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Experimental investigations of a quasi-counter flow parallel-plate membrane contactor used for air humidification

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ABSTRACT

A quasi-counter flow parallel-plate membrane contactor (QCFPMC) is proposed for air humidification. In the contactor, the liquid water stream is separated from the air stream by membranes, which selectively guarantee the permeation of water vapor while prevent other gases and liquid water from permeating. Therefore the liquid water droplets, which are harmful for indoor air environment, can be avoided. The air and the water streams flow in a quasi-counter flow arrangement. In this paper, a test rig has been set up to study the performances of the QCFPMC employed for air humidification. The air humidification test is conducted under various flowing arrangements, inlet flow rates, temperatures, air humidities, and membrane parameters. The effects of the inlet operation conditions, contactor structures, and membrane parameters on the pressure drop, humidification effectiveness and total mass transfer coefficient are analyzed. It is found that the performances of QCFPMC increase with the increase of water flow rate and temperature. Further, the key role of enhancing the transfer rate of water vapor is played by the water temperature.

1. Introduction

People would feel uncomfortable in cold and dry winter, such as sore throat and tightening skin. Also static electricity is easy to be produced, which may bring large damages to computers, household appliances and other furnitures. It has been known that the comfort and suitable air relative humidity is in the range of 40–60% RH [1]. However the relative humidity is often dropped to 20–40% RH when indoor air is heated in winter [1]. To address these problems, air humidification can be employed [1–3]. Several methods can be used to achieve the air humidification process [1–8]. Among them, membrane contactors employed for air humidification have gained more and more attention in recent years. The semi-permeable membranes, which selectively allow the permeation of water vapor, are used to form the membrane contactors for realizing air humidification [1]. Compared to the other technologies, the membrane-based air humidification approach has a less energy consumption and a higher efficiency. Further, the most important is that it can avoid water droplet entrainments. If the processing air carrying the water droplets is sent into indoor environment, it would be harmful for indoor furniture and human health.

A parallel-plate membrane contactor is a typical structure, which has been extensively used for air humidification [9]. The concept is similar to a parallel-plate heat exchanger. The air and the water streams flow in the contactor, which can be in cross-flow and counter flow arrangements. It has been found that a counter flow contactor may have higher effectiveness compared to the cross-flow one. Therefore it is desirable to have a pure counter flow parallel-plate membrane contactor to improve the performances. However the contactor with the pure counter flow arrangement is difficult in channel sealing between the air and the water streams. Therefore a quasi-counter flow parallel-plate membrane contactor (QCFPMC), as schematically depicted in Fig. 1, is proposed and employed for realizing air humidification. As seen, the air and the water streams flow through the upper and the bottom channels, respectively. It is obvious that the flowing arrangements of the air and the water streams are similar to a combination of counter and cross flow, which can also be called quasi-counter flow. It should be noted that the similar quasi-counter flow membrane contactor has been designed and used for liquid desiccant air dehumidification [10]. The effects of the flowing arrangements, operating parameters and membrane materials on the performances of the contactor employed for liquid dehumidification have been investigated [10]. However they are not suitable for air humidification because of the different heat and mass transfer processes.

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Nomenclature

A	area, m^2
H	channel height, m
k	convective mass transfer coefficient, m/s
L	duct length, m
P	pressure, Pa
W	channel width, m
T	temperature, K
Q	volumetric flow rate, L/min

Greek letters

ε	effectiveness
ω	humidity ratio, kg moisture/kg dry air
δ	membrane thickness, m
τ	pore tortuosity
ξ	porosity

Subscripts

a	air
h	humidification
in	inlet
m	membrane
out	outlet
s	saturated state of water
tot	total
w	water

The novelties in this study are that the effects of the flowing arrangements, operating parameters and membrane properties on the performances of the newly proposed QCFPMC employed for air humidification. The experimental work is operated and compared under various operating conditions, such as the inlet water temperature, inlet water/air flow rates, membrane parameters, and flowing arrangements. The results are useful for future contactor design, performance evaluation, and system optimum.

2. Experimental work

A schematic diagram of an experimental set-up used for air humidification is plotted in Fig. 2. As seen, the core component is the QCFPMC, which is used for realizing air humidification. Therefore it is also called humidifier, which is formed by two pieces of 200 mm × 200 mm × 10 mm organic glass plates. There exists a piece of parallel-plate membrane between the two plates. Therefore two parallel channels are formed. The water and the air streams flow in the parallel channels in a quasi-counter flow arrangement. This study is focused on the effects of the flowing arrangements, inlet operation conditions, contactor structures, and membrane parameters on the performances of the QCFPMC employed for air humidification. Further, for reasons of experimental cost and time consumption, only one membrane is used. However, the single membrane type contactor is enough to complete the investigations in present study.

