Performance analysis of a quasi-counter flow parallel-plate membrane contactor used for liquid desiccant air dehumidification

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HIGHLIGHTS

- A quasi-counter flow parallel-plate membrane contactor (QFPMC) is used for liquid desiccant air dehumidification.
- A two-dimensional steady-state heat and mass transfer mathematical model is developed.
- Compared to a cross-flow parallel-plate membrane contactor (CFPMC), the performances in the QFPMC are deteriorated.
- The solution channel pressure drop is increased.

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ABSTRACT

A quasi-counter flow (combined counter/cross-flow) parallel-plate membrane contactor (QFPMC) is proposed and employed for liquid desiccant air dehumidification. The air and the liquid desiccant streams, in a quasi-counter flow arrangement, are separated by the selectively permeable membranes, which only allow the permeations of heat and water vapor while preventing other gases and liquid desiccant from permeating. A two-dimensional steady-state mathematical model is developed to study the performances in the QFPMC used for liquid desiccant air dehumidification. A finite difference method is employed to solve the equations governing momentum, heat and mass transports. The pressure drop, sensible cooling and dehumidification effectiveness are then obtained. An experimental work is conducted to validate the results. It can be found that compared to a cross-flow parallel-plate membrane contactor (CFPMC), the cooling and the dehumidification effectiveness of the QFPMC used for liquid desiccant air dehumidification are deteriorated by approximately 5–29% and 2–13%, respectively. Further, the solution channel pressure drop is increased by about 0.15–4.84 times.

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1. Introduction

Recently, membrane-based liquid desiccant air dehumidification technology has been employed to overcome the substantial drawback of liquid desiccant droplet crossover encountered in the traditional direct-contacting liquid dehumidification method [1–7]. For the novel technology, the air and the liquid desiccant streams are separated from each other by selectively permeable membranes, which prevent the liquid droplets from escaping into the processing air while permitting the transports of heat and water vapor between the air and the solution streams [1–7].

A cross-flow parallel-plate membrane contactor (CFPMC) is a typical heat and mass exchanger, which has been employed for liquid desiccant air dehumidification [3–7]. It has been well known that a counter flow contactor may have higher effectiveness compared to the cross-flow one. Therefore it is desirable to have a counter flow membrane contactor used for liquid desiccant air dehumidification to improve the performances. However, a contactor with a pure counter flow arrangement is difficult in duct sealing between the air and the solution streams. Further, it is hard to construct in a limited space available in the HVAC system [4,8]. Therefore a quasi-counter flow parallel-plate membrane contactor (QFPMC), as schematically depicted in Fig. 1, is proposed and employed for realizing liquid desiccant air dehumidification. As seen, parallel-plate channels are formed by plate-type membranes stacked together. Equal spacing is kept between the neighboring membranes. The air and the solution streams flow alternatively through the parallel channels. The air stream flows uniformly in a straight path from left to right to control pressure drop and noise. However, the solution stream enters from the right header at the
right hand corner of the contactor and leaves it from the left header at the left hand corner. The solution stream may travel along an S-shaped path line through the solution channel. It is obvious that the flowing arrangement between the air and the solution streams is similar to a combination of counter and cross-flow, which can also be called quasi-counter flow.

The performance analysis and evaluation of the QFPMC used for liquid dehumidification are of vital importance in engineering applications. Regretfully, these issues have not been mentioned up until now. It is noteworthy that the performances of the QFPMC used for liquid desiccant air dehumidification are investigated based on a two-dimensional steady-state mathematical model. A finite difference method is employed to solve the equations governing momentum, heat and mass transports. The pressure drops, sensible cooling and latent dehumidification effectiveness are then numerically obtained and experimentally validated. The results can provide fundamentals for future contactor design, structural optimization and performance evaluation.

2. Mathematical model

2.1. Governing equations

In the above-mentioned membrane-formed contactor, as shown in Fig. 1, the air and the solution stream flow alternately through the parallel-plate channels in a quasi-counter flow arrangement. The contactor is comprised of several individual and identical elements. Further, for reasons of symmetry and simplicity in calculation, one membrane and two neighboring fluid flowing channels are selected as the calculating domain. The coordinate system of the element is depicted in Fig. 2. As seen, the air stream flows straightly along x-axis with a uniform velocity \(u_{in}\) into the upper channel and out from the left hand corner (outlet header). Both the inlet and the outlet headers have a length of \(x_0\), which is less than the contactor length \(X_0\), as shown in Fig. 1. Heat and moisture are exchanged through the

![Fig. 1. Structure of a quasi-counter flow parallel-plate membrane contactor (QFPMC) used for liquid desiccant air dehumidification.](image-url)
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