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SCALE EFFECT IN LABORATORY DETERMINATION OF THE PROPERTIES OF COMPLEX CARBONATE RESERVOIRS

Kamensky IP*1, AL-Obaidi SH*2, Khalaf FH*3

*1Assosiate Professor, Independent researcher, Scientific Research Center, Russia.

*2Professor, Department of Petroleum Engineering, Mining Institute, Russia.

*3Assistent Professor, Department of Petroleum Engineering, Knowledge University, Erbil, Iraq.

ABSTRACT

As it is well known that, formation porosity and permeability are fundamental rock properties. Porosity is a measure of the storage capacity of the rock and permeability is a measure of rock flow capacity. In this study the relationship of the scale effect with the features and type of the capacitive structure of complex reservoirs is shown. The characteristic conditions for the manifestation of large-scale effects in determining porosity and permeability are analyzed. Also in this work the influence of the scale effect on the representativeness of laboratory determinations of flow- storage capacitance (FSC) properties is shown. The relationship between the values of porosity and permeability with the object of the core study has been established.

Keywords: Permeability, Porosity, Scale factor, FSC, Core volume, Standard size.

I. INTRODUCTION

Knowledge of the reservoir properties (FSC) is necessary when calculating hydrocarbon reserves, designing and analyzing field development. The only direct methods for studying reservoir properties are laboratory methods of core analysis, based on the provisions of state and industry standards [1]. In accordance with existing concepts, the core under study should have the properties of statistical representativeness from the point of view of the studied reservoir. This means that its response to the action should be identical to the response of the studied formation in a statistical sense. This position is possible only if the studied core contains such a large number of elements, composing the formation, that their combined behavior both in the reservoir and in the studied core will be identical. In accordance with this requirement, “standard” sizes of core samples should be selected [2,3].

II. METHODOLOGY

Permeability and porosity properties are determined by the structure of the interstitial space - the size and shape of the pores, the nature of their connectivity with each other, the pore size distribution and other characteristics of pore systems [4,5]. For granular reservoirs, pore sizes rarely exceed tens of microns. Accordingly, if the pore size is of the order of particle size, then for particles with a size of ~ 0.5 mm, even 1 cm3 contains ~ 203 particles, with a porosity of 10%, the number of pores will be ~ 202. Consequently, small standard sizes of core samples (3x3 cm) contain a huge number of pores and the determined porosity and permeability properties of such cores characterize the result of averaged interaction of the ensemble of all pores. The individual properties of individual pores (geometry, size, relative position) do not play a significant role. Permeability - Porosity properties are determined by the ensemble of pores, not by the properties of individual pores, and that the properties of the entire ensemble that control these formation properties [6,7]. The representativeness of the core material is determined by the minimum dimensions of the test samples, for which the representativeness of the average pore ensemble is ensured, that is, the following inequality must be satisfied:

$$\sqrt[3]{V_{sam}} \gg d_{ens} \qquad (1)$$

Where V_{sam} is the representative volume of the test sample; dens is the characteristic size of a typical pore ensemble.

In the accepted standards, the size of the "standard" sample for laboratory determination of porosity and permeability is ~ 21 cm3, that is, the conditions for representativeness of the core material in terms of the granular porosity of reservoirs (when individual pores weakly interact with each other) are fully met. For complex reservoirs of fractured

porous-cavernous type, the situation is not so unambiguous. They are characterized by a complex polymodal distribution of voids by size [6]. In addition to granular pores of typical sizes, the samples contain large cavernous cavities (Fig. 1), which can be 0.5–1.5 cm or higher in size. However, samples of a full-size core with a diameter of 10 cm are also representative for this type of void ensembles. From the relation (1), it follows that for micro-cavernous reservoirs, both standard-size and full-size samples are representative. However, recent experimental data show that this situation is not always fulfilled and there is a large-scale effect when determining the formation permeability and porosity from the core [8-10].

