent determination of the boundary values turns out to be possible for estimating reserves and allocating reservoirs. Over the porosity interval of 5–15% (zone 2–3), an increase in the accumulated correlation values for both plots is observed. However, for a whole core at the porosity value of 9%, a sharp rise is noted, along with a gap caused by a significant contribution of fractures to the effective void space (zone 2). Subsequently, there can be seen a decline and flattening of the accumulated correlation curve due to the presence of caverns and pores in the void space. The accumulated correlation curve of the whole core samples demonstrates a closer relationship with porosity; however, at the porosity value of higher than 15%, a gap and a sharp increase are observed due to the predominance of open pores in permeability and porosity, which indicates the reliability of the obtained data (zone 4). Gaps in the whole core curve clearly fix the boundaries of separation by collector type in the presented section. According to standard-sized samples, this effect is indefinite and can only be judged by the change in the slope of the curve. The whole core curve is located higher than that for the standard-sized ones, demonstrating the scale effect. A conclusion therefore can be drawn that whole core samples are highly representative in terms of characterising the reservoir in complex collectors, while standard-sized samples can be applied for determining the boundary values.

At the second stage, the results of determining the coefficient of effective porosity and absolute gas permeability were compared (Fig. 3). The ratio of effective porosity and absolute gas permeability clearly distinguishes the different nature of the relationship between these indicators for complex carbonate reservoirs with different types of void spaces.

The entire batch of samples was divided into four groups by the reservoir type on the basis of methodological recommendations for calculating reserves depending on the predominance of fluid filtration in various voids: 1) fractured-porous; 2) pore-fractured-cavernous; 3) cavernous-porous; 4) porous (Fig. 3).

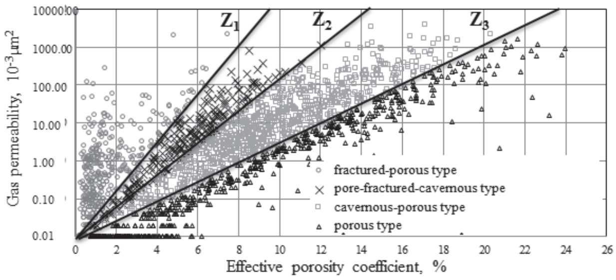

Fig. 3. Gas permeability plotted against porosity for samples divided by reservoir type

The data thus-obtained was used to construct linearly discriminant functions (LDF) dividing the correlation field into groups with a classification quality ranging from 92 % to 94 %. All the obtained LDFs are statistically significant and can be further applied to classification of core samples.

The LDFs for D_3fm object of the Tedinskoye field are as follows (1, 2, 3):

$$Z_1=0.919*(K_p)-0.907*(\log10(K_{gp}))-2.803, \quad (1)$$
$$clas=92\%; F_p/F_t=215.94,\ p<0.00001,$$

$$Z_2=0.773*(K_p)-2.066*(\log10(K_{gp}))-5.043, \quad (2)$$
$$clas=93\%; F_p/F_t=244.88,\ p<0.00001,$$

$$Z_3=0.776*(K_p)-2.940*(\log10(K_{gp}))-5.455, \quad (3)$$
$$clas=94\%; F_p/F_t=355.63,\ p<0.00001.$$

where K_p is the coefficient of effective porosity, %; K_{gp} is the gas permeability coefficient, 10^{-3} μm^2; clas is the percentage of correct classification, %; F_p/F_t is the ratio of the calculated and theoretical Fisher test values; p is the significance level.

Z1 and Z3 LDF allow the area of representative sampling for the D_3fm object of the Tedinskoye oil field to be constricted (Fig. 3).

Results

Applying the above-described approach, 4 zones can be distinguished (Fig. 4) most correctly reflecting the physical and hydrodynamic characteristics of

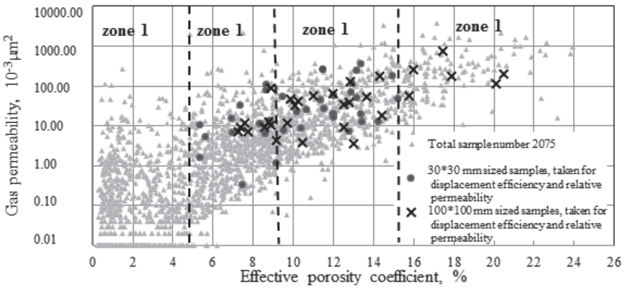

Fig. 4. Gas permeability vs porosity

the formation: 1) features no samples recommended for sampling (minimised by the boundary value of porosity); 2–3) features a mixture of standard-sized and whole core samples; 4) features exclusively whole core samples.

