Author's Accepted Manuscript

www.elsevier.com/locate/memsci

Modeling heat and mass transfer in cross-counterflow enthalpy exchangers

S. Koester, M. Falkenberg, M. Logemann, M. Wessling

PII: S0376-7388(16)32018-X
DOI: http://dx.doi.org/10.1016/j.memsci.2016.10.030
Reference: MEMSCI14816

To appear in: *Journal of Membrane Science*

Received date: 12 April 2016
Revised date: 11 October 2016
Accepted date: 23 October 2016

Cite this article as: S. Koester, M. Falkenberg, M. Logemann and M. Wessling Modeling heat and mass transfer in cross-counterflow enthalpy exchangers *Journal of Membrane Science,* http://dx.doi.org/10.1016/j.memsci.2016.10.030

Modeling heat and mass transfer in cross-counterflow enthalpy exchangers

S. Koester, M. Falkenberg, M. Logemann, M. Wessling*

[a]RWTH Aachen University, Chemical Process Engineering, Turmstrasse 46, D-52064 Aachen, Germany
[b]DWI-Leibniz-Institute for Interactive Materials, RWTH Aachen University, Forckenbeckstrasse 50, D-52056 Aachen, Germany

Abstract

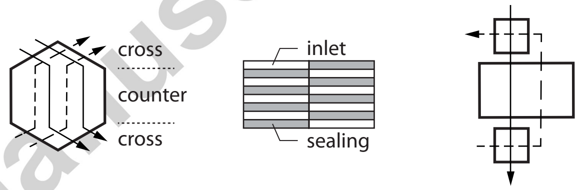
Membrane-based enthalpy exchangers are an upcoming technology in energy efficient building ventilation systems. Evaluation of system performance and potential energy savings require appropriate theoretical models. This is challenging since the favored module geometry combines areas of cross- and counter-flow. With CFD simulation tools it is possible to accurately discretize such geometries. However, these models cannot be applied in process simulations. To overcome such limitations, we replace the complex module geometry by a combination of standard cross- and counter-flow units. Transition terms linking 1D- and 2D-discretization are introduced. In addition, governing equations of heat and mass transfer are presented. The final set of equations is solved using Aspen Custom Modeler®, which is a commercial tool comprising an extensive fluid property data base. After the model is validated by means of experimental data, the final set of equations is used to investigate the impact of boundary layer resistance on water vapor transport.

Keywords: modeling, enthalpy exchanger, heat transfer, mass transfer, boundary layer

1. Introduction

The public interest in modern building ventilation systems has rapidly increased over the last decade [1]. One of the upcoming technologies enhancing sustainability is what we call a membrane-based enthalpy exchanger [2–4]. The assembly of such devices is similar to plate and frame heat exchangers with membranes replacing the impermeable exchanger plates. Since membranes are water vapor permeable, both sensible and latent heat (in terms of moisture) are recovered. It is known that module performance depends on membrane properties as well as flow configuration. In principal counter-flow arrangement is favored [5, 6]. However, different constraints need to be considered when designing air-to-air enthalpy exchangers. While pressure loss in tube and shell exchangers contradicts economic operation, the geometry of plate and frame modules hinders mere counter-flow solutions. The reason is that channels and inlets cannot be linked directly as known from cross-flow configurations. A way out is combining the advantages of cross-flow and counter-flow configurations in a single system. This yields a cross-counterflow geometry according to Fig. 1a.

Experimental evaluation of such exchangers is time consuming. It often needs hours to reach steady state conditions [7]. This limits the number of parameters which can be varied. A fundamental analysis of multiple parameters require numerical models instead. Many publications address the difficulty of conjugate heat and mass transfer in air-to-air enthalpy exchangers. While the majority of authors have focused on cross-flow setups [2, 8–13], only few have discussed counter-current [14] and cross-countercurrent [15–17] configurations. An important difference between cross-flow and cross-counterflow configurations can be found in the model applied. Counter-flow and cross-flow configurations are typically described using finite elements [2, 11, 12], NTU shortcut methods [8, 13] as well as CFD models [9, 10]. Contrary publications on cross-counterflow setup focus on CFD models only [15–17]. This is because CFD meshing tools enable a proper discretization of the (triangular) inlets and helps to disclose complex flow patterns and moisture distribution in detail. The situation is different, if the study aims to find shortcut models describing overall module performance without being interested in internal moisture distribution. Nasif et. al [17] have recently shown that experimental effectiveness of a cross-counterflow exchanger is in good agreement with modeling results obtained from a series connection of cross- and counter-flow units (Fig. 1c). However, validity of this approach was only proven for a fixed moisture load



(a) top view **(b)** front view **(c)** model

Figure 1: Geometry, flow arrangement and modeling approach of the cross-counterflow enthalpy exchanger.

*Corresponding author. Tel.: +49 241 80 95488
Email address: Manuscripts.CVT@avt.rwth-aachen.de (M. Wessling)