Figure 1 : Core samples of various sizes

III. EXPERIMENTAL WORK AND ANALYSIS

To study the effect of the scale factor, these reservoir properties (FSC) were determined on 46 samples of various sizes. For comparative analysis, samples were selected with a diameter of 100 mm preserved during drilling in the well and samples of a standard size located nearby along the sampling depth. Then from samples with a diameter of 100 mm parallel to bedding were cut samples with a diameter of 65 mm and the porosity and permeability were determined again. In Fig. 1 shows photographs of standard size samples and full-size cores with diameters of 65 and 100 mm. The volume of a sample of a standard size is ~ 20.9 cm3; a full-size core is ~ 215 and ~ 785.4 cm3. Thus, the volume of a full-size sample with a diameter of 100 mm is 37.5 times larger than the standard one, and, accordingly, the representativeness of the results obtained is noticeably higher. Let us consider the manifestation of the scale effect in determining the porosity and gas permeability. Figure 2 shows a comparison of the results of determining porosity (a) and permeability (b) for standard-size samples and full-size cores with a diameter of 100 and 65 mm.

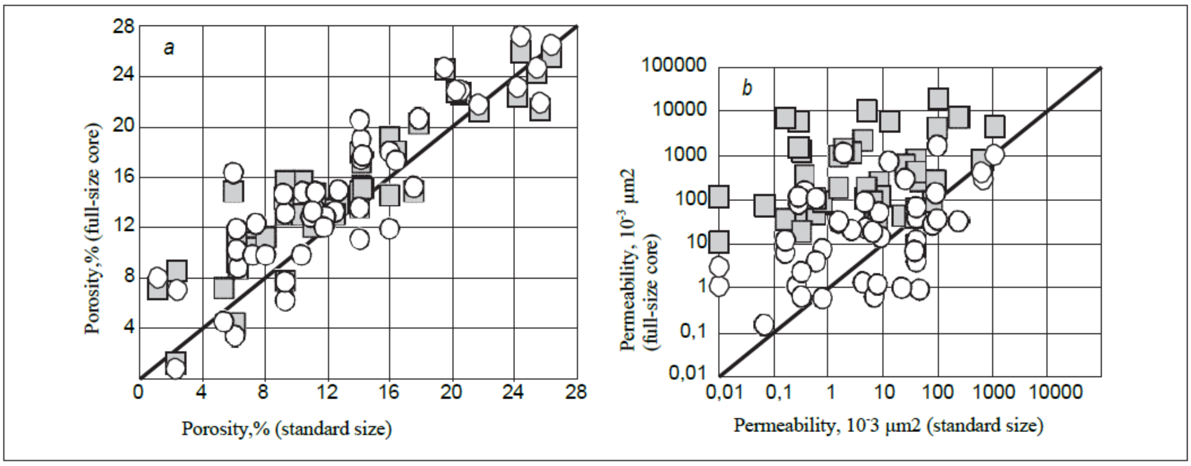

Figure 2: Comparison of the results of determining formation porosity and permeability on standard-size samples and full-size cores with a diameter of 100 (■) and 65 (○) mm

The results obtained indicate the presence of a scale effect in the case of using a full-size core with a diameter of 65 and 100 mm. Changes in porosity and permeability are shown in the Table 1.

Table 1: Change in porosity and permeability

Sample size	Porosity, %			Permeability, 10^{-3} μm²		
	min	max	the average	min	max	the average
Standard size	1,12	26,38	12,89	<0,01	1106,46	76,38
Full-size core diameter						
65 mm	0,79	27,18	14,70	0,15	1693,73	152,70
100 mm	1,26	25,90	14,88	9,29	19832,8	1712,50

The difference in porosity values can be 4–6%, which illustrates the significance of the scale effect. Experimental data also show that influence of the scale effect is ambiguous. There are a certain number of samples for which the scale effect does not appear. The significance of the scale effect does not correlate with the porosity of the core under study and obviously depends on the characteristics of the reservoir's capacitance structure. As can be seen from Fig. 2, b, there is a tendency to increase the permeability with an increase in the size of the tested cores. However, this trend is not clear and for some samples there is a coincidence of the results of determining reservoir permeability and porosity on different-scale cores. Thus, it is necessary to carry out the identification of the scale factor depending on the porosity type of the studied samples. In the practice of petrophysical studies, petrophysical connections are usually used to identify the type of porosity of complex reservoirs, which differ from each other depending on the type of void space [11,12]. According to the type of void space, the samples were divided into three main groups: 1) fractured reservoir - the predominant role of fractures; 2) cavernous-pore reservoir - the predominant role of pore channels in permeability and porosity and their additional increase due to caverns; 3) fractured porous-cavernous reservoir - rocks with a more complex type of void space due to intense cavernosity and fracturing.

