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Water vapor permeance: The interplay of feed and permeate activity

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Abstract

While the permeance of membranes is typically constant for ideal gases, this behavior changes for non-ideal gases and vapors. Due to swelling of the polymer, its simultaneous softening (plasticization) as well as clustering effects of the penetrant molecules, permeability becomes activity dependent. While most experimental investigations focus on studying the influence of feed activity, permeate activity is often neglected. By means of constant-volume variable-pressure measurements we show the importance of both feed and permeate vapor activity for a system of pure water vapor and a variety of membrane materials. We find that a change in activity can enhance or reduce membrane permeability. Either feed or permeate activity was identified to determine the overall mass transfer. Additionally the membrane support revealed a significant impact on overall mass transportproperties. This is surprising since concentration polarization effects known from mixed-gas measurements can be excluded. After more than half a decade of water transport studies, well known systems still render transport properties difficult to comprehend. While we succeed to categorize types of transport behavior, fundamental questions on the origin of the transport complexity remain a challenge for future research. Identification of engineering relationships for further module and process development is established however successfully.

Keywords: water vapor, activity, downstream pressure, permeance

1. Introduction

Over the last decades a broad spectrum of applications for water vapor permeable membranes has developed. Due to optimized manufacturing methods, nowadays materials with remarkable high vapor permeabilities and sufficient selectivities are available. Hereby technical applications like the dehydration of natural gas [1], the dehydration of flue gas [2] as well as the drying of compressed air [3] became economic. In addition the market of functional clothing has experienced a tremendous growth [4]. A recently upcoming market is the application of vapor permeable membranes in building ventilation systems [5–7]. In order to enhance the energy efficiency of those systems, plate-and-frame heat exchangers are replaced by so called membrane based enthalpy exchangers. Enthalpy exchangers ensure an indirect contact of fresh air and discharged air via a membrane as it is shown in Fig. 1. Heat and moisture is transferred without mixing both streams.

Specific humidity and temperature typically changes along the membrane (see Fig. 1). As a result water vapor activity changes on both sides of the membrane as well. Even though basic simulations use activity independent permeances for rough estimations this rigorous assumption is only valid for permanent gases at low to moderate pressures [8]. In fact, solubility and diffusivity of condensable gases is concentration dependent [9]. Consequently the permeability is a function of both the feed and the permeate activity. While variations in feed activity are addressed in many publications, the influence of permeate activity is often neglected [10–14]. Only few publications consider this effect and report significant impacts [8, 15, 16]. Azher et al. recently published water vapor permeances of Nafion 115 membranes with a non-linear dependence on membrane thickness [17]. They assume that the effects observed can be explained with an inhomogeneity in swelling and a significant impact of downstream activity.

The scope of this work is to quantify the water transport rates of different potential materials as a function of feed and permeate water vapor activity. In particular, we quantify pure water vapor permeation rates without any concentration polarization influences. By the choice of a large variety of materials, we aim to establish a li-

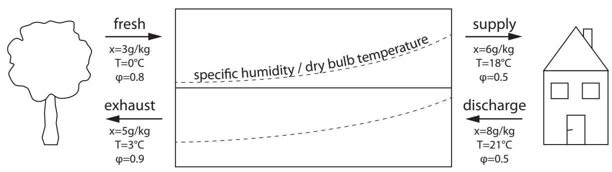

Figure 1: Humidity profile of enthalpy exchangers in building ventilation systems

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