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INVESTIGATION OF THERMAL PROPERTIES OF RESERVOIR ROCKS AT DIFFERENT SATURATION

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ABSTRACT

Oil and gas production using formation thermal stimulation or treatment represents one of the main enhanced oil recovery methods. In this study the thermal properties of rocks and their relationship to the nature of rock saturation were investigated.

The method, experimental setup, and results of studying the thermal characteristics of fine - and medium-grained highly porous sandstones at their different saturation are presented. The highest values of thermal diffusivity, thermal conductivity and heat capacity correspond to water-saturated samples, smaller values correspond to oil-saturated ones and the lowest values corresponds to dry (extracted) samples. The obtained data can be used in the selection of the technology of thermal formation stimulation on the reservoir and control over the process of oil field development.

Keywords: Saturation, EOR, Thermal diffusivity, Heat capacity, Thermal conductivity, PSU.

I. INTRODUCTION

The use of enhanced oil recovery (EOR) methods for oil and gas extraction has a wide area in the oil industry [1, 2 , 3]. The oil or gas production using these methods in some countries reaches more than 40% of the total production [4]. Formation thermal treatment represents one of the main EOR methods. Thermal methods impact on productive formations is becoming more and more relevant in connection with the need to increase oil recovery at the late stage of field exploitation. These methods are involved in the development of fields of high-viscosity oils [5 , 6 ,7]. At the same time, the availability of reliable information on the thermal properties and their changes during the heating process will significantly improve the quality of design work and the economic efficiency of thermal methods for extracting hydrocarbons [8 , 9 , 10]. Consideration of the type of fluid that saturates rocks is also necessary when choosing a technology for thermal stimulation of the reservoir and monitoring the development of an oil field.

II. METHODOLOGY

This paper presents the results of a study of the thermal characteristics of sandstones, represented by fine and medium-grained highly porous (open porosity varies in the range from 25.38 to 28.42%) differences [11 , 12 , 13]. Rock samples were taken from the intervals 1303-1308 m and 1314-1320 m, well. No. 16 of the Soldier oil field.

Thermo-physical studies of samples were performed at different saturation levels: from air-dry (extracted samples) to oil - and water-saturated. The samples prepared for research had the form of cylinders (disks) with a diameter of 25 and a thickness of 5.95 to 10.24 mm.

The heat cell consists of two semi-bounded reference bodies 3 and 6 from the point of view of thermal vibrations, made of materials certified for thermal diffusivity and thermal conductivity at the Mendeleev VNIIM [14, 15, 16].

At the end of the reference body 3, facing the test sample 5, there is a flat low-inertia source of thermal vibrations 4.

In another reference body 6, a temperature sensor is placed. It is a differential thermocouple "chromel-Kopel", the hot junction of which is located near its end face facing the rock sample under study, and the cold junction is placed on the opposite end face.

To ensure good thermal contact between the test sample and the reference bodies, the corresponding end surfaces were pre-sanded, and during the Assembly of the working cell, a high-heat-conducting lubricant was introduced into the contact zone.

The cell with the reference semi-bounded bodies and the test sample was enclosed in a core holder 1 and fixed with a screw 2.

