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IDEAL MODEL FOR GAS SEPARATION PROCESSES IN MEMBRANE ABSORBER

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Introduction

The prospects are considered of using systems with mobile liquid extractants flowing over the surface of the membrane. Application of moving liquids in combination with a membrane allows one to unite in one module two gas separation methods - membrane and absorption. One can identify two principal types of basic elements in such systems - absorber and desorber modules (Fig.1). The systems in which such modules are connected in various manner we called "membrane absorber".

Theoretical consideration

We shall perform a simplified analysis of the work of a membrane absorber consisting only from one absorber and one desorber modules. An analytical solution of the problem for the steady-state can be obtained for the following assumptions: gas diffusion coefficients in the liquid is much greater than those in polymeric membranes; distribution of penetrant concentration over the polymeric membrane in non-steady state is linear; flow-rate profile of the liquid is uniform; diffusion of the liquid component through the polymeric membrane does not affect the penetrant gas-transfer coefficients; absorption of the gas in the liquid follows Henry's law; the membrane in absorber and desorber modules is of rectangular shape and of equal surface area.

With the above assumptions the work of a membrane absorption-desorption gas separation system is described by the following equations:

$$\begin{cases} \sigma_1\Omega/(Q_{Ma}\cdot S)\cdot\dfrac{\partial\theta_{1a}}{\partial\xi} = 1 - \theta_{1a} \quad ; \quad 0<\xi<1 \\ \sigma_1\Omega/(Q_{Md}\cdot S)\cdot\dfrac{\partial\theta_{1d}}{\partial\xi} = - \theta_{1d} \quad ; \quad 1<\xi<\eta \end{cases} \qquad (1)$$

d ?

$$\hat{G} = \frac{D\sigma}{L_M}$$

$\theta=C_1/C_o$; $\eta=(L_a+L_d)/L_d$; $\xi=y/L_a$; $C_o=\sigma_1\cdot p_o$; $S=H\cdot L$

where σ- solubility coefficient [$cm^3(STP)/cm^3.atm$], L- membrane length [cm], H- membrane width [cm], p_o- partial pressure of the penetrant [atm], Q- productivity [$cm^3(STP)/cm^2.s.atm$], Ω- volume flow rate of the liquid [cm^3/s] S- membrane area [cm^2], y- coordinate in the direction of moving liquid. Subscripts: a- absorber module, d- desorber module, l- liquid, M- membrane.

One can identify two principal types of membrane absorbers: the continuous-flow and the circulating ones.

In a continuous-flow membrane absorber fresh liquid is fed into the absorber module. It carries the penetrant, which has passed through the membrane, into the desorber module and is then discharged out of it. The boundary conditions in this case are: with $\xi=0$, $\theta_{1a}=0$, and with $\xi=1$, $\theta_{1a}=\theta_{1d}$. Applying these conditions to the ordinary differential equations (1) ($Q_{Ma} = Q_{Md} = Q_M$, $S_a = S_d = S$) we shall get for the flux J [cm^3/s]

$$J = \sigma_1 p_o\Omega\cdot(1 - \exp(-Q_M\cdot S/(\sigma_1\cdot\Omega))^2 \; ; \qquad Q_d= J/(S\cdot p_o)$$

Corollaries: with $\Omega \to 0$, $J \to 0$. At small Ω values, $J \simeq \Omega$, i.e. the flow linearly increases with increasing volumetric flow rate of the liquid. With large Ω values, $J \to 0$.

The selectivity factor in membrane absorber for a pair of gases A and B is determined by the formula: $\alpha_{A/B}=Q_d^A/Q_d^B$. The limits

$$\lim_{\Omega \to 0} \alpha_{A/B} = \sigma_1^A/\sigma_1^B; \qquad \lim_{\Omega \to \infty} \alpha_{A/B} = (Q_M^A/Q_M^B)^2 \cdot (\sigma_1^B/\sigma_1^A)$$

The dependences of normalized productivity and selectivity factors, for gases A and B in membrane absorber, via flow rate of the liquid are shown in Figure 2 and Figure 3, respectively. One may see (Fig.2) that the maxima of productivity for gases A and B are at different flow rates of the extractant although $Q_M^A=Q_M^B$. The position of the maximum in the case of continuous-flow membrane absorber is determined by the solubility coefficient of a gas in liquid. Besides the following rule is fulfilled: the greater the solubility coefficient is the less is the liquid flow rate at maximum productivity. It is obvious that varying the flow rate of the liquid one can inverse the selectivity factor in continuous-flow membrane absorber (Fig.3).