Figure 3 shows a comparison of gas permeability and porosity. The studies were conducted on standard-size samples and a full-size core with a diameter of 100 mm. Relationship equations were derived for each type of void space.

From Fig. 3, we can conclude that the obtained petrophysical relationship are differentiated not only by the type of pore space, but also by the size of the tested core, which indicates the existence of a relationship between the size of the tested core and the type of interstitial ensemble. Since the characteristic sizes of the pore cavities certainly satisfy the condition for the representativeness of the samples under study (1), the observed effects can be caused by the formation of a connected interstitial ensemble consisting of pore capacities of various types.

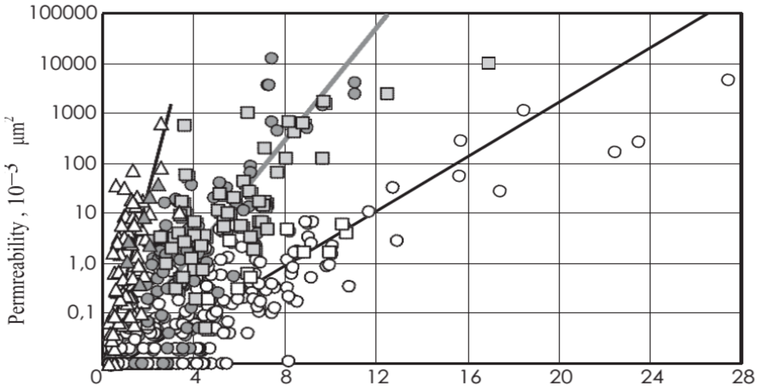

Figure 3 : Comparison of gas permeability and porosity: ○ □ cavernous-porous reservoir (standard size and full-size core), log K = 0.276 φ - 2.326, R = 0.868n = 345; ● ■ fractured porous-cavernous reservoir (standard size and full-size core), log K = 1.747 φ - 2.075, R 0.559n = 87; △ ▲ fractured reservoir (standard size and full-size core), log K = 0.561 φ - 2.013, R = 0.746n = 123

To establish the regularities of the influence of the volume of the tested core on the reservoir properties, the porosity and permeability values obtained for different volumes of the studied core were compared. Figure 4 compares the average values of porosity (a) and permeability (b) and core volume. The values are presented in normalized values. The presented porosity is defined as the ratio of the porosity of a full-size core (65 and 100 mm) to the porosity of a standard-sized sample. The volume shown is equal to the ratio of the volume of a full-size core to the volume of a standard-sized sample. As can be seen from figure 4, when scale effects occur, there is a clear relationship between the values of reservoir properties (FSC) and the volume of the tested sample. This relationship has a power function form and high correlation coefficients.