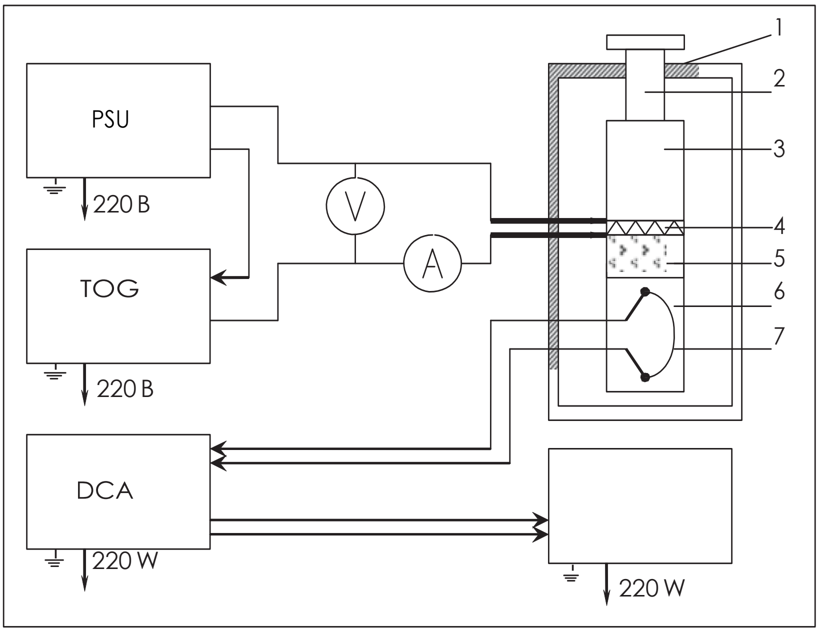

Figure: 1 Schematic diagram of the installation for determining the thermal properties of rock samples.

The electrical circuit of the experimental unit is designed for setting the boundary conditions of the experiment and recording temperature and heat flow fluctuations. Setting the heat flow fluctuations of a fixed frequency and amplitude is carried out using an adjustable power supply unit (PSU) and a thermal oscillation generator (TOG) with a frequency divider and an electromagnetic relay.

Measurement of the amplitude of the power consumed by the flat electric heater 4 is carried out using an ammeter and a voltmeter included in the output circuit from the power supply unit (PSU) and the TOG. Temperature fluctuations with amplitude from a few to tens of microvolts are amplified by a direct current amplifier (DCA), which simultaneously compensates for the constant component of the signal picked up by the thermocouple 7. The amplified periodic part of the measurement signal, as well as fluctuations in the heat flow, is recorded using a self-recording device (SD).

III. RESULTS AND DISCUSSION

In fig. 2 the study results of thermal conductivity λ of the described samples are presented. As can be seen from Fig. 2, the λ of sandstones depends significantly on the nature of their saturation. The averaged dependence of the thermal conductivity of rocks on the type of their fluid saturating is shown in Fig. 3.

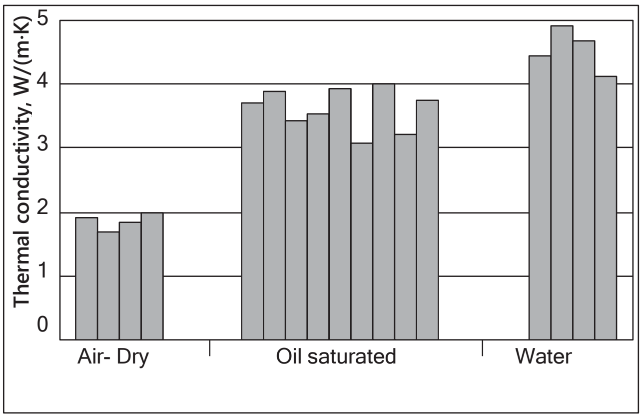

Figure: 2 Histogram of sandstones thermal conductivity

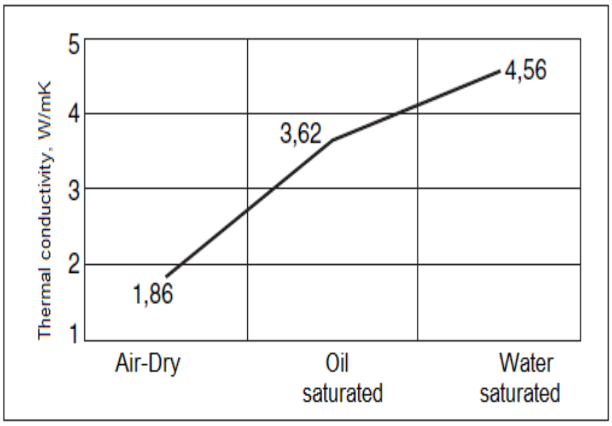

Figure: 3 Dependence of the average thermal conductivity of on the nature of their saturation

The lowest values of thermal conductivity have air-dry samples, higher - oil-saturated and the highest - water-saturated. This is due to the significant influence on the λ of the rocks by the thermal conductivity of the fluid saturating their pores.

