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Spacer enhanced heat and mass transfer in membrane-based enthalpy exchangers

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Abstract

Gas permeation processes are often evaluated without considering concentration polarization effects. This is due to the assumption that gas diffusion coefficients are large enough to immediately compensate any concentration differences. However recent studies revealed that this assumption do not hold for systems comprising water vapor and air. Here the combination of high permeance and selectivity causes a limitation of mass transfer by the built up of a concentration boundary layer. A system most likely affected by such limitations is what we call a membrane based enthalpy exchanger. Due to simultaneous heat transfer the stagnant layer is expected to have a tremendous impact on overall performance. Mass and heat recovery will be improved, if membrane spacers are applied. However the application of such spacers is typically accompanied by an increase in pressure loss. In order to evaluate the economic benefit different module prototypes were assembled. Some of the systems comprised spacers others not. Comparing the experimental data of both configurations revealed a positive impact of membrane spacers on heat and mass transfer properties. In a subsequent case study module efficiency was evaluated using climate data of two locations, one in Central Europe and one in Canada. Even though the additional pressure loss reduced total savings, spacers accounted for a positive net balance in both cases.

Keywords: gas permeation, transport resistance, spacer, concentration polarization, enthalpy exchanger

1. Introduction

Sufficient ventilation rates are a prerequisite for a comfortable indoor climate. In addition they reduce health risks like Sick Building Syndrome [1–3]. Minimum ventilation rates recommended depend on building size, number of occupants and consumer habits [4, 5]. Even though most people are used to window ventilation this is a process far from being sustainable. Modern building ventilation systems make use of energy recovery devices instead [6]. A technology which becomes increasingly relevant and popular is what one calls a membrane based enthalpy exchanger [7–12]. Such devices ensure an indirect contact of fresh and discharged air via vapor permeable membranes in order to recover sensible as well as latent heat. Compared to ordinary heat exchangers internal surface area is smaller. This causes a reduction of sensible effectiveness. From literature it is known that heat transfer is most often limited by boundary layer resistance [13]. To overcome this limitation either cross flow velocity has to be increased or the free path length has to be shortened [14]. The latter is realized by application of membrane spacers [15]. Considering analogy of heat and mass transfer this is supposed to provoke a simultaneous improvement of mass transfer. While this hypothesis has been extensively proven for liquid systems [16–20] only few publications have addressed concentration polarization issues within gaseous systems [21–23]. It is often believed that high gas diffusion coefficients prevent the establishment of concentration profiles. However this assumption do not hold for systems combining high permeability and selectivity. Experimental results [23] as well as recently formulated research needs [24] motivated us to investigate the influence of spacers on heat and mass transfer in membrane based enthalpy exchangers. For this reason different prototypes were assembled, some of which comprising spacers others not. By directly comparing experimental data of both design specifications, it was possible to evaluate the change in module performance. Experimental data was subsequently used to perform a case study pointing out the economic benefit of spacers in building ventilation systems.

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2. Theory

Transport through the selective layer follows the well known solution-diffusion transport mechanism [25]

$$P = D \cdot S. \tag{1}$$

Here permeability P equals the product of solubility S and diffusivity D. An equation describing mass transfer from bulk to bulk is given to