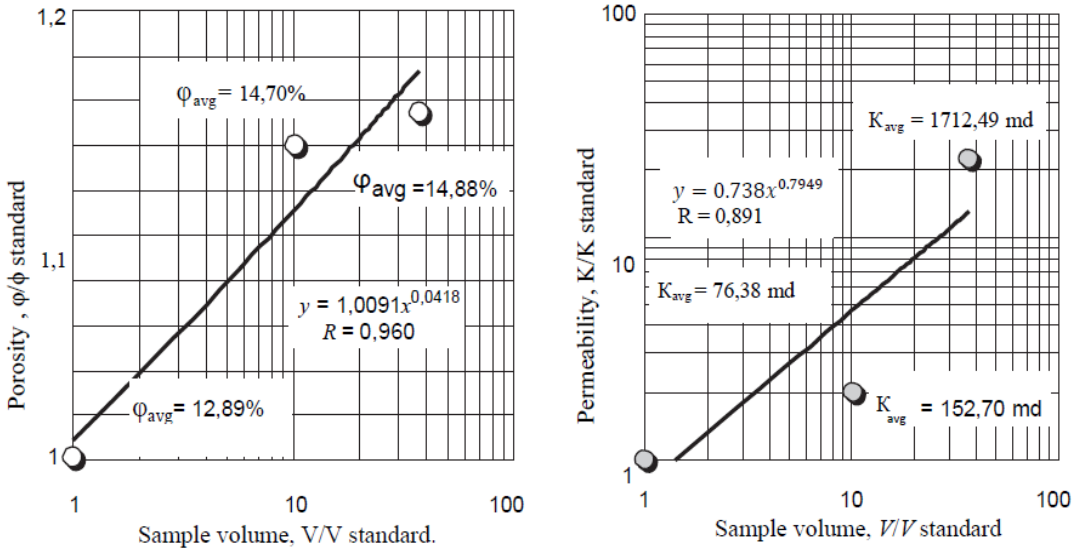

Figure 4 : Comparison of the average values of porosity and permeability and volumes of the studied core samples

The results of laboratory determinations of reservoir permeability and porosity depend on the representativeness of the investigated core material [1–3]. However, the available literature has traditionally associated the representativeness of the core material with the total number of standard-sized samples and did not pay attention to the influence of the scale factor. It was not explicitly implied that only the "statistically" representative volume of the core being studied matters, and the geometric dimensions of individual cores do not matter.

This approach did not take into account the indications in the literature on the effect of core size on the results of determining the reservoir properties (FSC) [3, 4]. The studies [13-15] have shown that, when studying complex reservoirs, neglecting the influence of the scale effect leads to significant errors in determining the (FSC) of reservoirs. With an increase in the size of the tested cores, an increase in the average values of porosity and permeability is observed. The difference in reservoir properties, determined on different-scale cores, indicates the difference in the void structures of different-scale cores. If the interstitial structures remain unchanged at different scales, the scale effect does not appear. Quantitative regularities of the scale effect can be described by type dependencies.

$$C_v = C_{st}\left(\frac{V}{V_{st}}\right)^{\propto} \tag{2}$$

Where C_v - the value of reservoir properties (FSC), depending on the volume; C_{st} is the reservoir properties value obtained on standard size cores; V, V_{st} - current and standard volume of the studied core; α is an exponent.

The relation (2) is similar in structure to the form of representation of fractal properties of the reservoir [4]. However, the ratio in this relation indicates an infinite increase in the values of reservoir properties (FSC) with an increase in the volume of the core being studied. Obviously, this is not true.

Accordingly, it is necessary to assume that there is a saturation volume, after which the reservoir properties (FSC) will no longer depend on the studied volume. In this case, relation (2) will be written as

$$C_v = C_{st}\left(\frac{V}{V_{sat}}\right)^{\propto} \tag{3}$$

Where, V_{sat} is the maximum volume corresponding to the capillary volume of the interconnection of the elements of the ensemble of the void space structure. In the experiments carried out, the saturation volume turned out to be greater than the maximum volumes of the studied cores.

IV. CONCLUSION

Thus, the study showed that, the representativeness of the results obtained is noticeably higher when using the volume of a full-size sample with a diameter of 100 mm, which is 37.5 times larger than the standard one.

The results obtained indicate the presence of a scale effect in the case of using a full-size core with a diameter of 65 and 100 mm. Changes in porosity and permeability values are well observed. It was observed also that the significance of the scale effect does not correlate with the porosity of the core under study and obviously depends on the characteristics of the reservoir's capacitance structure.

When scale effects occur, there is a clear relationship between the values of reservoir properties (FSC) and the volume of the tested sample. This relationship has a power function form and high correlation coefficients.

It was concluded that the obtained petrophysical relationship are differentiated not only by the type of pore space, but also by the size of the tested core, which indicates the existence of a relationship between the size of the tested core and the type of interstitial ensemble.

The difference in reservoir properties (FSC), determined on different-scale cores, indicates the difference in the void structures of different-scale cores. If the interstitial structures remain unchanged at different scales, the scale effect does not appear.

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