



Research Paper

Performance study of sodium alginate-nonwoven fabric composite membranes for dehumidification

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HIGHLIGHTS

- The composite membrane SA-NWFs for dehumidification is fabricated in a simple way.
- Water vapor permeance of membranes increases with the increasing LiCl mass.
- Working efficiencies of the ERV with composite membranes are higher.
- The composite membranes show great potential to be applied on the ERV.

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ABSTRACT

A novel composite membrane is proposed to improve the dehumidification performance of the membrane-based energy recovery ventilator (ERV). In this study, the composite materials based on nonwoven fabrics, sodium alginate and lithium chloride (LiCl) were fabricated. Nonwoven fabrics were adopted as supporting constructions; sodium alginate and LiCl were the corresponding active layer and hydrophilic additive. Membranes with different LiCl mass fraction were tested and analyzed to evaluate practical performance when applied in the ERV. Results show that the highest vapor permeance of the composite membrane is $29.8 \times 10^{-8} \text{ kg/m}^2 \cdot \text{s} \cdot \text{Pa}$, 10 times higher than that of composite one without LiCl. Water solubility declines to 20.6%, which demonstrates a certain waterproofness of membranes. Besides, simultaneous thermal analysis shows that LiCl accelerates evaporation rate of bound water. Furthermore, two ERVs with different composite membranes are fabricated and characterized by measuring their sensible, latent and enthalpy efficiencies. It is found that these three efficiencies can reach up to 83.9%, 87.4% and 86.7% under summer condition, and 80.8%, 81.7%, and 81.1% under the winter condition, respectively.

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1. Introduction

Humidity control is important for indoor environment. A high humidity level will lower the indoor air quality by inducing fungal reproduction, asthma, hypersensitivity and reducing thermal comfort of occupants. Furthermore, statistic data shows 20–40% of the total energy consumption in a HVAC system is caused by air dehumidification [1]. Currently, dehumidification in an air conditioning system is mainly realized by dew-point condensation. In this system, the supply air must be cooled below the dew point temperature to realize condensation of water vapor. For large scale system, a reheating process is required to heat the supply air to a satisfied level [2], resulting in a large amount of extra energy consumption.

Desiccant dehumidification methods based on adsorption/absorption principles can overcome this shortage. In such systems, desiccant material is adopted to adsorb water vapor in humid air and latent load of the process air is removed. Besides, the system can be regenerated by thermal energy. However, some drawbacks such as large volume and high initial investment limit the further development of desiccant AC systems. Especially, liquid desiccant dehumidification has a significant drawback of entrainment of desiccant droplets, which will corrode air duct and equipment as well as affect indoor air quality. To overcome the problem of desiccant droplets, an innovative method called liquid desiccant membrane system was proposed [3,4]. Semi-permeable membranes were used to separate the desiccant solution and the process air from each other. However, this dehumidification method also faces slow liquid-air transport coefficients, regenerator leakage, Liquid desiccant crystallization and blockage of the desiccant channels. Compared with these methods, membrane-based energy recovery

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Nomenclature

d	humidity ratio, kg/kg	i	inlet
h	enthalpy, J/kg	o	outlet
P_s	saturation vapor pressure at test temperature, Pa	1	relative humidity at the source
P_v	partial vapor pressure at test temperature, Pa	2	relative humidity at the constant climate chamber
RH	relative humidity, %		
<i>Subscripts</i>			
e	exhaust air		
f	fresh air		

ventilator (ERV) becomes increasingly popular due to its merits of simple structure, low energy consumption, no rotary parts and no cross contamination.

ERV consists of vapor-permeable membranes and the intersection of air-to-air channels [5]. The driving force is temperature and vapor partial pressure differences between indoor exhaust air and outdoor supply air. For mass transfer process, water vapor from higher humidity air is firstly absorbed by hydrophilic materials on the surface; then it diffuses across the membrane, and finally, it desorbs to the lower humidity air. In summer operation, supply air is precooled and dehumidified by indoor exhaust air with lower temperature and humidity ratio. In winter operation, on the contrary, supply air recovers a large fraction of heat and humidity from the exhaust stream. Performance of membranes especially the vapor diffusion capacity is crucial for both latent and enthalpy efficiencies of ERV.

In the preliminary stage, single membranes mainly made from hydrophilic polymers such as polyvinyl alcohol [6], polyether-polyurethane [7], Nafion [8,9] and polyvinylidene fluoride [10] are widely adopted in ERV systems. In order to maintain the membrane stability, these single membranes should be thick, which results in low vapor diffusion that is usually in the magnitude of 10^{-12} – 10^{-13} m²/s.

