

Determination of surface area of porous adsorbent by ultrasonic measurement(*)

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ULTRASONIC method of measurement of pore surface area is discussed on the ground of the theory of fluid – saturated porous solid, accounting for the process of gas adsorption. The starting point of the discussion is the fact that the wave propagation velocities in the elastic fluid-porous solid composition depend not only on the density of solid matrix, but also on the amount of gas attached to the porous skeleton due to adsorption, and on the fluid-added mass resulting from the influence of the pore structure on the relative fluid flow. The obtained results concerning the determination of the surface area by means of the ultrasonic transverse wave velocities prove to be very useful and, in a reduced form, coincide with the experimentally verified proposals given by other authors.

W pracy przedyskutowano sposób wyznaczania powierzchni wewnętrznej porowatych adsorbentów przy wykorzystaniu ultradźwięków. Za punkt wyjścia przyjęto teorię deformowalnych ośrodków porowatych nasyconych płynem z uwzględnieniem zjawiska adsorpcji fizycznej. Wykorzystano przy tym fakt, że prędkość propagacji fal w sprężystym nasyconym ośrodku porowatym zależy nie tylko od gęstości porowatej matrycy, ale także od ilości płynu dołączonego do szkieletu w wyniku adsorpcji i sprężenia dynamicznego w następstwie wpływu struktury porów. Proponowany sposób wyznaczania powierzchni wewnętrznej posiada wiele zalet, a w przypadku uproszczonym jest zbliżony z propozycją podaną przez innych autorów i zweryfikowaną doświadczalnie.

В работе обсужден способ определения внутренней поверхности пористых адсорбентов при использовании ультразвуков. За исходную точку принята теория деформируемых пористых сред, насыщенных жидкостью, с учетом явления физической адсорбции. При этом использован факт, что скорость распространения волн в упругой насыщенной пористой среде зависит не только от плотности пористой матрицы, но также от количества жидкости присоединенного к скелету в результате адсорбции и динамического сопряжения вследствие влияния структуры пор. Предложенный способ определения внутренней поверхности имеет много достоинств, а в упрощенном случае, совпадает с предложением, приведенным другими авторами и экспериментально проверенным.

1. Introduction

IN MANY TECHNICAL applications of porous and powdered materials the knowledge of pore surface area is extremely important. It is a measure of the adsorption capacity of various industrial adsorbents; it plays an important role in determining the effectiveness of catalysis, ion exchange columns, filters; and it is also related to the fluid conductivity or permeability of porous media.

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The most common method of determining this parameter is based on the analysis of adsorption isotherms, that is, by measuring the amount of gas adsorbed at given temperature as a function of pressure. For measuring the amount of gas adsorbed, the conventional techniques, i.e. gravimetric or volumetric, are commonly used [1], in which the gas adsorbed is usually nitrogen (N_2) at its normal boiling point (77° K). An application of such techniques, however, requires high sensitivity measurements of several quantities and some additional corrections [1].

In order to determine the amount of gas adsorbed within a sample of porous adsorbent, different technique has been recently proposed [2] which uses ultrasonic velocity measurements. It relies on the fact that wave velocity in an elastic solid depends on its total density. When a gas is admitted to an elastic porous sample, total density of the system increases so that the amount adsorbed can be calculated from the resulting decrease in the wave speed.

In [2], discussion of wave velocities in the case when any gas is or is not adsorbed is based, in fact, on the macrocontinuum model of one-component medium. Such model, however, does not reflect two-phase nature of gas-saturated porous solids and does not take into account interface force interactions appearing in this case which may, in a general case, significantly affect the wave propagation velocities.

The purpose of this paper is to discuss the determination of the surface area by the ultrasonic method based on the two-phase model of fluid-saturated porous elastic solid. A gas-saturated porous adsorbent is considered as a mixture composed of two kinematically distinguishable components. The first consists of a porous skeleton and an adsorbed gas film, and the second is non-adsorbed gas filling the pores. The analysis is confined to mechanical system only, and it is assumed that the wave-length is much greater than the characteristic pore diameter, so that the scattering phenomena due to microinhomogeneity of porous skeleton can be neglected.

