ISOTHERMAL DYNAMICS OF ADSORPTION IN DILUTED SORBENT LAYERS; THE ADSORBER WITH AN INFINITE SORPTION LAYER

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The phenomenological model of the adsorbate transport in isothermal adsorber with a constant diameter was solved for an infinite, static and statistically homogeneous and isotropic sorption layer of constant composition. The layer was formed by a mixture of the adsorbent and the inert material grains with identical form and size. The model applies the linear adsorption isotherm and accounts for contributions of the convection, axial dispersion, external and internal diffusion and rate of adsorption. The obtained Laplace's image of the solution was used for calculation of the statistical moments up to the fourth order. The analysis of the effect of dilution on the separation efficiency (characterized by a number of theoretical plates) has led to the conclusion that for equal amounts of the adsorbent, the more diluted layer will have higher efficiency, or, for equal separation efficiencies, the amount of the adsorbent in the more diluted layer will be lower than in the less diluted layer. It has been shown that the contribution of axial dispersion has a positive, primary effect on the separation efficiency.

The present concept of individual person protection against vapours of toxic compounds requires to apply such protective means which effect minimally the activity of their user. This requirement increases, consequently, the demands on the size and efficiency of the protective mask filters. Classical filters with the loose layer of granulated sorbents have been recently replaced by elements in which the sorption material is formed by the fine grained sorbent, fixed on a fibrous material[1,2]. In comparison to the loose layer, the sorption mass exhibits much better dynamic sorption properties. Application of materials of this type simplifies substantially the design of the protective filters, permitting in this way to reduce their size and weight.

In spite of large progress in technology, dynamic adsorption in the diluted sorption layers has not yet been systematically studied as a model system representing the sorption materials. It is therefore desirable from the practical and the gnoseological point of view, to analyze this problem both theoretically and experimentally.

The most simple specific case of the general phenomenological model[3] of isothermal dynamic adsorption in the diluted sorption layers is that of the adsorber with a constant diameter and with the infinite adsorption layer. Analytic solution of this problem for an arbitrary layer composition is quite complex because it is complicated by the changing linear velocity of the fluid phase, which results in the varying coefficient values for axial dispersion and external transport.

The whole problem can be simplified assuming a quasi-homogeneous sorption layer consisting of a mixture of the adsorbent and the inert material. Both components are supposed to have

grains of identical form and size. In this way it is possible to guarantee constant values of the mean external porosity and, under the assumption of incompressibility of the fluid phase, also a constant linear velocity.

This work has been intended to analyze the effect of dilution on the transport of the adsorbate and on the separation efficiency of the above mentioned type of adsorber, applying for this purpose the linear adsorption isotherm.

The studied problem is, in principle, related to the theories of non-ideal linear adsorption dynamics, which belong probably to the best studied dynamic models of undiluted adsorption layers. The models are most frequently analyzed by means of the method of Kubín[4] and Kučera[5], permitting to calculate the statistical moments of the breakthrough curves from the Laplace's image of the obtained solution. This method has been used with advantage in our present paper.

THEORETICAL

Formulation and Solution of the Problem

Let us consider the infinite isothermal adsorber of constant diameter, which is filled in its entire volume with a statistically diluted sorption layer. Let us also consider that: *1)* the mobile phase moves along the adsorber in axial direction, it is incompressible (having therefore constant density) and it consists of a mixture of the inert carrier medium and adsorbates. The individual adsorbates are present in low concentrations and they are mutually no interacting during the adsorption process. *2)* The vector field of the mobile-phase velocities is quasi-stationary. *3)* The sorption layer is formed by a mixture of porous granules of the adsorbent and non-porous and non-adsorbing grains of the inert material (both with particles of identical shape and size). The sorption layer is statistically homogeneous and isotropic, its composition constant, and it can be considered as a continuum[6-8]. *4)* The adsorbent granules (of equal size and with a statistically homogeneous and isotropic structure) can take the form of the spheres, "infinite" cylinders or "infinite" plates and they can be, therefore, also considered as a continuum. The adsorption on the external surface and the contact regions between the adsorbent grains can be neglected. *5)* The resistance of the phase boundary against mass transfer is nil. *6)* It is possible to neglect radial effects in the adsorber. *7)* The course of the adsorption is directed by the linear isotherm.

