# EXPERIMENTAL STUDY OF NONSTATIONARY LIQUID FLOW IN CAPILLARY-POROUS BODIES

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This paper describes the method and results of an experimental study of liquid flow in models of capillary-porous bodies and in capillary-porous bodies under isothermal conditions.

Numerous studies [1–3] on the physics of flow through porous media have shown that these processes do not as yet have the requisite theoretical foundation. To clarify the mechanism of moisture movement in capillary-porous bodies, we carried out tests on separate cylindrical capillaries, on a bundle of capillaries of different diameters, and on capillary-porous bodies.

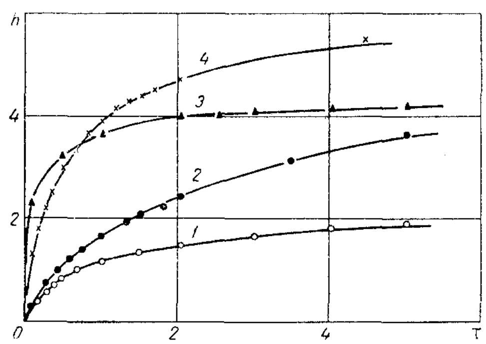

Fig. 1. Capillary rise of liquids in cylindrical capillaries (h, cm; $\tau$, min). 1) Castor oil; 2) glycerol; 3) water; 4) fish oil.

The capillaries were drawn from thick-walled glass tubes, washed beforehand in chromic $H_2SO_4$ cleaning mixture, acetone and distilled water so as to obtain a chemically clean surface, and dried in an oven. To avoid complications due to adsorbed films, only freshly-drawn capillaries were used in the tests.

The experiments took the following form [1, 3]. An image of the capillary was projected onto a screen, the magnification involved being determined by projecting the image of a transparent scale on the same screen. Capillary diameter was determined with a microscope.

A stopwatch was started at the moment of contact between the capillary and the liquid, and the liquid level was marked on the screen at definite intervals (usually 5 sec at the beginning, and subsequently at longer intervals). This gave the relation between liquid height h and rise time (Fig. 1).

The kinetics of liquid absorption by a cylindrical capillary were studied for various diameters and under isothermal conditions. For convenience, viscous liquids such as castor oil, glycerol, and fish oil were used. In addition, a complete series of tests was carried out with water. To examine the transition from a single capillary to a capillary-porous body, tests were run on bundles of capillaries of different diameters.

The kinetics of liquid absorption by both bundles and capillary-porous bodies were studied by the volumetric method [1, 3, 4]. Sand and clay were used as capillary-porous bodies (Table 1); water as the absorption liquid.

The apparatus consisted basically of a liquid-filled V-shaped glass container with branch diameters of 30 mm and 5 mm, respectively (Fig. 2).

The test material (bundle of capillaries, clay cylinder, column with sand) was lowered into the wide branch until it made contact with the liquid. As liquid was drawn up by the capillary-porous body, the level in the container fell. The position of the meniscus in the narrow branch gave an indication of the amount of liquid absorbed. A transparent scale attached to this branch gave the distance traveled by the meniscus. The value of a scale division was established by drawing off a definite quantity of liquid from the wide branch. To increase reading accuracy, the inclined tube and scale were projected onto a screen.

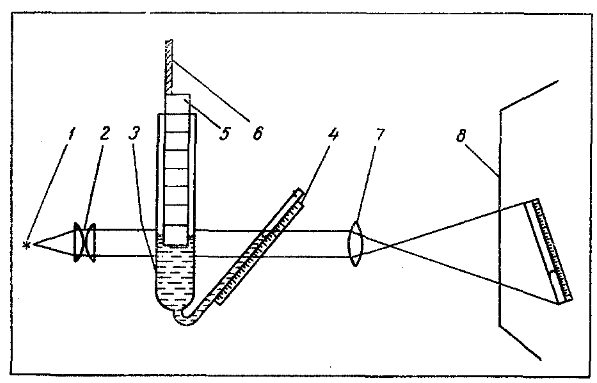

Fig. 2. Schematic of apparatus. 1) Light source; 2) condenser; 3) V-shaped container; 4) transparent scale; 5) demountable column; 6) graduated scale; 7) lens; 8) screen.

The clay samples were in the form of cylinders, dried at room temperatures, and then kept in an oven at 100°–110° C.