2. Surface area calculated from the BET (Brunauer, Emmett, Teller) equation

The specific surface area Σ of porous solid is the ratio of internal pore area S to mass M of the sample (see Fig. 1), [3], i.e.

$$(2.1) \quad \Sigma = \frac{S}{M} \text{ [m}^2\text{/g]}.$$

The most common method of determining the Σ -parameter from the process of physical gas adsorption, consists in measuring the amount of gas adsorbed within the porous sample. It is evident that the specific surface

area is directly related to the number of moles of adsorbate required to cover the pore area S with exactly one monolayer, and this relation is given by, [4],

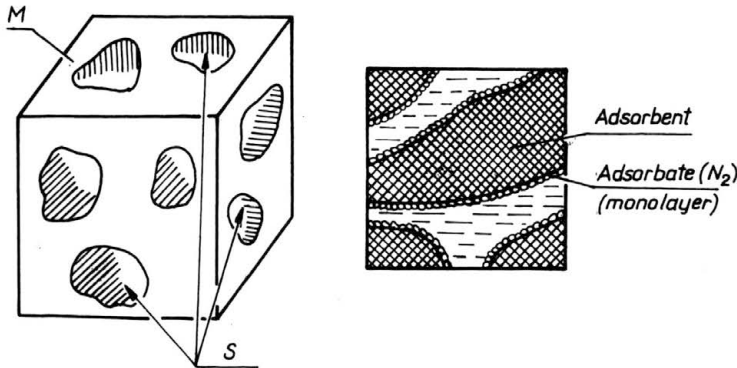


FIG. 1.

$$(2.2) \quad \Sigma = \frac{\bar{n}}{M} N_A \bar{\omega},$$

where \bar{n} is the number of moles of a monolayer, N_A is Avogadro's number, and $\bar{\omega}$ is the cross-sectional area of an adsorbate molecule.

In (2.2) the ratio \bar{n}/M is the unknown quantity and for its determination the widely accepted BET adsorption theory can be used. Applying the BET isotherm equation, [1], we have

$$(2.3) \quad \frac{\frac{P}{P_0}}{\frac{n}{M} \left[1 - \frac{P}{P_0} \right]} = \frac{1}{\frac{\bar{n}}{M} C} + \frac{C-1}{\frac{\bar{n}}{M} C} \frac{P}{P_0}, \quad 0 < \frac{P}{P_0} < 1,$$

where P is the equilibrium adsorbate pressure, P_0 stands for the saturation pressure, n/M is the amount of gas adsorbed within the porous sample at pressure P , and C is the BET constant expressing the adsorption energy.

A plot of $\frac{P}{P_0} \left[\frac{n}{M} \left(1 - \frac{P}{P_0} \right) \right]^{-1}$ versus P/P_0 , as shown in Fig. 2, yields a straight line of slope $s = (C-1) \left[\frac{n}{M} C \right]^{-1}$ and intercept $i = \left[\frac{\bar{n}}{M} C \right]^{-1}$, from which \bar{n}/M and C can be calculated. They are

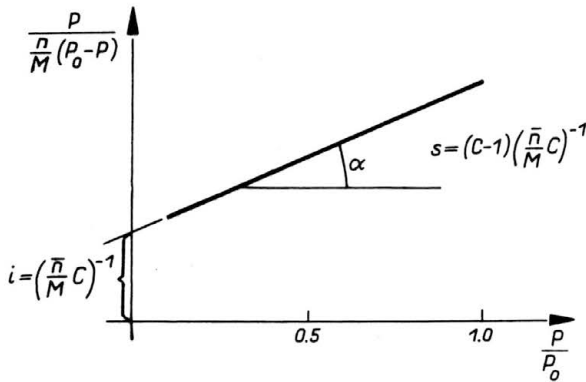


FIG. 2.

$$(2.4) \quad \frac{\bar{n}}{M} = \frac{1}{s + i},$$

and

$$(2.5) \quad C = 1 + \frac{s}{i}.$$

Having measured the amount of gas adsorbed n/M and the relative pressure P/P_0 , one can use relations (2.4) and (2.5) to determine the specific surface area,

$$(2.6) \quad \Sigma = \frac{1}{s + i} N_A \bar{\omega}.$$

It should be pointed out, however, that at measuring the quantity n/M by the conventional gravimetric or volumetric techniques, several strenuous requirements have to be satisfied. In the gravimetric method the sample must be weighed at 77°K inside the gas handling system and buoyancy corrections are needed. In the volumetric method calibrated volumes and dead volume corrections for the unadsorbed gas are required.

