Automation of technological processes in the examination of core samples

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Abstract. Currently, there are quite serious problems in the methodology of conducting petrophysical studies. These problems have a significant impact on the process profitability of obtaining analysis results. Improving the efficiency of laboratory analyses is an important direction towards enhancement of the methodological approaches used in the laboratory practice. Automation of the process of recording the volume of water displaced from the chamber of a group capillarimeter while determining the water saturation of standard and full-size core samples is analyzed.

1. Introduction
Increasing the reliability of solving a particular problem at the stages of geological, petrophysical and hydrodynamic modeling depends on the degree of study of the core material, determined by the human resources and the level of equipment of petrophysical laboratories [1].

In [2] it is noted that the task of improving the methods and modernizing the petrophysical laboratory equipment is relevant not only in the study of the mineral composition, but also in the determination of the filtration-capacitive and physical properties of rocks.

The automation of the process of laboratory determination of the current value of water saturation is one of the actual directions of automation of technological processes for the study of the core material.

The study of the capillary characteristics of the reservoirs makes it possible to reasonably model complex deposits, more accurately predict the oil and gas contours and the capacity of the transitional and pure oil zones [3]. Capillary phenomena have a significant impact on the processes of oil and gas accumulation and of fluid migration in the formation [4].

Capillary pressure is determined by the pressure difference between the oil and water phases, which depend on the radius of the pore channels of the rocks, the surface tension of the hydrocarbon-water and the wettability of the reservoir rocks [5].

In laboratory practice, both direct and indirect methods are used to assess the water saturation of samples.

Determination of water saturation by the amount of water in cores sampled from wells drilled with anhydrous fluid (direct method) is a rather laborious process that requires adherence to special recommendations for maintaining residual water saturation in a full-size core.

Indirect methods (the method of semi-permeable membrane and centrifugation) are the most common in quantifying the water saturation of reservoirs and plotting the capillary pressure curve [6].

The capillary pressure curve is characterized by the displacement pressure, the current and maximum capillary pressure.
The displacement pressure corresponds to the minimum pressure required for the continuous non-wetting phase to pass through the interconnected water-saturated pore channels of the rock. Typically, the displacement pressure is determined at the beginning point of the plateau-like section on the capillary pressure curve.

The current capillary pressure is a function of oil saturation, and the maximum capillary pressure occurs at the maximum oil saturation, that is, when the content of bound water in the capillaries is minimal.

In contrast to the semi-permeable membrane method, in which the capillary pressure corresponds to the pressure created in the capillarimeter chamber, for the centrifugation method the capillary pressure value is calculated taking into account the geometric characteristics of the centrifuge rotor, the frequency of its reversal, and the geometric dimensions of the samples.

In [7], it is shown that it is necessary to harmonize the results of determining the water saturation of samples by centrifugation and capillarimetry methods, and the priority of the reliability of the results obtained is given to the semi-permeable membrane method.

The semi-permeable membrane method [8] provides for the stratum water drainage or its model from saturated core samples through a semi-permeable membrane as a result of the creation of excess gas pressure in the chamber of the group capillarimeter. After stopping the outflow of water from the samples, the amount of water displaced from them is determined, which makes it possible to calculate the residual water saturation at the created excess pressure in the capillarimeter chamber.

The condition for the applicability of the method [8] for determining the current value of water saturation in oil and gas reservoir rocks is the ability to obtain data sufficient to construct a curve expressing the value of water saturation versus capillary pressure.

The modern level of automation of technological processes of core material research, aimed at increasing the reliability of the data obtained and optimizing the course of the experiments, makes it possible to switch from a visual assessment of the process of displacing water from the capillarimeter chamber to electronic recording of the displaced water level readings.

The aim of this work is to automate the process of displacing water from samples of terrigenous reservoirs with different permeabilities in the chamber of a group capillarimeter.

2. Methods

For the analysis, a collection of core samples was selected, presented by homogeneous fine-grained and medium-grained sandstones with a permeability of 10 to 100 mD, taken from productive strata of one of the fields in Western Siberia.

The morphological features of the core material were studied by scanning electron microscopy using JEOL JSM-6510LV microscope.

The operation of a scanning electron microscope is based on scanning the sample surface with a focused electron beam [9].

The studies were carried out on a fresh core samples chip [10].

Before the study, a thin silver film with a thickness of about 10 nm was applied to the chip surface. In this work, the values of the gas permeability coefficients of core samples were determined in accordance with [11].

