

Membrane Distillation

Membrane Distillation is a distillation process that uses the vapor pressure difference as the driving force. Heat and mass transfer are heavily intertwined in the process. In direct contact membrane distillation(DCMD) both the hot feed side and the cold permeate side are in direct contact with the hydrophobic, porous membrane. The temperature difference between the hot and the cold streams creates a vapor pressure difference across the membrane driving vapor across the hot side to the cold side. The vapor will condense on the permeate side with any ions such as NaCl left on the feed side.

The membrane has four properties we need to concern ourselves with. The porosity ϵ is the ratio of volume of pores to the total volume of the membrane. The tortuosity is a property describing the curvature inside the pores. It is the ratio of the actual length of the pore arc to the thickness of the membrane. The larger the tortuosity, the longer the path the vapor molecule has to travel. The thickness of the membrane, δ , is another property of concern. The last property of concern is the mean pore radius.

In membrane distillation there are four main temperatures of concern: the bulk feed temperature T_{bf} , the feed interfacial temperature T_{mf} , the bulk permeate temperature T_{bp} , and the permeate interfacial temperature T_{mp} . There are four contributions to the heat transfer across the membrane 1) heat transfer from the bulk fluid to the membrane interface 2) heat transfer across the membrane from conduction 3) heat transfer across the membrane due to evaporated water 4) heat transfer from the permeate membrane interface to the bulk[2]. This heat transfer balance can then be written as

$$h_f(T_{bf} - T_{mf}) = NH_v + h_m(T_{mf} - T_{mp}) = h_p(T_{mp} - T_{bp})$$

Expressions can then be derived for the interfacial membrane temperatures on the feed and permeate side,

$$T_{mf} = \frac{T_{bf} * h_f + h_m(T_{bp} + T_{bf} \frac{h_f}{h_p}) - NH_v}{h_p(1 + \frac{h_m}{h_f}) + h_m}$$

$$T_{mp} = \frac{T_{bp} * h_p + h_m(T_{bf} + T_{bp} \frac{h_p}{h_f}) + NH_v}{h_p(1 + \frac{h_m}{h_f}) + h_m}$$

In order to get a value for the heat transfer coefficients for the feed and permeate we calculate the average Nusselt number. The Nusselt number is a function of the Reynolds number, and the Prandtl number,

$$Re = \frac{\rho v D}{\mu}$$

$$Pr = \frac{c_p \mu}{k}$$

The fluid properties are a function of temperature and this must be accounted for in the code. Correlations for fluid properties as a function of temperature are provided by [3]. The Nusselt number can then be evaluated using a number of correlations depending on the geometry, and properties of the flow. Choosing the correct Nusselt number is one of the most

important parts of correctly modelling a real experimental setup. [1] tested a number of Nusselt correlations for both Laminar and turbulent flow. For their specific experimental setup the correlation used for Laminar flow was

$$Nu = 4.36 + \frac{.036RePr(D/L)}{1 + .0011(RePr(D/L))^{.8}}$$

And for turbulent flow,

$$Nu = .023(1 + 6D/L)Re^8Pr^{1/3}$$

These Nusselt number correlations were then used to get the heat transfer coefficients for the feed and permeate

$$h = \frac{Nu*k}{\delta}$$

In order to quantify conduction through the air polymer matrix we must have the heat transfer coefficient of the matrix, which means we must have the thermal conductivity of the air polymer matrix. Three models are generally proposed: Isostrain, Isostress, and Maxwell. The isostrain the resistances are considered to be in series, in IsoStress the resistances are considered to be in parallel, and the Maxwell correlation is a middleground between the two. [1] found the greatest agreement with the Isostress model and large error with the Isostrain model. Once the thermal conductivity of the membrane has been found the heat transfer coefficient is then,

$$h_m = \frac{k_m}{\delta}$$

The last value we need in order to calculate the interfacial temperature is the flux N through the membrane. At the membrane interface there will be a vapor pressure difference due to the difference in temperatures between the two sides. The vapor pressure on either side can be evaluated using the Antoine equation for pure water,

$$P = \exp(23.5377 - \frac{4016.3632}{T - 38.6339})$$

The dusty gas model is then used to evaluate the flux across the membrane currently. This is to be replaced with a lognormal model of membrane pores in order to calculate using Monte Carlo methods

References

1. Phattaranawik, Jirachote, Ratana Jiratananon, and Anthony G. Fane. "Heat transport and membrane distillation coefficients in direct contact membrane distillation." *Journal of Membrane Science* 212.1-2 (2003): 177-193.
2. Hitsov, I., et al. "Modelling approaches in membrane distillation: a critical review." *Separation and Purification Technology* 142 (2015): 48-64.
3. Sharqawy, Mostafa H., John H. Lienhard, and Syed M. Zubair. "Thermophysical properties of seawater: a review of existing correlations and data." *Desalination and water Treatment* 16.1-3 (2010): 354-380.