Ultrasonic technique, which will be discussed in the following sections, offers an advantage of making it possible to determine the surface area without the above requirements.

3. Two-component model of fluid-saturated porous adsorbent

3.1. Mass and motion equations for fluid-saturated porous solids with adsorbed layer

We assume that deformable, permeable adsorbent is completely filled with viscous fluid, a part of which forms the adsorbed layer on the interface, obeying the rules of physical adsorption. Such composition can be described within the theory of multicomponent continua, (see e.g. [5, 6, 7]). Since the production of heat due to physical adsorption is small [8], we confine our discussion to the purely mechanical case only.

To derive the mass and linear momentum macroscopic balance equations one can start from introducing the basic macroscopic field variables. This can be achieved by using the local volume averaging technique, [9]. Average quantities are obtained by integration of microscopic quantities $\Psi^{\alpha\alpha}$ of each α -component of the composition over a Representative Elementary Volume — REV (under the assumption that it exists), the result of which is referred to the volume of REV. For any microscopic quantity $\Psi^{\alpha\alpha}$ (scalar, vector, tensor) to which the above operation may be applied, the following space averaging procedures can be defined:

$$(3.1) \quad \bar{\Psi}^{\alpha} = \frac{1}{\Omega} \int_{\Omega^{\alpha}} \Psi^{\alpha\alpha} d\Omega, \quad \Psi^{\alpha} = \frac{1}{n^{\alpha} \Omega} \int_{\Omega^{\alpha}} \Psi^{\alpha\alpha} d\Omega,$$

where Ω^{α} represents the region of the control volume Ω occupied by the α -component, $\bar{\Psi}^{\alpha}$ and Ψ^{α} are bulk and effective volume average quantities, respectively. In Eqs. (3.1) n^{α} is the volume fraction defined by

$$(3.2) \quad n^{\alpha} = \frac{\Omega^{\alpha}}{\Omega},$$

where n^{α} is constrained by the conditions $\sum_{\alpha} n^{\alpha} = 1$, $0 \leq n^{\alpha} \leq 1$.

In our case the REV can be considered as composed of three parts, Fig. 3, i.e.

$$(3.3) \quad \Omega = \Omega^s + \Omega^{fn} + \Omega^{fa},$$

where Ω^s stands for the part occupied by skeleton, Ω^{fn} — by non-adsorbed fluid and Ω^{fa} — by adsorbed fluid; and the fluid region Ω^f is

$$(3.4) \quad \Omega^f = \Omega^{fn} + \Omega^{fa}.$$

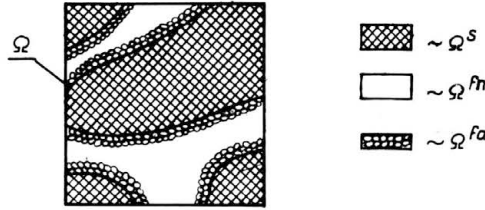


FIG. 3.

In modelling the physical adsorption phenomena it is commonly accepted that the adsorbed layer possesses the same kinematics as the skeleton particles located on the solid — fluid interface. Taking this into account one can define the following average velocities:

$$(3.5) \quad \begin{aligned} (\bar{\rho}^s + \rho^a) \mathbf{v} &= \rho \mathbf{v} = \frac{1}{\Omega} \left(\int_{\Omega^s} \rho^{ss} \mathbf{v}^{ss} d\Omega + \int_{\Omega^{fa}} \rho^{ff} \mathbf{v}^{ff} (= \mathbf{v}^{ss}) d\Omega \right), \\ (\bar{\rho}^f - \rho^a) \mathbf{v} &= \rho \mathbf{v} = \frac{1}{\Omega} \left(\int_{\Omega^{fn}} \rho^{ff} \mathbf{v}^{ff} d\Omega \right), \end{aligned}$$