Let us characterize the composition of the layer by a dilution function g_v (defined as the ratio of the volume of the adsorbent particles a_v and the overall volume of all granules in the given volume element of sorption layer):

$$g_v = a_v/(a_v + i_v) . \tag{1}$$

The process of dynamic adsorption of an arbitrary adsorbate, from the mixture can be represented by a set of equations:

$$\frac{\partial c(z, t)}{\partial t} + u \frac{\partial c}{\partial z} - D_p \frac{\partial^2 c}{\partial z^2} = Q_z(z, t) + Q_c(z, t) \tag{2}$$

$$\frac{\partial C(z, r, t)}{\partial t} - D_r \left[\frac{v - 1}{r} \frac{\partial C}{\partial r} + \frac{\partial^2 C}{\partial r^2} \right] = Q_n(z, r, t) \tag{3}$$

$$Q_c = -H_c[c - C|_{r=R}] \tag{4}$$

$$Q_n r = -\frac{\partial n(z, r, t)}{\partial t} = -H_n[K_n C - n] \tag{5}$$

with boundary conditions for

  a) equality of the flows on the adsorbent grain boundary

$$Q_c = -D_r \frac{P_v}{\alpha} \frac{\partial C}{\partial r}\bigg|_{r=R} \tag{6}$$

  b) symmetry in the centre of the adsorbent grain

$$0 = \frac{\partial C}{\partial r}\bigg|_{r=0}. \tag{7}$$

This is the usual phenomenological description (i) of the transport of the adsorbate in intergranular volume of the sorption layer and (ii) of the adsorption kinetics for one particle, including the external transport, the internal diffusion and the adsorbate transport from the volume of the pores to the active centres of the solid phase. In equations $(2)-(7)$, t denotes the time, z is the axial coordinate of the adsorber, r is the radial coordinate of the adsorbate grains, Q_z is the rate of increase of the adsorbate concentration in the intergranular volume, from the source and v is the shape factor depending on the form and taking for the prismatic, cylindrical or spherical adsorbent particles with a characteristic dimension R, the values 1, 2 and 3, respectively.

Equations of type (5) can be obtained also from a model in which the transport of the adsorbate from the volume, towards the inside surface of the pores, proceeds very rapidly and the adsorption rate itself is given by a linear expression:

$$\partial n/\partial t = k_a C - k_d n \equiv k_d[(k_a/k_d) C - n] ,$$

where coefficients k_a and k_d signify the adsorption and desorption rate constants.

The local adsorbate concentration in the fluid phase c, the linear velocity of the fluid phase u, the axial dispersion coefficient D_p, the rate of change of concentration c which is caused by the adsorbate transport into the adsorbent grains, Q_c, the external porosity α, the external surface of the adsorbent grains S_v (related to a unit volume of the layer) and the average area of the boundary between the pores and the external free volume P_v (also related to the unit volume of the layer), are all quantities averaged throughout a physically infinitesimal volume element[6-8] of the sorption layer.

Similarly, the local adsorbate concentration in the pores C, the local concentration of the adsorbed compound n (related to a unit pore volume), the effective coefficient of internal diffusion D_r, the rate of change of concentration C which is caused by the adsorption, Q_n, the coefficient of the adsorbate transfer from the volume towards the internal surface of the pores H_n, are all quantities averaged throughout a physically infinitesimal volume element of the *adsorbent* grain. The coefficient of external transport H_c in equation (4) is usually interpreted, on the basis of the stagnant-layer model, as a diffusion flow of the adsorbate at a unit concentration gradient (related to a unit intergranular free volume) through planar film, the thickness of which depends on the hydrodynamic conditions of the flow in the sorption layer and on the shape of the adsorbent granules. The surface of the film is equal to the boundary area of all adsorbent grains which are present in the volume element of the sorption layer.

The value of the coefficient H_c depends therefore not only on the flow-rate of the fluid-phase and on the form of the adsorbent granules but also on the size of these granules and on the structure and composition of the sorption layer. For this reason it is useful to define in the model of the diluted sorption layer a new coefficient of the external transport $H(u)$, representing the diffusion flow through a unit area of the planar film, averaged throughout a physically infinitesimal volume element of the sorption layer. It holds that:

$$H_c = HS_v/\alpha .\tag{8}$$

The following initial and boundary conditions can be written for the studied model:
For $t < 0$

$$c(z, t) = 0 \quad \text{for} \quad -\infty < z < +\infty$$

$$\left.\begin{array}{l} C(z, r, t) = 0 \\ n(z, r, t) = 0 \end{array}\right\} \quad \text{for} \quad -\infty < z < +\infty \quad \text{and} \quad 0 \leqq r \leqq R$$

