THE RESISTANCE OF A ROTATING DIFFUSER TO A GAS FLOW

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We examine the distribution of gas pressure in the case of convection diffusion in porous materials in the presence of centrifugal forces.

Evaporation centrifuges [1] make use, for example, of stepwise stages to intensify the effect of gas separation; similar stages are employed in a vibrating centrifuge [2], and with the thermosiphon method [3]. The authors of this article propose the filling of a centrifuge with a porous material. We will demonstrate that the combined action of the centrifugal force and the forces of diffusion can be used for the mutual intensification of their effects on the gas-pressure difference and, consequently, on the separative power.

Let a gas rotate at a certain angular velocity ω in a cylinder filled with a porous mass. The gas will enter at a certain pressure through the outside wall of the cylinder in a radial direction, while the gas is removed in the direction of the axis. The pressure differences near the outside wall and the axis of the cylinder are such that the flow within the porous rotating diffuser can be regarded as laminar. The dimensions of the pores of the diffuser are greater than the mean free path of the gas molecules.

The magnitude of the density of the gas-particle flow through some arbitrary diffuser layer can be found by application of the Poiseuille formula, whose reliability for porous materials has been verified by Warburg [4]. Let us write this formula in a form convenient for our purposes:

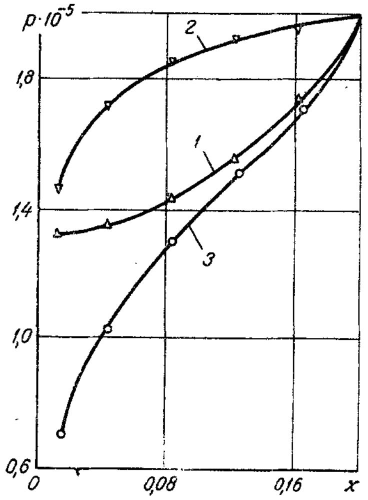

Fig. 1. Gas pressure p (N/m^2) as a function of the radius x (in m) of the diffuser layer: 1) in the rotating cylinder, without a diffuser; 2) in a nonrotating porous diffuser; 3) in a rotating porous diffuser.

$$j=N_0\sigma\frac{dc}{dt}\frac{1}{S}=\sigma\frac{N_0\left(1+\frac{8\psi}{d}\right)\pi d^4}{128\eta RTS}p\frac{dp}{dx}=Ap\frac{dp}{dx}. \tag{1}$$

Having denoted the increase in pressure as a consequence of centrifugal force and the convection flow by Δp_1 and Δp_2, respectively, we find that

$$\Delta p=\Delta p_1+\Delta p_2=\left(\rho x\omega^2+\frac{j}{Ap}\right)\Delta x. \tag{2}$$

The density of the flow through the cylindrical surfaces of the diffuser is associated with the density of the incoming flow by the relationship

$$j=j_0\frac{R}{x}. \tag{3}$$

Having substituted the value of j from (3) into (2) and having used the Mendeleev–Clapeyron equation to determine the gas density, we derive the differential equation

$$p\frac{dp}{dx}=Kxp^2+\frac{B}{x}. \tag{4}$$

The solution of (4) is given by the expression

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$$p^2 = \left[p_0^2 \exp(-KR^2) - \int_x^R \frac{2B}{x} \exp(-Kx^2)\, dx \right] \exp(Kx^2). \quad (5)$$

For small K we obtain

$$p^2 = \left[2B\left(\ln x - \frac{Kx^2}{2}\right) + p_0^2 \exp(-KR^2) - 2B\left(\ln R - \frac{KR^2}{2}\right)\right] \exp(Kx^2). \quad (6)$$

In the absence of rotation we have K = 0, which gives us

$$p^2 = p_0^2 - 2B \ln \frac{R}{x}. \quad (7)$$

With the rotation of a hollow cylinder, i.e., B = 0, we derive the familiar formula

$$p = p_0 \exp\left[-\frac{m\omega^2 (R^2 - x^2)}{2kT}\right]. \quad (8)$$

Figure 1 shows the curves for the relationships expressed by (6), (7), and (8) for a porous material with a pore diameter of $d = 10^{-7}$ m, an external pressure of $p_0 = 2 \cdot 10^5$ N/m^2, an outside cylinder radius of R = 0.2 m, an initial flow $j_0 = 5.5 \cdot 10^{22}$ 1/m^3, provided that the number of revolutions is n = 200 1/sec, and the porosity coefficient is $\sigma = 0.5$.

As we can see from the figure, there is a mutual intensification of the effects of a decline in pressure as a consequence of two forces (diffusion and centrifugal force). This leads to an increase in the separative power of the installation.

NOTATION

d	is the mean pore diameter;
λ	is the mean free path of the gas molecules;
σ	is the porosity factor;
j	is the magnitude of the gas-flow density;
c	is the molar concentration;
t	is the time;
S	is the area of the diffuser surface through which the gas passes;
p	is the pressure;
p_0	is the pressure near the outside wall of the cylinder;
m	is the mass of the gas molecule;
ω	is the angular velocity;
k	is the Boltzmann constant;
T	is the absolute temperature;
η	is the viscosity;
L	is the height of the cylinder;
x	is the distance from the axis of the cylinder to the layer through which diffusion proceeds;
N_0	is the Avogadro number;
$B = j_0R/A$	is a constant;
f	is the coefficient of reflection;
$K = m\omega^2/kT$	is a constant;
$\psi = (2 - f)\lambda/f$	is the coefficient of friction;
$A = \sigma(1 + 8(\lambda/d))d^2/32\eta kT$	is a constant;
π	is a constant.

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