where

$$(3.6) \quad \bar{\rho}^s = \frac{1}{\Omega} \int_{\Omega^s} \rho^{ss} d\Omega, \quad \bar{\rho}^f = \frac{1}{\Omega} \int_{\Omega^f} \rho^{ff} d\Omega, \quad \rho^a = \frac{1}{\Omega} \int_{\Omega^{fa}} \rho^{ff} d\Omega,$$

and

$$(3.7) \quad \rho^1 = \bar{\rho}^s + \rho^a, \quad \rho^2 = \bar{\rho}^f - \rho^a.$$

Consequently, the fluid-saturated porous adsorbent, from the macroscopic point of view, may be considered as a two-component mixture, the components of which are kinematically distinguishable, i.e. the first component of density ρ^1 is skeleton and a fluid adsorbed film that moves at velocity \mathbf{v}^1 ; the second component of density ρ^2 is non-adsorbed fluid moving at velocity \mathbf{v}^2 . Such components may interchange their mass due to the change of the amount of adsorbed fluid in time as a function of pressure, temperature and interaction potential, [1].

Taking this into account, the local form of mass continuity equations can be written as follows, [5 ,7],

$$(3,8) \quad \frac{\partial}{\partial t} \rho^1 + \operatorname{div} \left(\rho^1 \mathbf{v}^1 \right) = g^1, \quad \frac{\partial}{\partial t} \rho^2 + \operatorname{div} \left(\rho^2 \mathbf{v}^2 \right) = g^2,$$

where g^1 and g^2 are mass supply terms satisfying the condition

$$(3.9) \quad g^1 + g^2 = 0.$$

The derivation of the motion equations follows a conventional line, i.e. that of the two-component mixture theory (see, e.g. [7, 10]). We associate stress vector \mathbf{t}^i ($i = 1, 2$) with each i -constituent such that the scalar $\mathbf{t}^i \cdot \mathbf{v}^i$ represents the rate of mechanical work of a particular constituent per unit area of a surface bounding a bulk material. At the same time, Cauchy's theorem for stress

$$\mathbf{t}^i = \mathbf{T}^i \cdot \mathbf{n}$$

is satisfied, where \mathbf{T}^i is the partial stress tensor and \mathbf{n} stands for the normal vector for a surface element. The local form of the motion equation is

$$(3.10) \quad \begin{aligned} \nabla \cdot \mathbf{T}^1 + \rho^1 \mathbf{b}^1 + \boldsymbol{\pi}^1 &= \rho^1 \frac{D^1}{Dt} \mathbf{v}^1 + \frac{1}{2} g^1 \left(\mathbf{v}^2 - \mathbf{v}^1 \right), \\ \nabla \cdot \mathbf{T}^2 + \rho^2 \mathbf{b}^2 + \boldsymbol{\pi}^2 &= \rho^2 \frac{D^2}{Dt} \mathbf{v}^2 + \frac{1}{2} g^2 \left(\mathbf{v}^2 - \mathbf{v}^1 \right), \quad \frac{D^i}{Dt} = \frac{\partial}{\partial t} + \mathbf{v}^i \cdot \operatorname{grad}, \end{aligned}$$

where $\rho^1 \mathbf{b}^1$ and $\rho^2 \mathbf{b}^2$ stand for the body forces per unit volume and $\boldsymbol{\pi}^1$ and $\boldsymbol{\pi}^2$ represent the interaction forces. It is worth to notice that in the case when no fluid is adsorbed, i.e. $\Omega^{fa} = 0$, $\rho^a = 0$, we have $g^1 = g^2 = 0$, and the mass continuity and motion equations coincide with those for the porous skeleton and the fluid, respectively.