In order to improve the diffusion capacity, a wide range of composite membranes have been studied [11–14]. Composite membranes usually consist of active layers and porous supports [15,16]. Porous materials are adopted as mechanical support to guarantee the structural stability of composite membranes. Thus the ultrathin active layer made from hydrophilic materials can be manufactured owing to the underneath support, which can minimize the resistance of mass transfer and maximize vapor permeability. Zhong et al. [17] showed that, using the hydrophobic-hydrophilic composite membrane, sensible and latent efficiencies of the ERV can reach 69% and 63%, respectively. To explore more suitable and high quality materials, Zhang et al. [13] manufactured and explored the properties of polyvinyl alcohol/porous polyether sulfone composite membrane for air dehumidification. Ahluwalia et al. [18] developed a high flux water vapor transport composite membrane using perfluoro-sulfonic acid (PFSA) ionomer and polytetrafluoroethylene (PTFE) microporous layers. Aranda et al. [19] prepared a composite membrane by coating sulfonated polystyrene thin film on the surface of a microporous alumina support membrane and using a mathematical model to investigate the water-transport properties of composite membranes. Zhang et al. [20] researched the moisture transfer of polyvinyl alcohol/ polyvinylidene fluoride composite membrane between fresh air and exhaust air, which shows that the total mass transfer coefficient is in the magnetite of $(1.5\text{--}3.5) \times 10^{-3}$ m·s⁻¹. (5) Bui et al. [21] took advantage of porous TiO₂, lithium chloride, stainless steel scaffold and polyvinyl alcohol to prepare the thin and robust composite membranes for air dehumidification application. And the membrane displays

higher hydrophilicity, sorption and permeation. Varieties of materials have been researched in the previous literatures. Besides, Wahiba et al. [22] stated that higher vapor diffusivity of the membrane will dramatically facilitate the latent effectiveness of the ERV. Niu et al. [23] demonstrated that dehumidification efficiency was determined by both the operating conditions and the hydrophilicity of materials. Nonetheless, what is not ignored is that the high price of mechanical support material such as PVDF (polyvinylidene fluoride), PES (polyether sulfone), PTFE (polytetrafluoroethylene) and so forth obstructs severely these composite membrane application and expansion in the market. Compared with porous materials as stated above, non-woven fabrics (NWFs) with easy surface modification, larger surface area [24], low cost and lightweight are widely applied in air filtration [25], fertirrigation water treatment [26] and preparation of anti-fouling membranes [27]. These outstanding properties will make it a promising candidate for the support of the composite membranes.

For the active layer material, hydrophilic materials usually containing numerous hydrophilic functional groups of —NH₂, —COOH, —OH and the like show high ability to attract and absorb water molecule. Sodium alginate (SA), with copious —OH and —COO⁻ [28], is inexpensive and extensively sourced. Li et al. [29] discovered sodium alginate-gelatin polyelectrolyte laminated membranes exhibit high water vapor permeance in propylene dehydration. Gardner [30] proved that sodium alginate is capable of absorbing 200–300 times as much water as its own weight. These merits allow SA a potential selection for the active layer. However, few papers have reported the performance of the SA applied in the ERV. Due to the water solubility of SA, it is a prerequisite to make cross-linking reaction during the membrane preparation to decrease water solubility. Although cross-linking consumes a portion of the hydroxyl and leads to hydrophilicity reduction, the enhanced mechanical stability of membranes is worth the sacrifice. A low-cost and convenient way of cross-linking is immersing SA membranes into CaCl₂ solution for several minutes [31]. The coupled Ca²⁺ with oxygen molecule of the G-G sequences (α -L-gulonate) in the polymer chain build the “egg-box structure”, and the formation of insoluble calcium alginate follows. Besides, higher hydrophilic material contributes to higher vapor permeability [13]. In addition, LiCl appears an effective candidate to boost membrane hydrophilicity from the study of desiccant material [32].

In this study, SA-NWFs composite membranes are fabricated and their performance is systematically investigated to evaluate its application in the ERV system. Several properties of composite membranes are tested including water vapor permeance, water solubility (WS), scanning electron microscope (SEM), Fourier transform infrared spectroscopy (FT-IR) as well as simultaneous thermal analysis. Furthermore, the performance of the integrated ERV system based on such membrane is analyzed.

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