for $t = 0$

$$c(z, t) = c_i(z) \quad \text{for} \quad -\infty < z < +\infty \tag{9}$$

$$\left.\begin{array}{l} C(z, r, t) = C_i(z) \\ n(z, r, t) = n_i(z) \end{array}\right\} \quad \text{for} \quad -\infty < z < +\infty \quad \text{and} \quad 0 \leqq r \leqq R$$

for $t > 0$

$$c(z, t) = 0 \quad \text{for} \quad z \to -\infty \quad \text{and} \quad z \to +\infty \tag{9}$$

$$\left.\begin{aligned} C(z, r, t) &= 0 \\ n(z, r, t) &= 0 \end{aligned}\right\} \quad \text{for} \quad 0 \leqq r \leqq R; \quad z \to -\infty \quad \text{and} \quad z \to +\infty,$$

where $c_i(z)$, $C_i(z)$ and $n_i(z)$ describe the initial adsorbate distribution in the layer.

The dependence of S_v and P_v values on the dilution can be expressed as

$$S_v = v(1 - \alpha) g_v / R \tag{10}$$

$$P_v = \beta S_v, \tag{11}$$

where β is the internal porosity of the adsorbate granules.

The solution of the problem for the non-diluted sorption layer has been carried out by Kučera[5,9], by means of the Laplace integral transformation

$$L\{f(t)\} \equiv \tilde{f}(s) = \int_0^{+\infty} f(t) \exp(-st)\,dt, \tag{12}$$

where s is a complex parameter. Analogical solution of the set of equations $(2)-(7)$ (with the initial and boundary conditions (9)) for the diluted sorption layer, leads to the Laplace's image of the solution

$$\tilde{c}(z, s) = \int_{-\infty}^{+\infty} \frac{\gamma_v(\xi, s)}{2D_p\lambda(s)} \exp\left\{\frac{u}{2D_p}(z - \xi) - \lambda|z - \xi|\right\}d\xi, \tag{13}$$

where

$$\lambda = \left[\left(\frac{u}{2D_p}\right)^2 + \frac{\sigma_v}{D_p}\right]^{1/2} \tag{14}$$

$$\sigma_v = s + HS_v/\alpha\, A(s) \tag{15}$$

$$\gamma_v(z, s) = \tilde{Q}_z(z, s) + c_i(z) + HS_v\, \gamma(z, s)/\alpha\, A(s)\, \sigma(s) \tag{16}$$

$$\gamma(z, s) = C_i(z) + n_i(z)\, H_n/(s + H_n) \tag{17}$$

$$A(s) = 1 + \frac{H}{\beta}\frac{R_a}{D_r}\frac{\psi_v(\varrho)}{\varrho\psi_v'(\varrho)} \tag{18}$$

$$\sigma(s) = s[1 + H_n K_n/(s + H_n)]; \quad \varrho = R(\sigma/D_r)^{1/2} \tag{19},(20)$$

$$\psi_v(\varrho) = \sum_{k=0}^{+\infty} \frac{\varrho^{2k}}{2^k k! \, v(v+2) \dots [v+2(k-1)]} = \begin{cases} \text{ch}\,(\varrho) & (v=1) \\ I_0(\varrho) & (v=2) \\ \text{sh}\,(\varrho)/\varrho & (v=3) \end{cases} \qquad (21)$$

This solution can be obtained from the Kučera's treatment substituting formally H_c from equation (8) and the product εg_v for the porosity function $\varepsilon = \beta(1-\alpha)/\alpha$.

The Laplace's image of the solution can be used for the description of the transport in the diluted sorption layers, with both basic types of sampling. The effect of dilution is implicitly included in the dependence of S_v on g_v in equation (10).

A: In the elution case, the pulse injection can be mathematically described by the Dirac δ-function:

$$c_i(z) = \frac{M_a}{\alpha P_L} \delta(z, 0), \qquad (22)$$

where M_a is the total amount of the adsorbate injected into the adsorber and P_L is the total cross-section of the layer. For the injection at the point $z_0 = 0$ and for $Q_z = 0$ and the initial conditions $C_i(z) = n_i(z) = 0$, the Laplace's image of the solution takes the form:

$$\tilde{c}(z, s) = \frac{M_a}{\alpha P_L} \left\{ \exp \frac{u}{2D_p} z - \lambda |z| \right\} / 2 D_p \lambda. \qquad (23)$$

