A Joule-Thomson process of vapors with phase changes and capillary effects

T. Loimer[*], J. Reznickova[†], P. Uchytil[†] and K. Setnickova[†]

We investigate the flow of vapors through porous Vycor glass membranes with pore diameters between 20 nm and 200 nm. Due to the small pore diameters, the flow resistance is large and the fluid velocity is small. Hence, the flow can be described as a Joule-Thomson process.

All vapors close to saturation have a positive Joule-Thomson coefficient, i.e., they cool down in a Joule-Thomson process. We consider cases where vapors are in a state near saturation upstream of the membrane and in a state further away from saturation at the downstream side of the membrane. Because of the temperature difference, heat is conducted in downstream direction. However, a vapor close enough to saturation cannot release heat by cooling down, but must condense. Therefore, at the upstream front of the porous membrane there is either partial or full condensation of the vapor, liquid or a two-phase mixture flows through a part of the membrane, the fluid evaporates completely within the membrane and unsaturated vapor flows through the remaining part of the membrane and leaves the membrane in downstream direction. If the vapor condenses completely and liquid flows through a part of the membrane, the mass flux is greatly enhanced with respect to the mass flux of a vapor that remains in a gaseous state throughout the entire membrane. If the vapor condenses partially, the mass flux is nearly the same as the mass flux of a vapor in a gaseous state.

From an adiabatic, one-dimensional description of the flow process,[1] modeling the porous medium as a bundle of effective capillaries and taking into account effects of capillarity, it was found that the vapor condenses fully if (i) the permeability of the membrane is smaller than a characteristic permeability and (ii) if the upstream pressure is larger than a certain value, which is related to the pressure difference and to the pressure of a vapor which is in equilibrium with its liquid phase above a curved meniscus. The characteristic permeability, which is related to the pore size of the membrane, is a function of the thermal conductivity of the membrane and of the properties of the fluid. The minimum value of the upstream pressure for condensation to occur is given by the pressure difference, by the pore size of the membrane and by some fluid properties.

Measurements were carried out with butane and isobutane vapors permeating through porous Vycor glass membranes with a diameter of the membranes of approximately 20 mm and thicknesses between 0.5 and 1 mm. Our data qualitatively corroborates the influence of the characteristic permeability. Quantitatively, measured mass fluxes were smaller than predicted. Also, from the mass flow data we could not determine with sufficient accuracy the value of the upstream pressure above of which condensation occurs.

---

[*]Institute of Fluid Mechanics and Heat Transfer, Vienna University of Technology, 1040 Vienna, Austria

[†]Institute of Chemical Process Fundamentals, Academy of Sciences of the Czech Republic, Prague 6, Czech Republic

[1]Loimer et al., *J. Membr. Sci.* **301**, 107–117 (2007); Loimer, *ibid.* **383**, 104–115 (2011).