Drying of core samples was carried out at temperature of 105 °C. The drying was carried out to their constant weight. The samples with a high content of clay material were dried at 70 °C. The separation of core samples by clay content was carried out according to [12].

The dried samples were evacuated in a saturation unit, and then capillary imbibition and additional saturation with the working fluid were carried out.

The group capillarimeter is a metal vessel with a hermetically sealed lid, in which excess pressure is created.

In the capillarimeter model [13], the working chamber contains a base for placing a semi-permeable membrane and core samples, a central part and a cover, which are hermetically connected to each other using screw clamps. The capillarimeter [13] can be used only for samples of the same height, since
special spring mechanisms are used for contact of water-saturated samples with a semipermeable membrane.

In the capillimeter model [14], the working chamber consists of a lower base with a water outlet; the central part of the cylindrical shape; top base with a hole for a round removable lid for loading and unloading samples. It also has two metal posts welded to the upper base, with cutouts for the beam resting on the cutouts in the posts; forcing screw with a spherical end and a round removable cover. The use of only one forcing screw and a removable cover makes it possible to significantly simplify the processes of loading and unloading samples into the capillimeter. The height of the central part of the capillimeter is selected taking into account the possibility of conducting research not only on standard, but also on full-size core samples.

The process of displacing water at a given capillary pressure continues until the water level in the receiving tube stabilizes.

In the models of capillimeters discussed above, there is no electronic fixation of the readings of the displaced water level in the receiving tube.

In the course of the work, the automation of the process of displacing water from the capillimeter chamber was carried out and the problem of electronic fixation of the readings of the displaced water level in the receiver tube was solved by using an ultrasonic sensor.

Digitalization of the process of displacing water from the chamber of the group capillimeter when determining the water saturation of standard and full-size core samples allows to control the level of the displaced working fluid in the receiving tube and record readings into an e-journal in real time throughout the experiment for all stages of the capillary pressure.

3. Results and discussion

Figures 1 and 2 show the capillary curves and the size distribution of pore channels obtained by the semipermeable membrane method for core samples from the selected collection with different reservoir properties.

The presented capillary pressure curves clearly show a plateau corresponding to the typical size of large capillaries.

Note that in this region of curves with a slight change in pressure, the saturation gradient for a sample with a permeability equal to 95.6 mD (Figure 2) is higher than for a low-permeability sample (Figure 1).

Figures 1 and 2 show that with a decrease in the reservoir properties of the plateau rock samples, the plateau is getting smaller, the curves shift towards a higher saturation.

The distribution of pore channels by size (Figures 1 and 2) shows that with increasing pressure, the displacing phase penetrates into capillaries with an ever-smaller radius. The displacement process will end in fine pores when the capillary pressure forces are very high and the moistening fluid loses its mobility.

![Figure 1](image_url). Capillary curve and distribution of pore channels by core sample size (K = 2.02 mD).
Figure 2. Capillary curve and distribution of pore channels by core sample size (K = 95.6 mD).

The obtained results of the distribution of pore channels by sample size correspond to the results of studying the microstructure of core samples using a scanning electron microscope.

Figure 3 shows that the surface of the test sample is the surface of a chip of fine-fine-grained sandstone with carbonate-clay cement. A rather dense packing of the detrital skeleton and the presence of single subcapillary pore channels are noted. A few capillary and subcapillary open pores have both isothermal and anisometric shapes.

Figure 3. Micrograph of a section of a core sample (K = 2.02 mD). Magnification is 500 ×, marker size is 50 µm.

Figure 4. Micrograph of a section of a core sample (K = 95.6 mD). Magnification is 500 ×, marker size is 50 µm.

Figure 4 shows that the presented sample of core material intergranular capillary and subcapillary open pores communicate with each other through capillary pore channels.

The automation of the process of water displacement from the chamber of the group capillarimeter showed that the achievement of the process of stabilization of the displacement process significantly depends on the permeability of the samples.

The experiments have shown that the expected time of the end of water displacement from standard samples of terrigenous reservoirs with permeability from 10 to 100 mD is determined by the dependence of the form

\[ t = 245K^{-0.05} \]
where $t$ is the end time of displacement of water from standard samples, hour; $K$ is the permeability coefficient of the samples, mD.

4. Conclusion
Automation of the system for registering the process of water displacement from the group capillarimeter chamber made it possible to solve the problem of electronic fixation of the displaced water level readings, reduce labor costs during the experiment, and improve the accuracy of determining the current value of water saturation at a given capillary pressure by the semipermeable membrane method.

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