3.2. Wave equations. Dispersion relations

Since we are interested in the analysis of harmonic wave propagation in saturated porous adsorbent, linear form of Eqs. (3.10) is used. In the

linear theory, the displacement of the solid, velocities of the solid and of the fluid, together with their space- and time-derivatives are assumed to be small during the motion, and thus the linearized form of Eqs. (3.10) is

$$(3.11) \quad \nabla \cdot \mathbf{T}^1 + \boldsymbol{\pi} = \rho \frac{\partial}{\partial t} \mathbf{v}^1, \quad \nabla \cdot \mathbf{T}^2 + \boldsymbol{\pi} = \rho \frac{\partial}{\partial t} \mathbf{v}^2, \quad \boldsymbol{\pi} = -\boldsymbol{\pi}^2 = \boldsymbol{\pi}^1,$$

where body forces have been neglected.

For further discussion constitutive relations for stresses \mathbf{T}^1 , \mathbf{T}^2 and interaction force $\boldsymbol{\pi}$ are needed.

In formulation of the constitutive relations for the porous adsorbent variation of frame moduli due to adsorption effect should, in general, be taken into account. This was discussed mainly for water-saturated porous rocks, [11], where the elastic moduli of sandstones are very sensitive to moisture and its chemistry. In our case under the assumption that:

the adsorbed gas layer does not change the physical properties of the skeleton except its density,

the influence of the adsorbed gas on the change of pore structure geometry is negligible (the thickness of adsorbed layer is much smaller than the pore diameter),

one may adopt the linear constitutive relations for saturated porous elastic solid similar to those proposed by BIOT [12] and, later, discussed in [13]. For an isotropic elastic porous solid filled with fluid they have form

$$(3.12) \quad \begin{aligned} \mathbf{T}^1 &= 2A_1 \boldsymbol{\varepsilon}^1 + \left\{ A_2 \text{tr} \boldsymbol{\varepsilon}^1 + A_3 \varepsilon^2 \right\} \mathbf{1}, \\ \mathbf{T}^2 &= \sigma \mathbf{1} = \left\{ A_3 \text{tr} \boldsymbol{\varepsilon}^1 + A_4 \varepsilon^2 \right\} \mathbf{1}, \end{aligned}$$

and

$$(3.13) \quad \boldsymbol{\pi} = b \left(\mathbf{v}^2 - \mathbf{v}^1 \right) + c \frac{\partial}{\partial t} \left(\mathbf{v}^2 - \mathbf{v}^1 \right).$$

In Eqs. (3.12) $\boldsymbol{\varepsilon}^1$ is the strain tensor of porous skeleton, ε^2 represents the dilatation of fluid filling the pores, A_1 , A_2 , A_3 , and A_4 are elastic material constants.

The interaction force (3.13) consists of the diffusive part proportional to the relative velocity, resulting from the viscous interaction between constituents, and of the dynamic coupling term resulting from the normal interaction between the constituents. Parameters b and c are pore structure, fluid density and viscosity, dependent physical constants.

Combining the constitutive relations (3.12) and (3.13) and motion Eqs. (3.11), and applying the div and curl operations, one obtains the equations governing the propagation of dilatation waves:

$$(3.14) \quad \begin{aligned} \rho \frac{\partial^2}{\partial t^2} \varepsilon^1 &= 2A_1 \nabla^2 \varepsilon^1 + A_2 \nabla^2 \varepsilon^1 + A_3 \nabla^2 \varepsilon^2 + b \frac{\partial}{\partial t} (\varepsilon^2 - \varepsilon^1) + c \frac{\partial^2}{\partial t^2} (\varepsilon^2 - \varepsilon^1), \\ \rho \frac{\partial^2}{\partial t^2} \varepsilon^2 &= 2A_3 \nabla^2 \varepsilon^1 + A_4 \nabla^2 \varepsilon^2 - b \frac{\partial}{\partial t} (\varepsilon^2 - \varepsilon^1) - c \frac{\partial^2}{\partial t^2} (\varepsilon^2 - \varepsilon^1), \end{aligned}$$

and those of the transverse waves:

$$(3.15) \quad \begin{aligned} \rho \frac{\partial^2}{\partial t^2} \omega^1 &= A_1 \nabla^2 \omega^1 + b \frac{\partial}{\partial t} (\omega^2 - \omega^1) + c \frac{\partial^2}{\partial t^2} (\omega^2 - \omega^1), \\ \rho \frac{\partial^2}{\partial t^2} \omega^2 &= -b \frac{\partial}{\partial t} (\omega^2 - \omega^1) - c \frac{\partial^2}{\partial t^2} (\omega^2 - \omega^1). \end{aligned}$$

