LIQUID FILTRATION IN FINELY POROUS CAPILLARY STRUCTURES

A. A. Belyaev, A. Yu. Zubarev,
V. M. Kiseev, and N. P. Pogorelov

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A histeresis relationship between the permeability of a finely porous filter and its temperature has been revealed and investigated.

It is well known that various anomalous phenomena leading to a violation of Darcy's law occurs in filtering actual liquids. This may be caused by the non-Newtonian nature of the fluid [1, 2], adsorption of small impurity particles or polymer molecules on the walls of pore channels [3], blocking of pores by large particles [4-6] or gas or vapor bubbles [7, 8], and many other factors. The anomalous phenomena should manifest themselves especially strongly during filtration in fine-dispersion media (particle diameters, d_ρ = 1-10 μm) and finely porous capillary structures (with pore diameters $d_{\rho 0}$ = 1-10 μm). We provide here the results of experiments on the flow of distilled water through specimens of porous materials, obtained by sintering finely divided nickel powder with particle diameters of the order of 0.5 μm. It should be mentioned that investigation of the filtering process in such structures is also of interest because they are used as wicks in heat pipe loops.

Initial experiments have shown that the permeability K of a filter diminishes with the time τ after the liquid starts to flow through it (Fig. 1). The behavior of the function $K = K(\tau)$ can be described by Meyer's expression [7] after determining the empirical parameters appearing in it. This effect can be produced by the blocking of pores by impurity particles or by the formation of gas bubbles in the specimen's pores.

Additional experiments have shown that the value of K does not change to any noticeable extent if polymer filters where the pore dimensions are the same as or smaller than, those in the structure under investigation are provided before the "inlet" to the specimen. Thus, the transient effects are actually determined by the formation of gas bubbles. In this case, the permeability of the capillary structure must depend heavily on the temperature. Actually, the permeability diminished considerably when the filter and the distilled water passing through it were heated. In principle, this phenomenon, as well as the derived relationship $K = K(\tau)$, are well known [7]. However, during the heating and subsequent cooling of the measuring capsule containing the filter, a number of histeresis phenomena, not mentioned in the literature available to us, were revealed and investigated.

Figure 2 shows the results of experiments concerning the temperature effect on the filtration of distilled water through a specimen of a finely porous nickel capillary structure with the porosity Π = 72% and the pore diameter $d_{\rho 0}$ = 1 μm. All the experimental results given in these and other diagrams were plotted after the permeability K no longer varied appreciably with time. The experimental results are given in Fig. 2, a and b, while the difference between the experimental conditions was that the maximum heating temperature was equal to T_{max} = 90°C in the first case, and 96°C in the second.

It is evident from Fig. 2a that histeresis phenomena arise if the filter is heated to a temperature of the order of 90°C and then cooled. This is probably connected with the fact that the surface of particles is initially covered with adsorption layers, which hinder the formation of gas bubbles. As the specimen is heated, it is cleansed, which results in an increase in the density of bubble nuclei. During cooling, the state of the surface of particles does not change, since the specimen is located in distilled water.

As the specimen is heated to a temperature above 70°C, vigorous deaeration occurs in front of it (the evolving gas bubbles can be observed visually), and virtually deaerated water enters the filter, so that the specimen's permeability does not change with the temperature.

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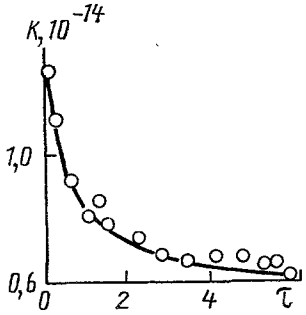

Fig. 1

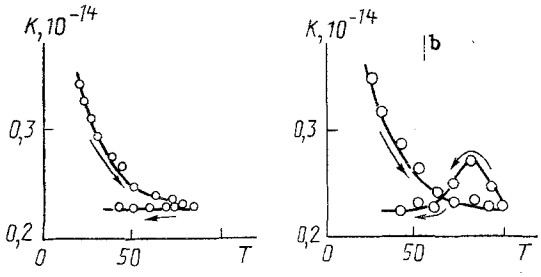

Fig. 2

Fig. 1. Permeability of a finely porous structure as a function of the flow time of distilled air-saturated water passing through it ($V' = 1.5$ cm^3/cm^3) at room temperature: K is given in m^2 units, and τ in hours.