Thus, the thermal conductivity of water is, on average, 4 times greater than the thermal conductivity of oil and 14–25 times higher than the thermal conductivity of natural gases and air, respectively.

In Fig. 4 Histograms of thermal diffusivity of dry (extracted), oil- and water-saturated sandstones were constructed. As can be seen from Fig. 4, the lowest thermal diffusivity corresponds to air-dry samples, the higher- to oil-saturated ones, and the highest-to water-saturated ones. This is clearly seen from Fig. 5, which shows the average thermal diffusivity of the samples depending on the type of their saturation.

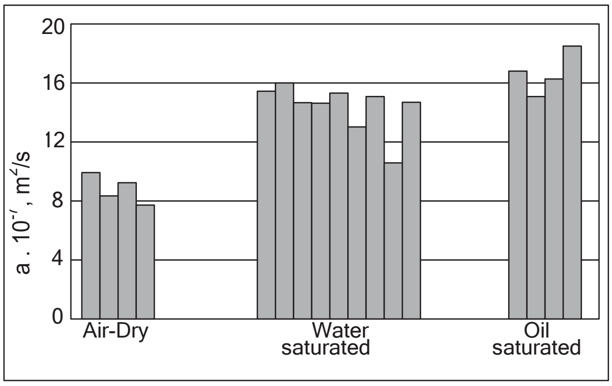

Figure: 4 Histogram of sandstones thermal diffusivity

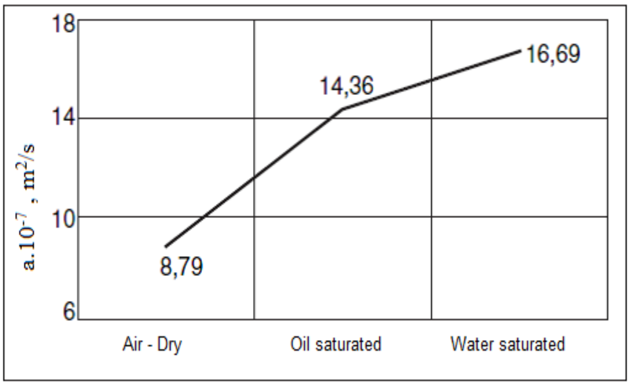

Figure: 5 Dependence of the average thermal diffusivity of sandstones on the type of saturation

The volumetric heat capacity (C_V) of the studied rocks is calculated from the data on their thermal conductivity (λ) and thermal diffusivity (a) [17, 18 ,19]:

$$C_V = \lambda / a$$

In contrast to thermal and thermal diffusivity, this is a more "conservative" parameter, i.e. it changes in a narrower range of values, as shown in figure 6. The average volumetric heat capacity (Fig. 7) also depends on the nature of saturation.

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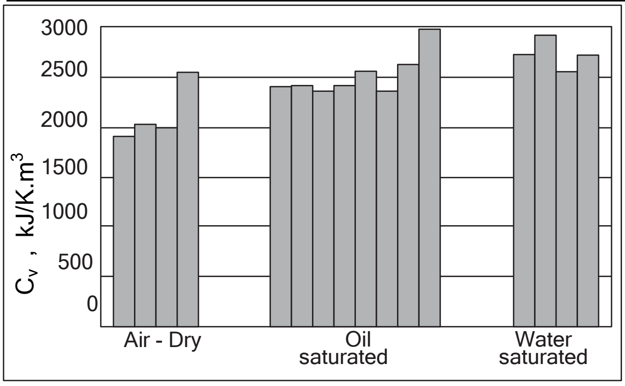

