UDC 66.083

MATHEMATICAL MODEL OF VACUUM MEMBRANE DISTILLATION OF ETHANOL

Istomin A. P., Ladieva L. R.
Igor Sikorsky KPI, listomin.andreyl@gmail.com

Membrane distillation is the separation of two or more volatile compounds from a liquid mixture in which a porous membrane is used as a physical barrier. The separation occurs due to the pressure drop on both sides of the membrane (solution compartment and permeate) [1].

Different configurations of the membrane apparatus can be used to control the flow. The difference between these configurations is the method of condensation of steam on the permeate side.

In vacuum membrane distillation (VMD), shown in Figure, the driving force is maintained by applying a vacuum to the permeate side. The applied vacuum pressure is below the equilibrium vapor pressure. Therefore, condensation occurs outside the membrane module [2].

Increasing the permeate flow and/or stirring rate reduces the effect of temperature polarization. Therefore, the temperature at the gas-liquid interface approaches the volumetric temperature on the permeate side. This usually increases the driving force across the membrane.

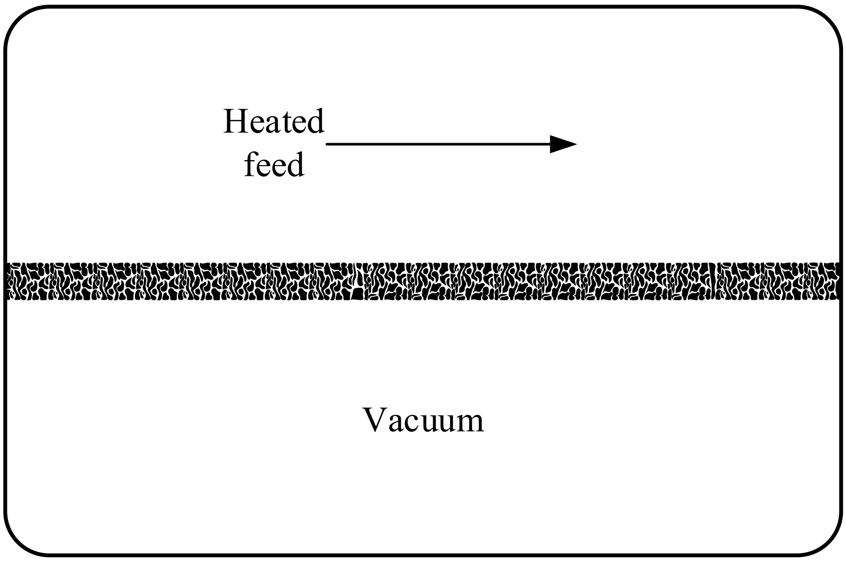
One of the advantages of this method is that undissolved inert gases blocking the pores of the membrane are sucked off by vacuum, leaving a large effective membrane surface active. In addition, lower boiling points result in more product at lower overall temperatures and less temperature differentials across the membrane.

Correct membrane selection is one the most important factor in the efficiency of separation of the distillation process. The membrane used for the membrane distillation process must be hydrophobic and porous. There are different types of membranes that meet these requirements, but the effectiveness of membrane distillation depends largely on additional factors such as resistance to mass transfer, heat resistance, thermal conductivity, wetting phenomena and the characteristics of the module.

During distillation, volatiles must change phase in order to pass through the membrane. The main advantage of this method is the ability to continuously remove ethanol at the production stage, which avoids inhibition of fermentation by the product and thereby increases production.

Unlike oil refined products, ethyl alcohol obtained as a result of vacuum membrane distillation is an absolutely environmentally friendly product, and when ethanol is used as a fuel for cars, the amount of exhaust gases emitted is significantly reduced.

The presented model (1) takes into account the temperature ($\theta(x)$) distribution along the length of the channels, but does not take into account the temperature variation along the height.



Schematic representation of VMD.

The differential equations of thermal balance are presented in formula 1.

$$\begin{cases} -W_{F,x}S\rho_F c_F \frac{\partial\theta_F(x,t)}{\partial x} - \alpha d(\theta_F(t) - \theta_P(t)) - K(x,t)d(\Delta P) = S\rho_F c_F \frac{\partial\theta_F(x,t)}{\partial t}, \\ -W_{P,x}S\rho_P c_P \frac{\partial\theta_P(x,t)}{\partial x} + \alpha d(\theta_F(t) - \theta_P(t)) + K(x,t)d(\Delta P) = S\rho_P c_P \frac{\partial\theta_P(x,t)}{\partial t}, \end{cases} \quad (1)$$

where $W_{F,x}$, $W_{P,x}$ – the speed of the solution and the permeate in the longitudinal direction of the channel; S, d – the area and width of the channel; c_F, c_P – heat capacity of solution and permeate, respectively; ρ_F, ρ_P – density of solution and permeate, respectively; $\Delta P = (P_F - P_P)$ – pressure difference on different sides of the membrane, K – mass transfer coefficient, α – heat transfer coefficient.

The main driving force of the process is the gradient of the partial pressure on the membrane – ΔP (1).

When compiling the model, it was assumed that temperature polarization is not taken into account.

In the course of further work on the model, it is planned to complicate the model by adding an equation that takes into account the concentration distribution in the longitudinal direction of the channel.

1. Benavides-Prada O., Guevara-Lastre C., Barón-Núñez F., Barajas-Ferreira C., Ortiz-Basurto R., Torrestiana-Sánchez, B., Muvdi-Nova C. Vacuum membrane distillation: Modeling and analysis for recovery of ethanol from ethanol/water solutions. *CT&F - Ciencia, Tecnología y Futuro*. Vol. 5, № 2. 2013. P. 47–60.

2. Pelin O. Membrane Distillation: Principle, Advances, Limitations and Future Prospects in Food Industry, Distillation – Advances from Modeling to Applications. *Trakya University Department of Food Engineering, Edirne*. 2012. P. 234–235.