The experimental rig consists of two flowing loops, one for the air stream and the other one for the water stream. Ambient air is insufflated into the contactor by a fan and the water is maintained by a pump. Before entering the membrane contactor, the air stream

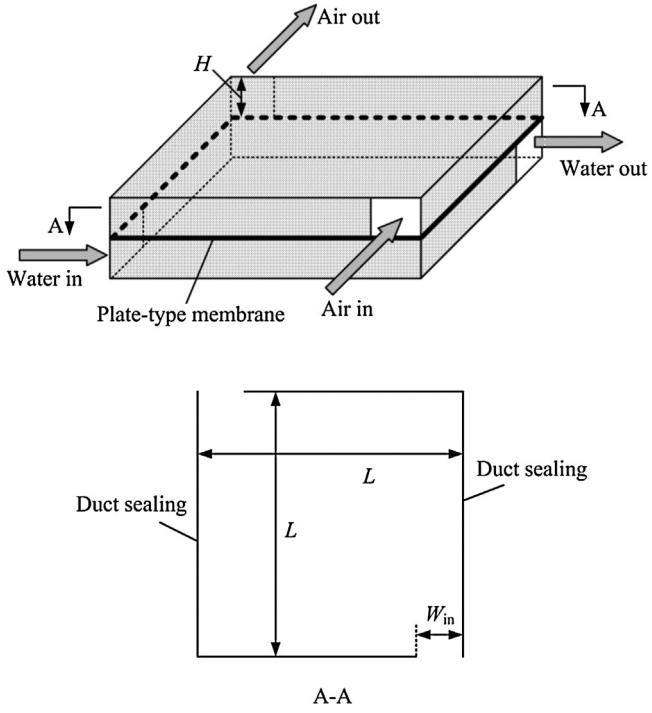

Fig. 1. Schematic of the quasi-counter flow parallel-plate membrane contactor (QCFPMC).

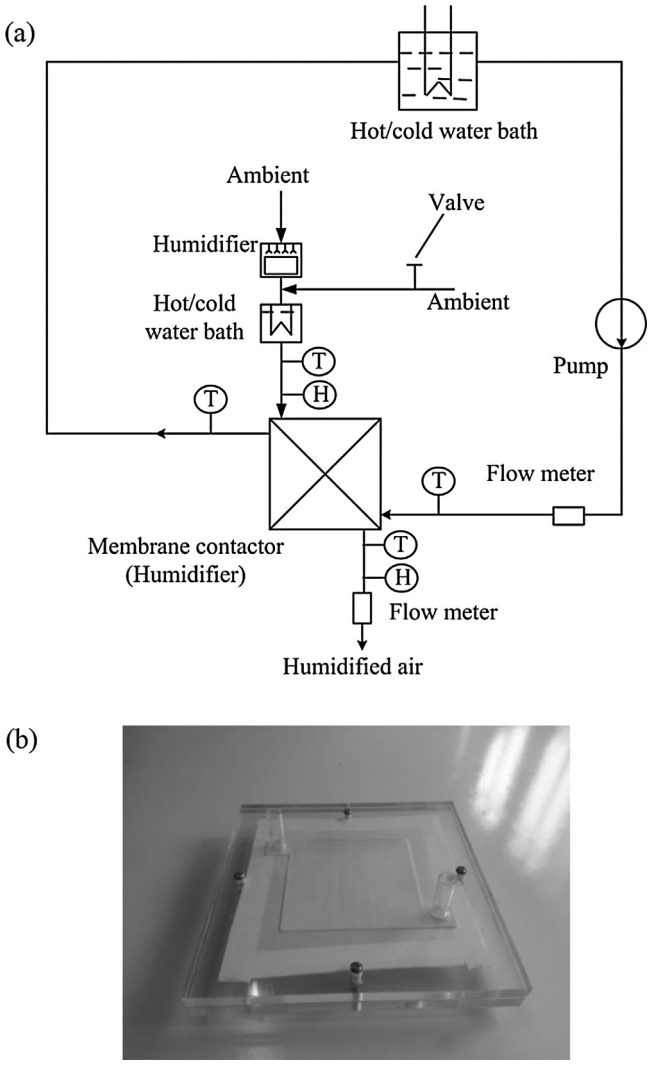

Fig. 2. Experimental set-up for the QCFPMC employed for air humidification; (a) Test rig. (b) Picture of the QCFPMC.