B: For the frontal case, the step injection at the point $z_0 = 0$ can be described, e.g., by the condition:

$$Q_z(z, t) = \Omega_0 \delta(z, 0); \quad \Omega_0 = \text{const.} \neq 0 \qquad (24)$$

and for the initial distribution $c_i(z) = C_i(z) = n_i(z) = 0$ we get:

$$\tilde{c}(z, s) = \frac{\Omega_0}{s} \exp \left\{ \frac{u}{2D_p} z - \lambda |z| \right\} / 2 D_p \lambda. \qquad (25)$$

The comparison of equations (23) and (25) gives, for $\Omega_0 = M_a / \alpha P_L$:

$$[c(z, t)]_{\text{elution}} = [\partial c(z, t)/\partial t]_{\text{frontal}}. \qquad (26)$$

Statistical Moments of the Breakthrough Curves

The transport of the adsorbate in the diluted sorption layer can be analyzed by means of the above mentioned Kubín's and Kučera's method of moment analysis. For the sorption layer which is formed only by adsorbent granules, Kučera[5,9] derived the

expressions for the statistical moments of elution curves up to the fifth order. Because of formal analogy of the Laplace's image of the solution in both models, one can obtain the statistical moments of the elution curves for the diluted sorption layer if substituting H_c from equation (8) and the product εg_v for ε in the Kučera's expressions. Thus, for the normal moments, we get:

$$\mu_0'(z) = 1 \tag{27}$$

$$\mu_1'(z) = \left(\frac{|z|}{u} + \frac{2D_p}{u^2}\right)(\chi_v)_1, \tag{28}$$

where

$$(\chi_v)_1 = 1 + \varepsilon(1 + K_n)\, g_v \tag{29}$$

$$\varepsilon = \beta(1 - \alpha)/\alpha. \tag{30}$$

For the central statistical moments is:

$$\mu_0(z) = 1 \tag{31}$$

$$\mu_1(z) = 0 \tag{32}$$

$$\mu_2(z) = \frac{2D_p}{u^2}\left(\frac{|z|}{u} + \frac{4D_p}{u^2}\right)(\chi_v)_1^2 + 2\varepsilon g_v\left(\frac{|z|}{u} + \frac{2D_p}{u^2}\right)(\chi_v)_2 \tag{33}$$

$$\mu_3(z) = \frac{4D_p^2}{u^4}\left(\frac{3}{u}|z| + \frac{16D_p}{u^2}\right)(\chi_v)_1^3 + 12\varepsilon g_v\frac{D_p}{u^2}\left(\frac{|z|}{u} + \frac{4D_p}{u^2}\right) \times$$
$$\times (\chi_v)_1 (\chi_v)_2 + 6\varepsilon g_v\left(\frac{|z|}{u} + \frac{2D_p}{u^2}\right)(\chi_v)_3 \tag{34}$$

$$\mu_4(z) = \frac{12D_p^2}{u^6}\left(z^2 + \frac{18D_p}{u}|z| + \frac{80D_p^2}{u^2}\right)(\chi_v)_1^4 + 24\varepsilon g_v\frac{D_p}{u^4} \times$$
$$\times \left(z^2 + \frac{12D_p}{u}|z| + \frac{40D_p^2}{u^2}\right)(\chi_v)_1^2 (\chi_v)_2 + \frac{12}{u^2}\varepsilon^2 g \times$$
$$\times \left(z^2 + \frac{6D_p}{u}|z| + \frac{12D_p^2}{u^2}\right)(\chi_v)_2^2 + 48\varepsilon g_v\frac{D_p}{u^2} \times$$
$$\times \left(\frac{|z|}{u} + \frac{4D_p}{u^2}\right)(\chi_v)_1 (\chi_v)_3 + 24\varepsilon g_v\left(\frac{|z|}{u} + \frac{2D_p}{u^2}\right)(\chi_v)_4, \tag{35}$$

where

$$(\chi_v)_2 = \frac{R^2}{D_r} \frac{(1 + K_n)^2}{v(v + 2)} + \frac{\beta R(1 + K_n)^2}{vH} + \frac{K_n}{H_n} \tag{36}$$

$$(\chi_v)_3 = \left(\frac{R^2}{D_r}\right)^2 \frac{2(1 + K_n)^3}{v^2(v + 2)(v + 4)} + \frac{R^2}{D_r} \frac{2(1 + K_n)}{v(v + 2)} \left[\frac{\beta R(1 + K_n)^2}{vH} + \frac{K_n}{H_n}\right] +$$

