THE KINETICS OF CAPILLARY ABSORPTION OF LIQUIDS IN A CONSTANT MAGNETIC FIELD

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UDC 532.63:538.12

The method and technique of experimental study is described with respect to the kinetics of capillary absorption of distilled water and a 10% aqueous solution of NaCl by quartz sand in a nonuniform magnetic field. The results of this experimental study are given.

The effect of magnetic fields on various systems has recently been the subject of intensive investigation, both at home and abroad [5-8]. We found that the effect of a magnetic field leads to an extensive range of physical, technological, and similar characteristics. As demonstrated in [1-2], electric diffusion due to a gradient in electric-field strength, and magnetic diffusion due to a gradient in magnetic-field strength should result from the presence of nonuniform electric and magnetic fields.

With only a constant magnetic field in effect, the transport equation is written in the form

$$j = -a_m \gamma_0 \nabla U - a_m^T \gamma_0 \nabla T - a_m^{\mathrm{mag}} \gamma_0 (\nabla B)/\Pi_{\mathrm{mag}}, \tag{1}$$

where a_m^{mag} is the coefficient of magnetic moisture diffusion in a porous body.

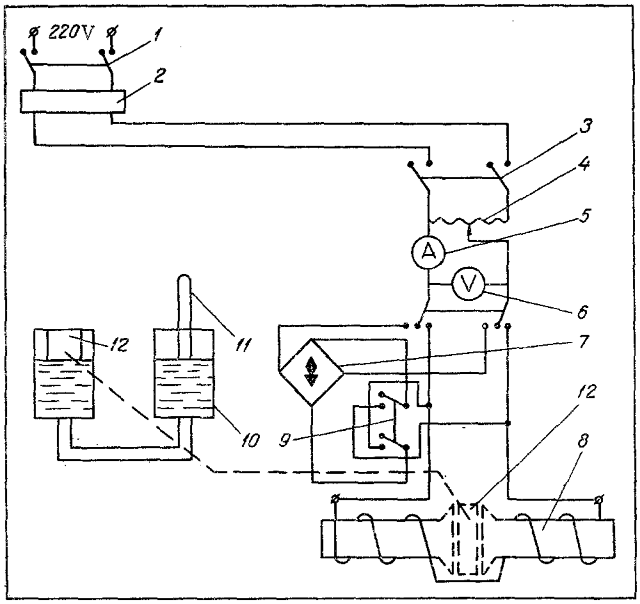

Fig. 1. Diagram of the installation used to investigate the kinetics of capillary absorption in an electromagnet field: 1) automatic unit; 2) voltage stabilizer; 3) switch; 4) autotransformer; 5) M-104 ammeter; 6) voltmeter; 7) rectifier; 8) electromagnet with removable poles; 9) switch; 10) U-shaped vessel; 11) metering tube; 12) test specimen.

Here we consider the special problem relating to the kinetics of capillary liquid absorption under the action of a constant magnetic field.

In solving the problem of developing an electromagnet, we proceeded on the basis of considerations which made provision for the need to achieve the maximum possible field strength for the greatest gap between the poles. The electromagnetic field was established by means of a dc and an ac electromagnet (Fig. 1). The electromagnet consists of a rectangular magnetic circuit made up of 0.35 mm electrical steel sheet and removable poles covered with segmented windings. The magnetic circuit is bolted tight with steel plates. With this device it is possible substantially to reduce the leakage flux and to ensure excellent rigidity for the system.

The magnetic circuit is fashioned so that an orifice 124 × 124 mm remains at the ends for the installation of the poles. The shifting of the poles and the setting of the required gap is accomplished by turning a knob. The distance between the pole pieces may vary from 0 to 90 mm.

The magnetizing coils are made up of eight segments with PB wire (3.05 mm in diameter)

Institute of Heat and Mass Transfer, Academy of Sciences of the Belorussian SSR, Minsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 16, No. 2, pp. 270-275, February, 1969. Original article submitted July 3, 1968.

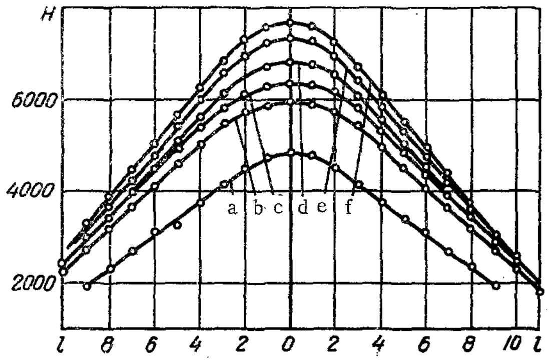

Fig. 2. Distribution of magnetic-field strength H, in Oe in the 60 mm gap between the poles of the electromagnet, along the axis perpendicular to the magnetic lines of force, as a function of the current strength in the winding of the electromagnet: a) I = 10 A; b) 15 A; c) 18 A; d) 20 A; e) 25 A; f) 28 A; l, in cm.

used for the winding, and the fill factor is 0.9. There is a total of 2800 turns. The coils can be series-connected, or they can be connected in parallel. The electromagnet is fitted out with a device which makes it possible to turn the electromagnet about the axis through 180°, thus permitting various types of research to be conducted in the field of the electromagnet.