Figure: 6 Histogram of the volumetric heat capacity of sandstone

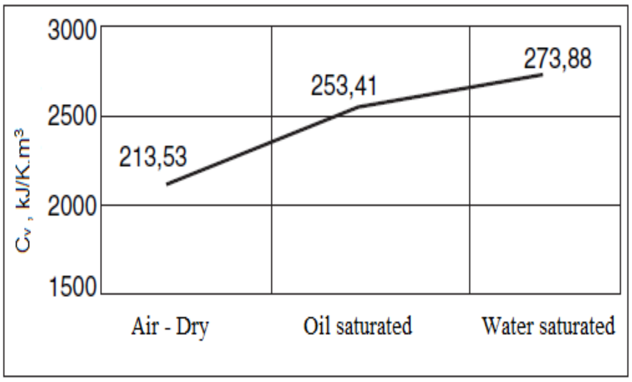

Figure: 7 Dependence of the average volumetric heat capacity of sandstone on the type of their fluid saturation

The highest volumetric heat capacity corresponds to water-saturated rock samples.

Based on the data on thermal conductivity (λ), thermal diffusivity (a) and density (ρ) of rock samples, it is possible to determine their specific heat capacity (C_{sp}) [20 , 21 , 22 , 23] :

$$C_{sp}=\lambda/(a.\rho)$$

Figure 8 shows histograms of the specific heat capacity of dry, oil-and water-saturated Sandstone samples, and figure 9 shows the dependence of their average specific heat capacity on the nature of saturation. As can be seen from Fig. 9, the specific heat capacity of rocks also increases when saturation changes from air - dry to oil- and water-saturated.

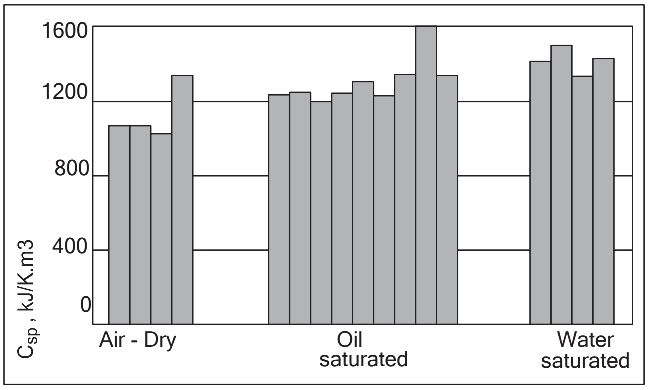

Figure: 8 Histogram of specific heat capacity of sandstone

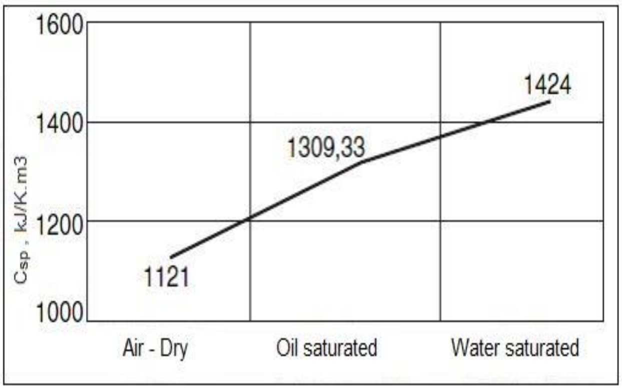

Figure: 9 Dependence of the average specific heat capacity of sandstones on the type of fluid saturating them

IV. CONCLUSION

Based on the conducted research, the following conclusions can be drawn:

- The effect of the type of saturating fluid on thermal properties is most clearly seen in highly porous rocks (sandstones);
- The thermal properties of highly porous sandstones depend significantly on the nature of their saturation. The highest values of λ , a , C_V, and C_{sp} correspond to water-saturated rock samples, the lower ones correspond to oil-saturated rock samples, and the lowest values correspond to dry (extracted) ones. In this regard, water-saturated interlayers are more heat-conductive than oil-saturated and especially gas-saturated ones;
- Water-saturated samples of the studied rocks have higher values of heat and thermal conductivity than oil - saturated ones, so in the process of replacing oil with water (during the development of oil deposits) λ and a of the layers increase.

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