$$+ \frac{R^2 \beta^2 (1 + K_n)^3}{v^2 H^2} + \frac{2\beta R(1 + K_n) K_n}{vH H_n} + \frac{K_n}{H_n^2} \tag{37}$$

$$(\chi_v)_4 = \left(\frac{R^2}{D_r}\right)^3 \frac{(5v + 12)(1 + K_n)^4}{v^3(v + 2)^2(v + 4)(v + 6)} + \left(\frac{R^2}{D_r}\right)^2 \frac{(1 + K_n)^2}{v^2(v + 2)(v + 4)} \times$$

$$\times \left[\frac{\beta R(5v + 12)(1 + K_n)^2}{vH} + \frac{(6v + 12) K_n}{H_n}\right] +$$

$$+ \frac{R^2}{D_r} \frac{1}{v(v + 2)} \left[\frac{3\beta^2 R^2(1 + K_n)^4}{v^2 H^2} + \frac{6\beta R(1 + K_n)^2 K_n}{vH H_n} + \frac{(2 + 3K_n) K_n}{H_n^2}\right] +$$

$$+ \frac{\beta^3 R^3(1 + K_n)^4}{v^3 H^3} + \frac{3\beta^2 R^2(1 + K_n)^4 K_n}{v^2 H^2 H_n} + \frac{\beta R(2 + 3K_n) K_n}{vH H_n^2} + \frac{K_n}{H_n^3} . \tag{38}$$

The factor $\varepsilon(48(D_p/u^3) z + 196(D_p^2/u))$ (attached to the product $(\chi_v)_1 (\chi_v)_3$ in the expression for the fourth central moment) is given in the original Kučera's papers[5,9] incorrectly. The correct value is $\varepsilon(48(D_p/u^3) z + 192(D_p^2/u^4))$.

The statistical moments can be used for the determination of the transport coefficients[10], prediction of the elution-curve courses[5,9] or determination of the breakthrough times[11,12], for the required adsorbate concentrations and the frontal way of sampling.

DISCUSSION

We shall use as the criterion of the separation efficiency, the number of theoretical plates, N, defined by the expression:

$$N = (\mu_1')^2/\mu_2 . \tag{39}$$

Let us have two sorption layers with different dilution $(g_v)_1 > (g_v)_2$. The number of theoretical plates for a layer segment, defined by the distance L from the sampling place, can be determined substituting expressions for the moments μ_1' and μ_2 (equations (28) and (33)) in the defining equation (38).

The ratio of the theoretical plates for equal segments of both considered sorption layers is then given as:

$$[N(L)]_1/[N(L)]_2 \gtreqless 1 , \tag{40}$$

where the individual cases in this relation are expressed by the conditions

$$(g_v)_1 (g_v)_2 \gtreqless 1/\varepsilon^2 (1 + K_n)^2 . \tag{41}$$

The Henry constant K_n and the porosity function ε reach for the usually used types of adsorbents, values in the range $10^2 - 10^3$ and $1 - 10^{-1}$, respectively. The values of the dilution function vary, for "reasonable" dilutions, in the range $\langle 0.1, 1 \rangle$. This range corresponds to the $10 - 100$ vol.% content of the adsorbent in the layer. In such a case, the relation $>$ is valid in the expression (41) and the efficiency of the more diluted layer is thus lower. The cases $\leqq$, corresponding to equal or larger efficiencies of the more diluted layer, can appear only at very large adsorbent dilutions (for very small product values $(g_v)_1 (g_v)_2$) or for the less frequent cases of very low product values $\varepsilon(1 + K_n)$.

Let us look now for an expression which would give us the required extension of length L which is needed for achieving equal efficiencies of both layers. We shall assume that:

$$[N(L)]_1 = [N(L + \Delta L)]_2 . \tag{42}$$

The calculation gives us (for $L + 4D_p/u \approx L + 2D_p/u$):

$$\Delta L \approx \frac{\varepsilon(\chi_v)_2 (L + 2D_p/u) (G_2 - G_1)}{\varepsilon(\chi_v)_2 G_1 + D_p/u^2} , \tag{43}$$

where

$$G_{1,2} = (g_v)_{1,2}/[1 + \varepsilon(1 + K_n) (g_v)_{1,2}]^2 . \tag{44}$$

For $L \gg 2D_p/u$, is:

$$\Delta L \approx \frac{\varepsilon(\chi_v)_2 L (G_2 - G_1)}{\varepsilon(\chi_v)_2 G_1 + D_p/u^2} . \tag{45}$$