$$\omega^1 = \text{curl } \mathbf{u}^1, \quad \omega^2 = \text{curl } \mathbf{u}^2,$$

where $\varepsilon = \text{tr } \varepsilon$ and \mathbf{u}^1 and \mathbf{u}^2 represent the displacement vectors for the skeleton and the non-adsorbed fluid, respectively. Solutions of Eqs. (3.14) and (3.15) in case of plane waves may be written in the form

$$(3.16) \quad \begin{aligned} \varepsilon^i &= C_i \exp [j(lx - \omega t)], \\ \omega^i &= D_i \exp [j(kx - \omega t)], \quad i = 1, 2, \end{aligned}$$

where $j = \sqrt{-1}$, l , k are complex wave numbers and ω is the frequency.

The requirement of existence of non-zero solution leads to the dispersion relation for the dilatation waves,

$$(3.17) \quad Y l^4 - \{ [Hc + \rho A_4 + \rho(2A_1 + A_2)] \omega^2 - Hbj\omega \} l^2 + (\rho \rho + \rho c) \omega^4 - \rho bj\omega^3 = 0,$$

and for the transverse wave

$$(3.18) \quad A_1 \left[- \left(\rho + c \right) \omega^2 + bj\omega \right] k^2 + \left(\rho \rho + \rho c \right) \omega^4 - \rho j \omega^3 = 0,$$

where

$$\begin{aligned} Y &= (2A_1 + A_2) A_4 - A_3^2, \\ H &= 2A_1 + A_2 + A_4 + 2A_3, \\ \rho &= \rho + \rho. \end{aligned}$$

From Eqs. (3.17) and (3.18) it follows that in the considered porous adsorbent two dilatational and one transverse wave can propagate. The attenuation of these waves results from the existence of the diffusive part of the interaction force (3.13). In the case of ultrasonic wave in gas-saturated porous solids, the role of diffusive force, due to small gas viscosity and high frequency, is insignificant, and then the following condition is satisfied

$$(3.19) \quad \frac{b}{\omega \rho} \ll 1,$$

which is the criterion of weak attenuation, [13].

4. Amount of gas adsorbed as a function of transverse wave velocity

Taking into account the criterion (3.19), from the dispersion relations (3.17) and (3.18) one can calculate the approximate values of propagation parameters for weak attenuated waves. Similar results were derived in [13] for a saturated solid without adsorption.

The velocities v_1 , v_2 and v_3 of fast and slow dilatational waves and transverse wave, respectively, are

$$(4.1) \quad v_1 \cong \sqrt{2Y(X - \sqrt{X^2 - 4rY})}^{-1},$$

$$(4.2) \quad v_2 \cong \sqrt{2Y(X + \sqrt{X^2 - 4rY})}^{-1},$$

$$(4.3) \quad v_s \cong \sqrt{\frac{A_1}{\rho - \rho c (\rho - c)}}^{-1},$$

where

$$X = Hc + \rho^1 A_4 - \rho^2 (2A_1 + A_2),$$

$$r = \rho^1 \rho^2 + \left(\rho^1 + \rho^2 \right) c.$$

In view of the above propagation velocities, the simplest formula allowing to calculate analytically the density of adsorbed gas is that for the velocity of transversal wave (4.3). It is important to notice that the transversal wave velocity v_s in saturated porous adsorbent is influenced by the mass of adsorbed gas due to the increase of the adsorbent bulk density. Moreover, it can be seen that the decrease in the ultrasonic wave speed is caused not only by the amount of adsorbed gas, but also due to the dynamic solid-fluid coupling which results from the pore structure effect. Thus, when a gas is admitted to a porous adsorbent, the amount of gas adsorbed can be calculated from the resulting decrease in the wave speed.

