DESCRIPTION OF CAPILLARY POTENTIAL CURVES OF POROUS MATERIALS

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1. Introduction

The capillary potential curve determine the relationship between the volume and pressure of the mercury intruding against the capillary forces into pores of a sample of porous material. Such relationship is the direct result of measurements conducted with a help of the mercury porosimeter and is a base for the standard method of determination of the pore size distribution. These distributions are important characteristics of microscopic structure of the pore space of porous materials. They enable one to determine the basic macroscopic parameters of such materials (e.g. the volume porosity, permeability or the internal surface) which play important role in many physical and chemical processes occurring in permeable porous materials (e.g. filtration, transport of mass, momentum and energy, wave propagation or chemical reactions).

The aim of this paper is to formulate the description of capillary potential curves of porous materials based on microscopic and macroscopic model of the mercury intrusion into porous material. In the microscopic description the chain model of pore space architecture has been used, whereas the macroscopic description has been based on the diffusion model of the intrusion process.

The analysis of influence of parameters characterizing pore size distribution on the capillary potential curve was performed for both microscopic and macroscopic models the intrusion process. The influence of the capillary diffusion coefficient on the form of this curve was illustrated. These models have been used to identify the pore size distribution of selected natural and model materials.

2. Microscopic model of mercury intrusion in a porous layer

In the microscopic description of pore space of porous material the pores are modeled as cylindrical pipes (links) with random distribution of their diameter D and length s, described by the density of probability $\psi(D,s)$. In this case, the pore space structure of porous medium is determined by two independent factors: the pore size distribution and the way of their connection, called here the architecture of the pore space, [1]. Consequently, even for the same pore diameter distribution, the pore space structure may be different. Regarding the pore architecture, one can distinguish three kinds of models of the pores space structure: the capillary, chain and network models. In the capillary model, the links of the same diameters are joined in series and form long capillaries of the constant diameter, crossing the whole material. The diameters of different capillaries have random values. In the chain model the links are randomly combined in series, creating the capillaries of step-wise changing cross-section. In the network model, the randomly connected links form a spatial net. The capillary and chain models are the limiting models of the network model describing the curves of capillary potential.

The expression describing the capillary potential curves for porous materials with the capillary pore architecture takes the form

$$(1) \qquad \frac{V_L(p)}{V_o} = \int_{D^*}^{\infty} \vartheta(D)dD \;,$$

where $D^* = 4\sigma cos(\theta)/p$, is the critical diameter of link in which the menisci is in equilibrium at a given pressure, $\vartheta(D) = D^2\bar{\psi}(D)/\overline{D^2}$ describes the volumetric distribution of pore diameters, whereas $\bar{\psi}(D)$ is the pore diameters distribution and $\bar{D}$ stands for its mean value.

For the chain model of pore space architecture we have

$$(2) \qquad \frac{V_L(p)}{V_o} = \left[2\beta(1 - exp(-\frac{1}{\eta\beta})) - \frac{1}{\eta}exp(-\frac{1}{\eta\beta}) \right] \int_{D^*}^{\infty} \vartheta(D)dD \,,$$

where

$$(3) \qquad \beta = \frac{\bar{D}_N/\bar{D}}{(1-\eta)N} \,, \quad \eta = \int_{D^*}^{\infty} \bar{\psi}(D)d(D),$$

whereas $N = L/a$ and a is the mean value of pore length.

3. Macroscopic model of mercury intrusion in a porous sample

The other possibility of description of mercury intrusion into a porous layer gives the diffusive model of capillary transport in porous media. In such model the quasistatic process of inviscid fluid intrusion coused by progressive increase of pressure is considered at the macroscopic level like non-stationary process of diffusion. For the simplest case equation describing fluid distribution in porous material takes the form, [2],

$$(4) \qquad \frac{\partial \rho}{\partial p} - div(C(\rho)grad(\rho)) = 0 \,,$$

where $C(\rho)$ stand for coefficient of capillary diffusion of inviscid fluid in porous material.

Solution of equation (4) for fluid intrusion into porous layer (at constant C) and for boundary condition obtained from the microscopic model is given by expression, [4],

$$(5) \qquad \rho(x,p) = \overline{\rho}[1 - \frac{4}{\pi} \sum_{m=0}^{\infty} \frac{1}{2m+1} exp(-\frac{(2m+1)^2\pi^2}{L^2}Cp)sin(\frac{(2m+1)\pi x}{L})\alpha].$$

In this case the capillary potential curve takes the form

$$(6) \qquad \frac{V_L(p)}{V_o} = [1 - 8 \sum_{m=0}^{\infty} \frac{1}{(2m+1)^2\pi^2} exp(-\frac{(2m+1)^2\pi^2}{L^2}Cp)] \int_{D^*}^{\infty} \vartheta(D)dD.$$

The derived expressions (1), (2) and (6) have been used in the analysis of influence of pore size distribution and capillary coefficient of diffusion on the capillary potential curve. Both types of models were applied to interpretation of such curves obtained by mercury intrusion method for samples of model and natural materials.

4. References

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