If we require the amount of the adsorbent in segment $L + \Delta L$ of the more diluted layer to be smaller, or equal, to the amount of the adsorbent in segment L of the less diluted layer, then the following condition must be valid:

$$\Delta L \leqq L[(g_v)_1 - (g_v)_2]/(g_v)_2 . \tag{46}$$

Substituting ΔL in equation (45), we get for $\varepsilon(1 + K_n)(g_v)_{1,2} \gg 1$ the unequality:

$$D_p/u^2 \geqq 0 \qquad (47)$$

which is equivalent to the condition (46). For equal separation efficiencies, the amount of the adsorbent in the less diluted layer will be smaller (at $D_p > 0$), or equal (at $D_p = 0$), to the amount of the adsorbent in the less diluted layer.

In the same way in which we have compared the efficiencies of the two differently diluted layers, for the segments of equal lengths, it is possible to find an expression for the ratio of efficiencies of the two differently diluted layers, for segments containing the same amount of the adsorbent.

Applying the equality (46) (and for $L \gg 4D_p/u$ and $\varepsilon(1 + K_n)(g_v)_{1,2} \gg 1$) we get:

$$\frac{[N(L)]_1}{[N(L + \Delta L)]_2} = \frac{\varepsilon K_n^2(D_p/u^2)(g_v)_2 + (\chi_v)_2}{\varepsilon K_n^2(D_p/u^2)(g_v)_1 + (\chi_v)_2}. \qquad (48)$$

Under the assumption $(g_v)_1 > (g_v)_2$ is:

$$[N(L)]_1/[N(L + \Delta L)]_2 \leqq 1, \qquad (49)$$

where the symbol $=$ corresponds to the case $D_p = 0$. For equal amounts of the adsorbent in the considered segments of both layers, the separation efficiency of the more diluted layer will be higher.

It can be therefore concluded that the efficiency of the diluted sorption layers is positively affected, in the first place, by the axial dispersion. The extension of the
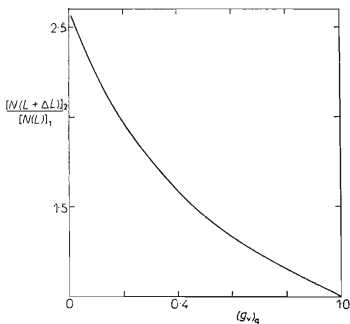

Fig. 1

Dependence of $[N(L + \Delta L)]a/[N(L)]_1$ on $(g_v)_2$ calculated from the experimental values of Zikánová, Dubinin, Kadlec[13] using equation (48), (for $(g_v)_1 = 1$)

sorption layer which is needed for obtaining the original efficiency (after transition to higher dilutions) will be the smaller, the higher is the value of D_p/u^2 (see equation (45)). Similarly, the separation efficiency of the more diluted layer increases (compared to the less diluted layer), with the increasing influence of the axial dispersion (equation (48)). Analogical quantitative conclusions are obtained also from a solution of the model of the adsorber with a diluted semi-infinite sorption layer[12].

Fig. 1 gives an illustration of the dependence of the ratio of the efficiencies of the diluted and undiluted layers, on the dilution, for equal amounts of the adsorbent. This dependence was calculated from the experimental values obtained by Zikánová, Dubinin and Kadlec[13], by means of the equation (48) (for $(g_v) = 1$). The following values[13] were used for the calculation: $\alpha = 0.399$, $\beta = 0.705$, $v = 3$, $K_n = 3.13$ . . 10^5, $R = 0.875$ mm, $u = 4.44 . 10^{-2}$ m/s, $D_p = 0.82 . 10^{-4}$ m²/s, $D_r = 3.2 . 10^{-6}$ m²/s, $H_c \approx 90$ s^{-1}, $H_n \to +\infty$. The values were determined from the measurement of the kinetics and dynamics of the adsorption of benzene vapours, carried out on Sovciet active charcoal SK (activated with K_2S, grain size $1.5 - 2.0$ mm). This commercial, ordinary type active charcoal has the following characteristics[13]: the parameters of Dubinin–Radushkevich equation $W_0 = 5.57 . 10^{-4}$ m³/kg, $B = 0.802 . 10^{-6}$, the apparent (mercury) density $0.641 . 10^3$ kg/m³, the real (helium) density $2.17 . 10^3$ kg/m³. It is evident from Fig. 1 that the increase of separation efficiency with increasing dilution can be, in the practical cases, quite substantial.

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