In a <u>circulatory membrane absorber</u> the extractant, after leaving the desorber, is again fed to the absorber inlet. The main advantage of this modification is that the extractant continuously circulates between the absorber and the desorber and is not consumed. In this case the boundary conditions are as follows: $\theta_{1a}(1)=\theta_{1d}(1)$ and $\theta_{1a}(0)=\theta_{1d}(\eta)$. The total flow of the penetrant at the desorber outlet is

$$J=\sigma_1 p_o \Omega \cdot \frac{[1-\exp(-Q_M S/(\sigma_1 \Omega))]^2}{1-\exp(-2Q_M S/(\sigma_1 \Omega))}$$

Corollaries: with $\Omega \to 0$, $J \to 0$. At small Ω values, $J \simeq \Omega$, i.e. the flow linearly increases with increasing volumetric flow rate of the liquid. With large Ω values, $J \to Q_M \cdot p_o \cdot S/2$. The limits for the selectivity factor are

$$\lim_{\Omega \to 0} \alpha_{A/B} = \sigma_1^A/\sigma_1^B; \qquad \lim_{\Omega \to \infty} \alpha_{A/B} = Q_M^A/Q_M^B$$

The maximum productivity to be achieved in circulatory membrane absorber is one-half of the membrane productivity for gas under investigation (Fig.2). The selectivity factors for pair of gases A and B are lies in the limits from σ_1^A/σ_1^B at $\Omega \to 0$ (selectivity of absorption liquid) to Q_M^A/Q_M^B at $\Omega \to \infty$ (selectivity of membrane). Varying the flow rate of the extractant one can change the selectivity factors of separation (Fig.3).

It should be noted that all the solutions were obtained for the ideal plug flow model and in real systems the flux of penetrant at given flow rate will be less, in comparison with theoretical value, due to the concentration polarization effect and non-uniform distribution of the liquid flow rate. To minimize these deviations it is necessary to provide a turbulence flow of the liquid or to minimize the liquid thickness as much as possible.

<u>Conclusions</u>

Asymptotical solutions for productivity and selectivity factors in continuous-flow and circulatory membrane absorbers were obtained. The analysis performed in this work shows that membrane absorbers provide the researcher with a variety of ways to control the processes of gas separation. Among them are: selecting membranes for the absorber and desorber modules, choosing the appropriate extractant, the rate of its motion, organization of absorber and desorber modules in gas separation unit.

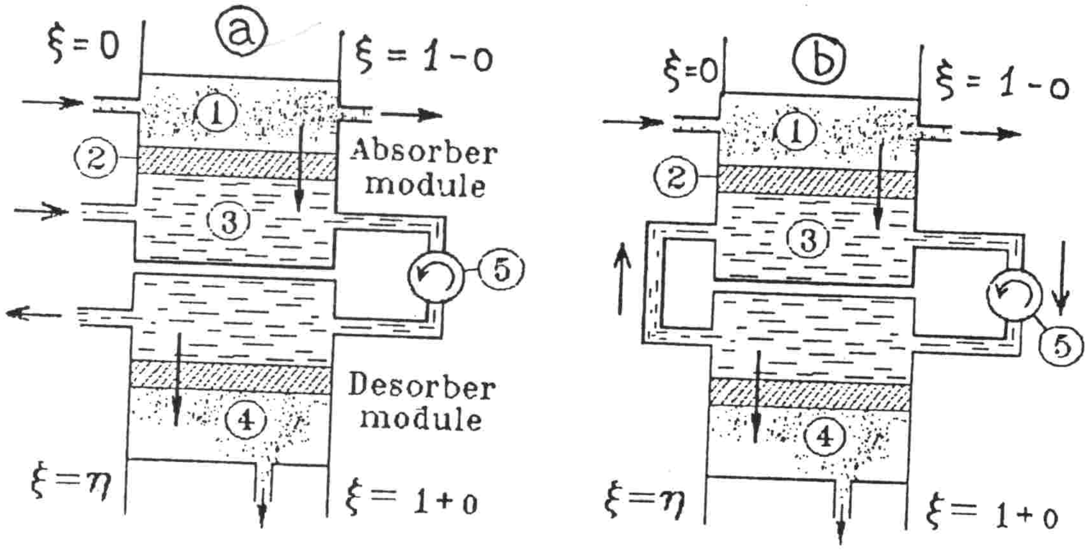

Fig.1 Block diagrams of the different modifications of membrane absorbers.

a) continuous-flow membrane absorber

b) circulatory membrane absorber

1- feed gas, 2- membrane, 3- liquid, 4-sweep gas, 5- pump.

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