EXPERIMENTAL EVALUATION OF THE CRITERIAL NUMBER FOR DIFFUSIVE MASS AND HEAT TRANSFER IN SAND SATURATED WITH PETROLEUM AND WATER

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UDC 536.24:532.72

An experimental method of determining the criterial number for diffusive mass and heat transfer in sand saturated with petroleum and water is proposed and results are shown.

Heat propagates by diffusive mass transfer during the heat treatment of petroleum beds. It is of interest here to evaluate the diffusive mass and heat transfer in sand saturated with petroleum and water.

The simplest mode of diffusive mass transfer is isothermal, effected by the mechanism of isothermal capillary impregnation with liquid and by vapor diffusion. As a result of relatively small temperature gradients in porous collectors, this mode of mass transfer does apparently occur when petroleum beds are heat treated. The authors present here the results of an experimental evaluation of the diffusive mass and heat transfer in sand specimens with various petroleum, water, and air saturation levels at various temperatures.

The diffusive mass and heat transfer is characterized by the following dimensionless criterial number [1]:

$$\mathrm{Lu} = \frac{a_m}{a_q}.$$

It is not difficult to see that, in the case of a petroleum collector, this number defines the ratio of heat involved in diffusive mass transfer to total heat transferred by the mechanism of effective conduction.

Determining the criterial number for diffusive mass and heat transfer consists in a separate measurement of liquid diffusivity and thermal diffusivity in the same sand specimens.

A determination of liquid diffusivity by the standard method [2] with filter paper as the reference substance has proven ineffective in the case of petroleum-saturated collectors. This is due, apparently, to the high rate of surface activity in petroleum and the resulting fast blockage of capillaries in the first sheets of filter paper, which retards further mass diffusion. In view of this, a method has been developed on the principle that at the contact boundary between two semiinfinite sand specimens, one completely dry and one saturated with a liquid, the specific mass contents are equal under steady-state conditions. In this case we are dealing with a linear problem of specific mass contents in two semiinfinite bodies and obtain easily

$$u(x, \tau) = \frac{u_0}{2}\left(1 + \operatorname{erf}\frac{x}{2\sqrt{a_m\tau}}\right). \tag{1}$$

We will define the quantity of liquid passing through a unit contact area per unit time as

$$\frac{dM}{d\tau} = -a_m\rho_0\left(\frac{du}{dx}\right)_{x=0}. \tag{2}$$

After inserting (1) into (2) and integrating, we have

All-Union Scientific-Research Institute of Petroleum and Natural Gas, Moscow. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 22, No. 6, pp. 1027-1030, June, 1972. Original article submitted July 8, 1971.

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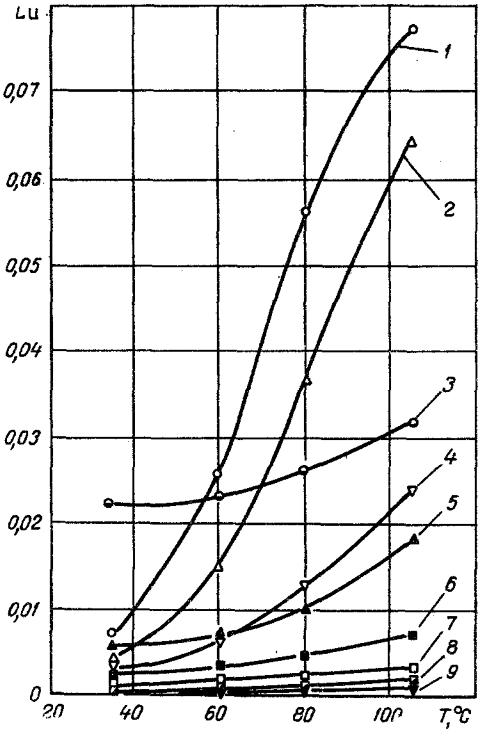

Fig. 1. Criterial number for diffusive mass and heat transfer, as a function of the temperature, at various levels of petroleum and water saturation in a specimen: 1) 100% petroleum; 2) 60% petroleum and 40% air; 3) 100% water; 4) 60% water and 40% air; 5) 20% water and 80% air; 6) 20% water and 80% petroleum; 7) 20% water and 40% petroleum and 40% air; 8) 60% water and 20% petroleum and 20% air; 9) 60% water and 40% petroleum.

$$a_m = \frac{\pi}{\tau}\left(\frac{M}{u_0\rho_0}\right)^2. \tag{3}$$

Relation (3) is very simple and requires only the determination of the quantity of liquid passing through a unit contact area.