Since, as it was assumed, the adsorbed layer does not change the pore structure geometry, the coefficient of dynamic coupling c (see Eq. (3.13)) is related to the pore parameter \varkappa , [13], in the same way as in the case when no adsorption exists, i.e.

$$(4.4) \quad c = \rho^2 \left(1 - \frac{1}{\varkappa} \right).$$

When a porous sample with mass M and volume V is filled with a gas of density ρ^f , and if n moles of a gas of molecular mass m are adsorbed within the pore volume of V , the particular densities are

$$(4.5) \quad \bar{\rho}^s = \frac{M}{V}, \quad \rho^a = \frac{nm}{V}, \quad \rho^2 = \rho^f f_v,$$

where $f_v \left(= n^f = \frac{\Omega^f}{\Omega} \right)$ is the volume porosity of adsorbent.

Using Eqs. (4.3), (4.4) and (4.5) we can calculate the amount of gas adsorbed per unit mass of the sample as a function of the velocity v_s , i.e.

$$(4.6) \quad \frac{n}{M} = \frac{1}{m} \left(\frac{A_1}{v_s^2 \bar{\rho}^s} - 1 - \frac{\rho^2}{\rho^1} (1 - \varkappa) \right) = \frac{1}{m} \left(\frac{v_0^2}{v_s^2} - 1 - \frac{\rho^2}{\rho^1} (1 - \varkappa) \right),$$

where v_0 is the transverse wave velocity in the case when no gas is admitted to a porous skeleton, i.e.

$$v_0 = \sqrt{\frac{A_1}{\rho^{-s}}}$$

Thus, by ultrasonic transversal wave velocity measurements the adsorption term can be completely identified and next, the specific surface Σ can be determined from Eq. (2.6).

5. Discussion and conclusions

From Eq. (4.6) it can be seen that when the condition

$$(5.1) \quad \frac{\rho}{\rho^{-s}}(1 - \kappa) \ll \frac{v_0^2}{v_s^2} - 1.$$

holds, the influence of the dynamic coupling on the amount of gas adsorbed determined by ultrasonic method is insignificant, and the amount adsorbed can be obtained from the reduced formula

$$(5.2) \quad \frac{n}{M} = \frac{1}{m} \left(\frac{v_0^2}{v_s^2} - 1 \right).$$

This may occur in two particular cases:

1. When the density of gas filling the pores is much less than the skeleton density,

2. For the bundle, channel-like pore structure, for which $\kappa = 1$.

Considering important practical situations in which the adsorbate is nitrogen N_2 ($\rho^f = 0.00465$ g/cm³ at saturation pressure) and the porous adsorbent is e.g. Vycor ("Thirsty Glass") made by acid leaching a phase separated borosilicate glass ($\rho^{-s} = 1.5$ g/cm³, $f_v = 0.286$) or a ceramic made by sintering Al_2O_3 powder ($\rho^{-s} = 2.54$ g/cm³, $f_v = 0.36$), [2], it can be found that the ratios of densities are:

$$\left. \frac{\rho}{\rho^{-s}} \right|_{\text{Vycor}} \cong 8.7 \times 10^{-4}, \quad \left. \frac{\rho}{\rho^{-s}} \right|_{\text{Ceramic}} \cong 6.6 \times 10^{-4},$$

while the ultrasonic measurements at the pressure $P = P_0$ give

$$\left. \frac{v_0}{v_s} \right|_{\text{Vycor}} \cong 1.07, \quad \left. \frac{v_0}{v_s} \right|_{\text{Ceramic}} \cong 1.01.$$

Since parameter κ for the materials considered takes approximately the value 0.5, [13], the above data prove that in such a case the condition (5.1) is satisfied and, therefore, formula (5.2) can be used to determine the amount of gas adsorbed. This is also valid for the pressure P the values of which are less than the saturation pressure P_0 , i.e. for $0 < \frac{P}{P_0} \leq 1$.

The last results obtained in this paper coincide with those proposed in [2], so that the considerations given here and based on a two-constituent model of porous adsorbent justify the method of ultrasonic determination of the specific surface applied in [2].

It should also be pointed out that the proposed ultrasonic technique offers an important advantage: it does not require simultaneous corrections for dead volumes or buoyancy and, consequently, small samples and large cells can be used. The only limitation is the restriction to samples which allow for the propagation of plane ultrasonic waves.

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