After the constant magnetic field is set up, the electromagnet is fed from a rectifier which operates on a three-phase bridge circuit.

The output voltage of the rectifier varies smoothly from 0 to 220 V, thanks to the RNT-220-6 voltage regulator. Armco-iron pole pieces are used for work in a constant magnetic field.

Figure 2 shows the distribution curves for the strength of the magnetic field along the axis. The strength of the magnetic field is measured by an E11-3 magnetic induction meter, accurate to within 2-3%.

To study the mechanism of liquid motion in capillary-porous bodies, we produced the installation shown in Fig. 1.

The main part of the installation is the U-shaped vessel filled with the test liquid, with the test material in a column on one of the arms, and the other arm containing a sealed glass metering tube. The glass metering tube is filled with the test liquid and, at the open end, is brought into contact with the liquid in the U-shaped vessel.

Prior to the beginning of the experiment $P_1 + h\gamma = P_a$, where P_1 is the air pressure above the level of the liquid in the metering tube; P_a is the barometric pressure; h is the height of the liquid column.

As soon as the absorption process begins, the liquid level in the U-shaped vessel drops, and air bubbles enter the metering tube which ejects a specific amount of liquid until an equilibrium state is again established. Thus the liquid level in the U-shaped vessel is kept constant. The quantity of absorbed liquid can be judged in the metering tube from the movement of the meniscus. The U-shaped vessel is housed in a plastic container – thermally insulated with foam plastic – through which water is kept circulating from a TL-150 ultrathermostat. The temperature is maintained to within an accuracy of 0.1°C. All of the experiments were performed at a temperature of 22°C.

The experiments were carried out in the following sequence. A column with a reticulate bottom is filled with the test material which is compressed for 1 min on a vibration stand. The column is then placed into one arm of the U-shaped vessel, and it is kept between the poles of the electromagnet until contact with the liquid. At the instant that it comes into contact with the liquid, a stopwatch is started and the height of the liquid rise in the column is followed visually on a scale marked on the column, and note is also taken of the quantity of absorbed liquid from the movement of the liquid meniscus in the metering tube.

Here we present the experimental results obtained from our study into the kinetics of capillary absorption of distilled water and a 10% aqueous solution of NaCl in quartz sand of the following granulometric composition: 17% with a diameter of 0.1-0.2 mm; 49% with a diameter of 0.2-0.315 mm; and 34% with a diameter of 0.315-0.5 mm.

We performed experiments in a uniform magnetic field with a strength of up to 11,000 Oe, as well as in a nonuniform magnetic field with various field gradients.

In the experiments in a uniform magnetic field we found that the magnetic field exerts no noticeable effect on the mechanism of capillary liquid absorption.

The experimental data for the nonuniform magnetic field are shown in Fig. 3. Here we also show the rates of absorption as functions of the quantities reciprocal to the height of liquid rise $dh/d\tau = f(1/h)$, derived by graphical differentiation of the above-cited curves.