Fig. 2. Permeability of the finely porous structure as a function of the temperature of the air-saturated, distilled water passing through it heated to $T_{max} = 90°C$ (a) and $T_{max} = 96°C$ (b).

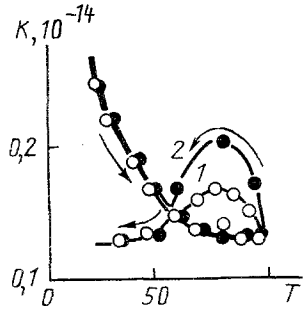

Fig. 3

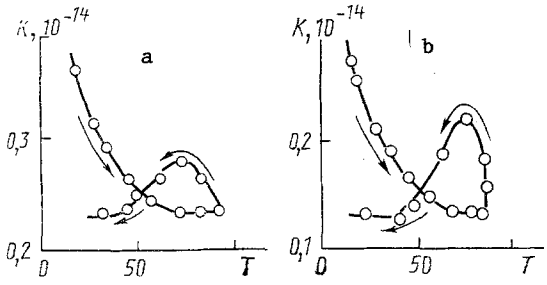

Fig. 4

Fig. 3. Effect of the pressure drop across the specimen on the permeability rise in cooling: 1) $\Delta P = 3 \cdot 10^3$ Pa; 2) $6 \cdot 10^3$.

Fig. 4. Effect of the porosity of a finely porous structure on the increase in the specimen's permeability during cooling: a) Π = 70.5%; b) 65.0%.

In heating to $T_{max} = 96°C$, the dynamic equilibrium in the pores is disturbed because vigorous vapor generation starts under constrained conditions in the pores ($d_{p0} = 1$ μm). As a result, the gas bubbles, which grow to a size beyond the critical one due to the evolving vapor, are carried away by the flowing liquid. New bubbles, no longer gas, but vapor bubbles, develop at the same places. As a result of prolonged heating of the filter and of the liquid flowing through it at a temperature 94-97°C, only vapor bubbles remain in the filter. As the specimen cools down, the vapor in the bubbles condenses, which reduces the bubble size and causes the permeability to increase considerably. With the temperature dropping still further, deaeration at the filter inlet stops, and aerated water flows into the specimen, so that gas bubbles form again in the cleared meniscuses, which reduces the filter permeability.

If the above explanation of the origin of the histeresis loop of the $K = K(T)$ curve is accurate, the behavior of this curve must be very sensitive to the pressure drop ΔP between the specimen's ends. Actually, the larger the value of ΔP, the more intensive the breaking away of the gas bubbles and the larger the number of vapor bubbles "sitting" at their locations. Figure 3 shows the results of the experiments performed on the same specimen with a finely porous capillary structure, but for different values of the pressure drop across

the specimen. It is evident that, according to the assumptions made, the histeresis loop is the larger, the larger the value of ΔP, while K is not responsive to the value of ΔP outside the histersis region.

The amplitude of the histeresis loop must also depend on the porosity of the material. Figure 4 shows the results of experiments performed under identical conditions on specimens of the same nickel powder, but characterized by different porosities. Specimens with porosity values close to each other, $\Pi_1 = 70.5\%$ (Fig. 4a) and $\Pi_2 = 65\%$ (Fig. 4b), where considered in order to ensure the same pore dimensions ($d_{p0} = 1$ μm). In spite of the small differences between the porosity values, the permeability values of the specimens are different from each other, and the relative peak-to-peak amplitude of the histeresis loop is much larger in the case of low-porosity specimens. The physical cause of this is obvious — in the case of lower porosity, there is a larger number of bubble nuclei.

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