Afterwards, using the selected standard-sized and whole core samples (68 experiments, including 38 and 30 with standard-sized and whole core samples, respectively), physical and hydrodynamic studies were carried out for the D_3fm object of the Tedinskoye oil field. As a result, a number of indicators were obtained: the coefficient of water-oil displacement, relative phase permeability and the coefficient of residual oil saturation. These indicators, which are determined during laboratory studies aimed at modelling thermodynamic conditions on the core from productive intervals, most reliably reflect the hydrodynamic picture of the processes occurring in the reservoir (Dmitriev et al. 2015, Zheltov et al. 1997, Musket 2004, Mikhailov et al. 1990, Mikhailov and Gurbatova 2011, Honarpour and Mahmood 1998, McPhee and Arthur 1994).

Discussion

An analysis of the results obtained for the coefficient of residual oil saturation demonstrated lower values of the standard deviation for 0.0647 unit fraction (u.fr.) and lower values of the maximum values of 0.512 u. fr. for the whole core samples (at average values of 0.305 u. fr.) in comparison with standard-sized samples values of 0.1123, 0.639 and 0.337 u. fr., respectively.

The residual oil saturation values were used to calculate the dynamic porosity coefficient by the formula (4):

$$K_{dyn.p}=K_p*(1-S_{res.w}-S_{res.o}), \quad (4)$$

where K_p is the coefficient of effective porosity, %; $S_{res.w}$ is the initial water saturation, u.fr.; $S_{res.o}$ is the residual oil saturation, u.fr.

The dynamic porosity coefficient reflects the pore volume, in which the oil movement is possible when they are extracted from the reservoir. Regression equations were obtained for the whole core (5) and standard-sized samples (6):

$$K_p = 1.677*K_{dyn.p} + 2.8, \quad (5)$$
$$n=30, r=0.95,$$
$$K_p = 1.219*K_{dyn.p} + 5.8, \quad (6)$$
$$n=38, r=0.76,$$

where n is the number of samples; r is the correlation coefficient.

The obtained linear dependency equations are statistically significant. The highest correlation coefficient of 0.95 is observed for whole core samples, and the value of 0.76 is established for samples of standard size. Thus, the dependence for whole core samples appears to be more reliable.

When the dependence is obtained using only standard samples, the boundary value of the porosity coefficient becomes overestimated and equals 5.8 %. The difference between the boundary values for standard and whole core samples comprises 3 %, which is very important for calculating reserves. Therefore, the porosity boundary value for a given field must be accepted by the whole core samples, since standard-sized samples fail to fully reflect the structure of the pore space for the conditions of D_3fm carbonate formations of the Tedinskoye oil field. Thus, using the proposed approach, the boundary values of the effective porosity coefficient can be distinguished for the pore volume attributed to the oil reservoir movement with the obtained value applicable for estimation of reserves and geological support of field development.

In order to carry out a detailed analysis of the scale effect on the basis of the experimental data obtained, the accumulated correlation between coefficients of effective and dynamic porosity was calculated for the entire batch of samples used in physical and hydrodynamic studies. Accumulated correlation plots were constructed separately for whole core and standard-sized samples (Fig. 2).

The plots of the accumulated correlation reflect the relationship between the coefficients of effective and dynamic porosity in different ranges of porosity, thus being of value for characterising recoverable reserves during water-oil displacement.

Gaps, breaks and curvature in the plots for whole core and standard-sized samples reflect a change in the structure of the void space across different ranges, demonstrating the consistency with the data presented in Figure 2. As can be seen from Figure 5, over the range of effective porosity from 5 to 8 % (zone 2), a high dispersion is observed for samples of standard size with no traced correlation. However, starting from 8 % in this zone, the accumulated correlation values for both plots increase. In zone 3, scattering of points by samples of standard size is observed reflecting no correlation; however, the degree of dispersion is here lower than for zone 2. For whole core samples, the accumulated correlation is stabilised; however, at a porosity value of 11 %, the correlation relationship breaks due to a change in the structure of the void space. Zone 4 is represented only by whole core samples, with the accumulated correlation showing a smooth growth reaching the level of stabilisation.