Tests were performed with a brass cylinder, 0.104 m long and 0.09 m in diameter, and a removable insert with a filter mesh dividing the cylinder vertically into two halves. One half was filled with the reference substance, namely with dry quartz sand with the same porosity characteristics as the test specimen. The test specimen saturated with water, petroleum, and air in definite proportions was poured into the other half of the cylinder.

The cylinder dimensions were based on the similarity condition pertaining to two semiinfinite media, according to which the change in specific mass content at the end surface of the saturated cylinder half during a test could be disregarded. It is not difficult to establish that, with the given cylinder dimensions and according to formula (1), the difference between the initial and final specific mass content at the end surface of the saturated cylinder half would not exceed 3% at temperatures below 60°C but would increase by up to 10% at temperatures from 60 to 200°C.

The cylinder was hermetically sealed at both ends with screw-on covers and placed horizontally inside a thermostat, where it was held for 3 h under isothermal conditions. After that period of time, the quantity of liquid was determined which had passed into the reference specimen. Each test was repeated at least three times. The total experiment included 150 tests at various temperatures and saturation levels.

Model liquids were Yareg petroleum (density 945 kg/m^3, viscosity 3500 cP at 20°C) and distilled water (density 987.8 kg/m^3, viscosity 1.006 cP). The collector used was washed, dried, and sifted sand from the Lyubaretsi quarry with grains 0.2-0.4 mm in diameter. The porosity of a dry specimen was 39.2%, its density was 1600 kg/m^3.

The thermal diffusivity of specimens was determined by the standard method with a regular duty cycle of the first kind [3].

The test specimen was hermetically sealed inside a thin-walled cylindrical calorimeter 0.048 m in diameter and 0.075 m long. A thermocouple was installed at the center of the specimen. The calorimeter was then heated in a water bath up to 80-90°C and thermostatted at 20-22°C. The temperature decrease was recorded with a model ÉPP potentiometer and plotted to a semilog scale. The thermal diffusivity was then calculated by the formula

$$a_q = km. \tag{4}$$

The cooling rate in the regular mode was calculated by the formula

$$m = \frac{\ln T_1 - \ln T_2}{\tau_2 - \tau_1}.$$

The values of thermal diffusivity obtained in this way were averages over a temperature range from 20 to 90°C. In view of this, additional experiments were performed in order to determine the thermal diffusivity of specimens within narrow temperature ranges. Differences between average values of thermal diffusivity and actual values at the extreme ends of a given temperature range did not exceed 3%. On this basis we concluded that the thermal diffusivity of saturated specimens could be considered independent of the temperature, within the test range.

The temperature characteristic of the criterial number for diffusive mass and heat transfer at various levels of petroleum and water saturation is shown in Fig. 1. According to the diagram:

1. The criterial number for diffusive mass and heat transfer in specimens saturated with petroleum and water is not larger than 0.1 and, therefore, the fraction of diffusive mass transfer in the total heat transfer by the mechanism of effective conduction does not exceed 10%.

2. In specimens containing more than 60% petroleum the criterial number for diffusive mass and heat transfer depends strongly on the temperature.

3. The fraction of diffusive mass transfer in the total heat transfer is most often greater for specimens saturated with a binary liquid mixture (petroleum–water) than for specimens saturated with a single liquid.

NOTATION

a_m	is the liquid diffusivity of collector substance, m^2/sec;
a_q	is the effective thermal diffusivity of collector, m^2/sec;
u_0	is the initial specific mass content in sand specimen, kg/kg;
u	is the specific mass content in sand specimen at any time, kg/kg;
x	is the linear coordinate, m;
τ	is the contact time, sec;
M	is the quantity of liquid passing through a unit contact area, kg/m^2;
ρ_0	is the density of liquid, kg/m^3;
$k = 1/11,820$	is the form factor, m^2.

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