CRYOGENIC TECHNOLOGY, PRODUCTION AND APPLICATION OF INDUSTRIAL GASES

STUDY OF THE PROCESS OF SEPARATION OF A Ne–He MIXTURE ON A QUARTZ GLASS MEMBRANE


The method of separation of a Ne–He mixture on a membrane made from quartz glass with the goal of obtaining a high-concentration of He is an alternative to the cryogenic method and has advantages such as relatively low production cost per unit product; simple separator module design; does not require cooling down to cryogenic temperatures.

The basic problems in studies of this method are: determination of the effect of external parameters (the flow rate of the original mixture, the temperature, the pressure gradient during separation); correction of the calculation technique taking into account the experimental results obtained; optimization of the separation process and the apparatus design.

The permeability coefficient of the membrane is proportional to the diffusion coefficient and the solubility of the gas in glass. The dependence of the change in the permeability on the change in the temperature is exponential; in this case, we can assume that the solubility is constant as the temperature varies within a considerable range. According to available experimental data, gases can be placed in the following order according to the increase in permeability in quartz glass: N₂, O₂, Ne, H₂, He. The diffusion coefficient of the gas in glass increases as the content of acidic oxides (such as B₂O₃, SiO₂) increases and decreases as the content of basic oxides increases. The amount of diffusing gas changes in proportion to the change in the pressure gradient, and does not depend on the type of gas.

The complexities of the analytical calculation for the penetration of a gas through a membrane are connected with determination of the diffusion coefficient and the choice of the diffusion model. The experimental results agree well with the assumptions of the activation model of diffusion. In this case, we also need to determine the surface concentration of the components, which is connected with the choice of the sorption model. To a first approximation, we can assume that the surface concentration depends linearly on the concentration of the component in the mixture.

Let us consider the operation of the separator module (Fig. 1).

A stream G with He and Ne concentrations of respectively \( x_{1G} \) and \( x_{2G} \) is supplied to the module. The penetrate D (enriched in He and of composition \( y_{1D}, y_{2D} \)) and the waste stream L (enriched in Ne and of composition \( x_{1L}, x_{2L} \)) are withdrawn from the module. Between the cavities of the delivery and drainage channels, there is a pressure gradient which supports the penetration process.

From material balance for the case of ideal mixing, in the delivery and drainage channels we obtain

\[
D y_{1D} = \frac{2 \pi l K_1 l_1 (P_{GL} x_{1L} - P_{D} y_{1D})}{\ln(d_2 / d_1)};
\]

\[
D(1 - y_{1D}) = \frac{2 \pi l K_2 l_2 (P_{GL} (1-x_{1L}) - P_{D}(1-y_{1D}))}{\ln(d_2 / d_1)}.
\]

where $p_{GL}$ is the average pressure in the delivery channel; $p_D$ is the pressure in the drainage channel; $d_1$, $d_2$ are the outer and inner diameters of the glass capillaries; $K$ is the permeability coefficient for He or Ne; $\rho_1$, $\rho_2$ are the densities.

These equations may be supplemented by the equation

$$x_{1G} = \theta y_{1D} + \zeta x_{1L},$$

where $\theta = D/G$; $\zeta = L/G$.

From expressions (1)–(3), we obtain a dependence reflecting the interconnection between the flow rate of the input stream, its composition, and the flow rate of the penetrate for the specified pressure gradient between the channels and the temperature,

$$y_{1D}^2 + y_{1D} \left\{ \frac{(1-\theta) + \theta \xi}{(1-\xi)(\theta + (1-\theta)\pi)} - \frac{x_{1G} + (1-\theta)\pi}{\theta + (1-\theta)\pi} \right\} -$$

$$- \frac{x_{1G}}{(1-\xi)(\theta + (1-\theta)\pi)} = 0,$$

where $\pi = p_D / p_{GL}$; $\xi = K_1 \rho_1 / K_2 \rho_2$.

The flow rate of the input stream can be represented in the following form:

$$G = \frac{2\pi K_k}{\theta \ln(d_2 / d_1)},$$

where