An analysis of the accumulated correlation fields shows scattering of the standard sample points and a regular increase in the values of the accumulated correlation for whole core samples. This information

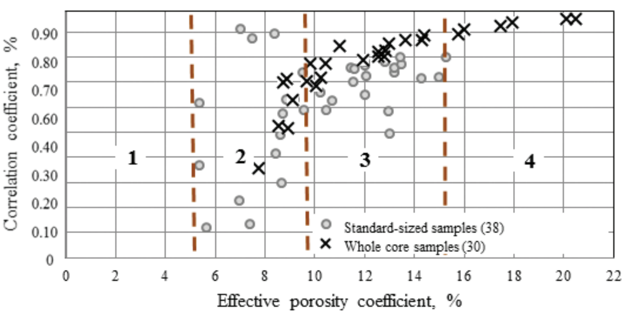

Fig. 5. Correlation coefficient vs porosity

is of value for describing filtration processes over this range, thus affecting the quality of the obtained regression equation for a whole core samples expressed in the correlation coefficient of 0.95.

In general, the accumulated correlation for whole core samples is located higher and shows a higher correlation value, thus demonstrating a large-scale effect for the filtration parameters and reliably describing the physical and hydrodynamic processes occurring in a reservoir with moving fluids. It should be noted that the manifestation of the scale effect was established even in a relatively small sample batch.

Conclusion

The performed linear discriminant analysis allowed us to solve a practical problem of dividing the D_3fm object of Tedinskoye oil field by the type of productive sediment reservoir.

For the first time in permeability studies, it is proposed to conduct space zoning during the selection of core samples so that the void structure and the scale effect could be taken into account. The results of such studies provide more detailed physical and hydrodynamic characteristics of a reservoir, thus facilitating with the calculation of reserves and preparation of project documentation.

The conducted analysis of the results of physical and hydrodynamic studies has confirmed the significance of the scale effect in studying the porosity and permeability properties of complex reservoirs. It is shown that the void structure has a pronounced effect on the value of residual water-oil saturation.

The feasibility of using whole core samples is substantiated, taking into account the quantitative measure of the scale effect differentiated over a wide range of porosity and permeability, when determining the boundary values of porosity for carbonate deposits of the D3fm object of the Tedinskoye oil field.

The obtained results show that the calculation of geological and recoverable reserves should take into account both the scale effect and the structural features of the void.

References

- Aleksin GA, Kleschev AA, Rossikhin YuA (1982) Prospects for oil and gas exploration in the north of the Timan-Pechora province. VNIIOENG Publ., Moscow, 144 pp. [In Russian]
- Dmitriev NM, Kuzmichev AN, Mikhailov NN, Maksimov VM (2015) An experimental study of the filtration properties of anisotropic hydrocarbon reservoirs. Drilling and Oil 11: 6–9. [In Russian]
- Gubaidullin MG, Belozerov IP, Yuryev AV (2017) Experimental studies of relative phase permeability and oil displacement coefficient in complex reservoirs. Geology, Geophysics and Development of Oil and Gas Fields 2: 49–52. [In Russian]
- Gurbatova IP, Melekhin SV, Yuryev AV (2010) Features of the study of petrophysical and elastic properties of core in complex reservoirs of oil and gas in modelling thermobaric reservoir conditions. Geology, Geophysics and Development of Oil and Gas Fields 5: 66–67. [In Russian]
- Honarpour MM, Mahmood SM (1998) Relative-Permeability Measurements: An Overview. Journal of Petroleum Technology 40: 15–19.
- McPhee CA, Arthur KG (1994) Relative Permeability Measurements. An Inter-Laboratory Comparison: European Petroleum Conference, London, 199–211. https://doi.org/10.2118/28826-MS
- Mikhailov NN, Dzhemesyuk AV, Kolchitskaya TN, Semenova NA (1990) The study of residual oil saturation of the developed formations. VNIIOENG Publ., Moscow, 59 pp. [In Russian]
- Mikhailov NN, Gurbatova IP (2011) The scale effect in the laboratory determination of the reservoir properties of complex carbonate reservoirs. Oil and Gas Technologies 4(75): 32–35. [In Russian]
- Musket M (2004) The flow of homogeneous liquids in a porous medium. NIC Regular and Chaotic Dynamics Publ., Moscow, 629 pp. [In Russian]
- Petersilier VI, Rabits EG, Belov YuYa (1980) Methods and instruments for studying the reservoir properties of reservoir rocks on large samples. Nedra Publ., Moscow, 53 pp. [In Russian]
- Zheltov YuV, Kudinov VI, Malofeev GE (1997) Development of complex viscous oil fields in carbonate reservoirs. Oil and gas, Moscow, 387 pp. [In Russian]