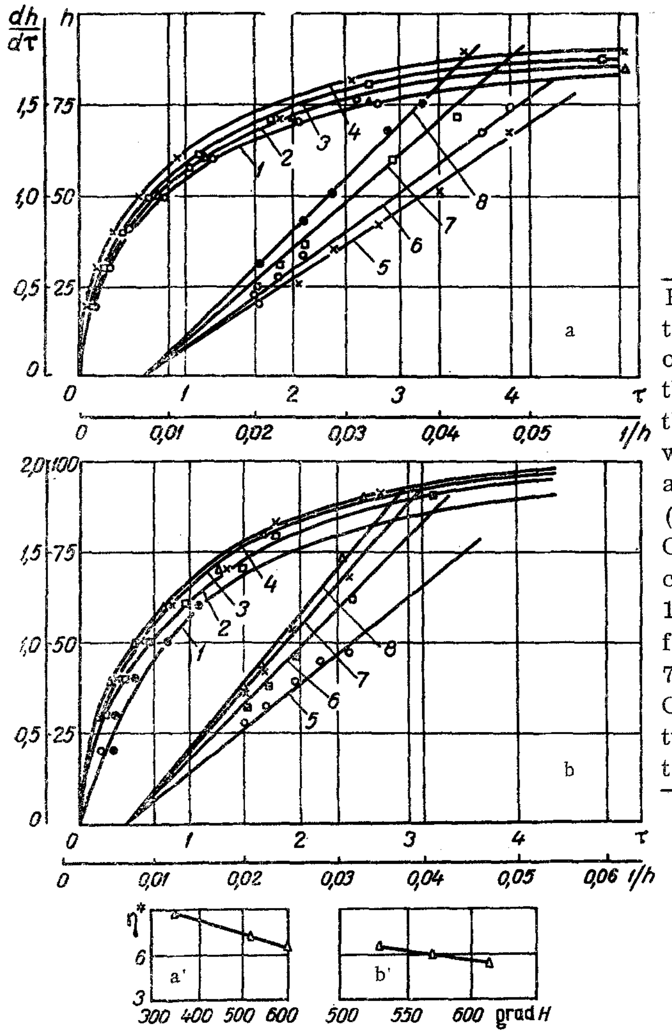

Fig. 3. Curves for the kinetics of capillary absorption of distilled water (a) and a 10% aqueous solution of NaCl (b) in quartz sand for various gradients of the magnetic-field strength: 1) the height h (mm) of the capillary rise as a function of the time τ (min) without a magnetic field; 2) in a magnetic field, with an average strength gradient of dH/dx = 372 Oe/cm (a) and 537 Oe/cm (b); 3) for 537 Oe/cm (a) and 575 Oe/cm (b); 4) for 610 Oe/cm (a and b); 5) rate of capillary absorption dh/dτ (mm/sec) as a function of 1/h (mm^{-1}) without a magnetic field; 6) in a magnetic field for dH/dx = 372 Oe/cm (a) and 537 Oe/cm (b); 7) for 537 Oe/cm (a) and 575 Oe/cm (b); 8) for 610 Oe/cm (a and b); a' and b' show the relationships between η^* and grad H (Oe/cm), respectively, for distilled water and a 10% aqueous solution of NaCl.

We see from Fig. 3 that the rate of capillary absorption of distilled water and 10% aqueous solution in quartz sand in a magnetic field differs from the rate of capillary absorption without a magnetic field to an extent that is greater, the greater the gradient of the magnetic-field strength. The relationships between the rates of capillary absorption and the magnitudes reciprocal to the height of liquid rise are plotted as straight lines which intersect the positive axis of abscissas.

As shown in [3-4], the rate of capillary liquid absorption in capillary-porous bodies can be presented in an equation of the form

$$\frac{dh}{d\tau} = \omega_0 \left(\frac{1}{h} - \beta \right), \tag{2}$$

where β represents the segment cut by the straight line of the dh/dτ as a function of 1/h on the positive portion of the axis of abscissas:

$$\beta = \frac{1}{h_{\max}}, \quad \omega_0 = \operatorname{tg}\varphi, \tag{3}$$

where φ is the angle at which the straight line slopes to the horizontal.

It should be pointed out that these straight lines intersect the axis of avscissas at only a single point, both for the case of distilled water and for the case of a 10% aqueous solution of NaCl, for various gradients of the magnetic-field strength.

Consequently, the maximum height of liquid rise (or the maximum quantity of absorbed liquid) in the above-cited cases for various magnetic-field gradients is identical.

According to [3-4], the liquid viscosity is given by the expression

$$\eta = \frac{\gamma_0 R^2_{\text{eff}} g h_{\max}}{8 \operatorname{tg} \varphi}, \tag{4}$$

where γ_0 is the liquid density; R_{eff} is the effective mean capillary radius; tan φ is the tangent to the angle of straight-line inclination to the horizontal. The tangent to the angle of inclination for the straight line given by $dh/d\tau$ as a function of $1/h$ thus determines the liquid velocity as a function of the mean magnetic-field strength gradient

$$\eta^* = \frac{\eta}{\eta_0} = \frac{\operatorname{tg} \varphi_0}{\operatorname{tg} \varphi}, \tag{5}$$

where η_0 is the liquid viscosity without a magnetic field; η is the liquid viscosity in a magnetic field.

Figure 3 shows η^* as a function of the magnetic-field strength gradients for distilled water and a 10% aqueous solution of NaCl. As we can see from the figure, η^* diminishes with an increase in the magnetic-field strength gradient.

Analyzing the resulting experimental data, we can draw the conclusion that a nonuniform magnetic field accelerates the motion of a liquid in capillary-porous bodies and this, apparently, is associated with the reduction in liquid velocity in a nonuniform magnetic field.

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