The sand was poured into a 15-mm diameter column, which was composed of glass sections glued together with BF-2 glue, and which had a latticed

Table 1

Characteristics of Materials Used

| Material | % Size distribution for diam. in mm | | | | | | | | Specific gravity |
|---|---|---|---|---|---|---|---|---|---|
| | 2—1 | 1—0.5 | 0.5—0.25 | 0.25—0.1 | 0.1—0.05 | 0.05—0.01 | 0.01—0.005 | <0.005 | |
| Sand 1 | 0.6 | 9.5 | 69.8 | 18.0 | 0.90 | 0.50 | 0.70 | | 2.66 |
| Sand 2 | 0.30 | 0.20 | 5.0 | 79.2 | 13.3 | 0.4 | 1.6 | | 2.61 |
| Clay | | | 0.30 | 0.50 | 8.7 | 33.5 | 14.9 | 42.10 | 2.82 |

Table 2

Experimental Values of Coefficients $\alpha$ and $\beta$

| Body | Liquid | Capillary radius, cm | $\alpha$, cm²/min | $\beta$, cm⁻¹ |
|---|---|---|---|---|
| Cylindrical capillary | glycerol | 0.017<br>0.008 | 1.04<br>1.9 | 0.2<br>0.06 |
| " | fish oil | 0.042<br>0.039 | 20.7<br>27.0 | 0.62<br>0.58 |
| " | castor oil | 0.042<br>0.033 | 1.64<br>1.4 | 0.52<br>0.58 |
| " | water | 0.031<br>0.034 | 8.55<br>7.0 | 0.213<br>0.31 |
| Sand 1 | " | — | 25.0 | 0.24 |
| Sand 2 | " | — | 36.6 | 0.96 |
| Clay | " | — | 0.007 | 0.21 |
| Sand 1-clay mixture (5:2) | " | — | 0.17 | 0.84 |

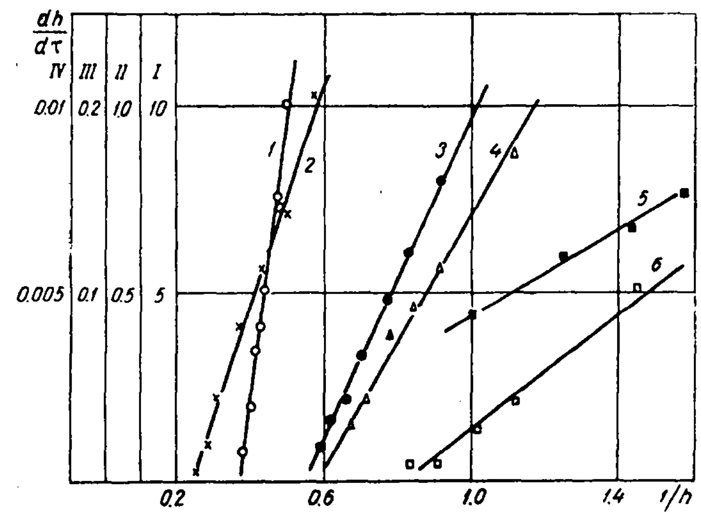


Fig. 3. Relation between capillary absorption rate dh/dτ, cm/min, and 1/h, $cm^{-1}$. 1, 3, 4) Cylindrical capillaries; 2) sand; 5) clay; 6) sand-clay mixture; 1, 2, 3) given in coordinate column I; 4) in column II; 5) in column IV; and 6) in column III.

bottom. When the test was completed, the column was dismantled and the contents of each section were measured by drying in weighing bottles. This made it possible to plot a curve of moisture against height.

Both the clay cylinder and the column containing the sand were firmly attached to the graduated scale, from which the rise of the liquid could be measured.

At the moment of contact between the body and the liquid, a stopwatch was started. The position of the meniscus and the liquid height were noted, first at short, and then at longer intervals.

Thus, the relations absorbed liquid volume W versus time $\tau$, and height h versus $\tau$ were obtained simultaneously.

Rate of flow is an important factor in defining liquid capillary flow in capillary-porous bodies. To obtain such curves we graphically differentiated the experimental h versus $\tau$ curves (Fig. 3).

The conclusion, based on the results of more than 45 tests, is that the rate at which the liquid rises depends linearly on 1/h both for single capillaries and for capillary-porous bodies. Consequently, we can write:

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

where $\alpha$ and $\beta$ are constants, depending on the material properties and test conditions (Table 2), and $\alpha = \mathrm{tg}\varphi$ ($\varphi$ is the angle of inclination of the rate of rise curve to the axis of abscissas) and $\beta = 1/h_{max}$, i.e., the reciprocal of the maximum capillary rise. Hence, the graphs in Fig. 3 make it possible to determine $h_{max}$, which is extremely difficult to do from the absorption kinetics curves, since these approach a constant value, their asymptote, only very slowly.

Thus, our test results show that under isothermal conditions liquid capillary movement conforms to the same law for both individual capillaries and capillary-porous bodies.

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