



## Review

## State-of-art in modelling methods of membrane-based liquid desiccant heat and mass exchanger: A comprehensive review



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## ABSTRACT

Air dehumidification is of vital importance in building air conditioning and production safety. Semi-permeable membrane module is a novel heat and mass exchanger, which separates the air and liquid desiccant to overcome desiccant droplet carry-over problem in traditional direct-contact systems. Recently, some research works have been carried out in mathematical modelling and experimental testing of membrane-based liquid desiccant dehumidification technology. Compared with the experimental testing, the mathematical modelling has advantages of significant time and cost reductions, practically unlimited level of detail, more profound understanding of physical mechanism and better investigation of critical situation without any risks. This paper presents a comprehensive review of various modelling methods for two types of membrane-based liquid desiccant modules: flat plate and hollow fiber.

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## Nomenclature

$A$	membrane surface area ( $\text{m}^2$ )		
$c_p$	specific heat capacity ( $\text{J/kg K}$ )		
$C$	heat capacity rate		
$C_r^*$	capacitance ratio		
$D_v$	diffusivity ( $\text{m}^2/\text{s}$ )		
$h$	convective heat transfer coefficient ( $\text{W/m}^2 \text{K}$ )		
$h_{fg}$	enthalpy of phase change for saturated water ( $\text{J/kg}$ )		
$h_v$	specific heat of evaporation of vapour ( $\text{kJ/kg}$ )		
$H^*$	operating factor		
$k$	thermal conductivity ( $\text{W/m K}$ )		
$m^*$	solution to air mass flow rate ratio		
$\dot{m}$	mass flow rate ( $\text{kg/s}$ )		
$m_{\text{lat}}^*$	latent heat ratio		
$\dot{m}_{\text{rr}}$	moisture removal rate		
$m_v$	moisture emission rate		
$NTU$	number of heat transfer units		
$NTU_m$	number of mass transfer units		
$T$	temperature ( $^{\circ}\text{C}$ )		
$U$	overall heat transfer coefficient ( $\text{W/m}^2 \text{K}$ )		
$U_m$	overall mass transfer coefficient ( $\text{kg/m}^2 \text{s}$ )		
$\dot{V}$	volumetric flow rate ( $\text{l/min}$ )		
$W$	humidity ratio ( $\text{kg/kg dry air}$ )		
		<b>Greeks</b>	
		$\varepsilon$	effectiveness
		$\delta$	thickness of membrane ( $\text{m}$ )
		$\rho$	density ( $\text{kg/m}^3$ )
		<b>Superscripts</b>	
		*	dimensionless
		<b>Subscripts</b>	
		air	air flow
		in	inlet
		lat	latent
		m	mass transfer
		max	maximum
		mem	membrane
		min	minimum
		num	numerical
		out	outlet
		sen	sensible
		sol	solution flow

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## 1. Introduction

Buildings are responsible for a significant part of global energy consumption. In particular, heating, ventilation and air-conditioning (HVAC) systems account for around 50% of energy consumed in buildings [1]. As a matter of fact, 20–40% of the total energy are consumed in the dehumidification process, and it can be even higher when 100% fresh air ventilation is required for better indoor environment [2]. In coastal areas where the humidity level is significantly high, air dehumidification is a necessity otherwise living would be seriously affected by the humid climate. The ASHRAE Standard 62-2001 recommends the relatively humidity of 30–60% for indoor environment [3]. However in some coastal regions, the outside air humidity can reach 80–90% continuously for a dozen of days, and latent cooling load accounts for 20–40% of total energy consumption of HVAC system [4]. High humidity level would lead to discomfort and affect the body surface temperature. Furthermore, production safety and quality would be seriously influenced by too high humidity level [2]. It has been reported that building energy consumption could be decreased by 20–64% using efficient dehumidification technologies [5].

There are many air dehumidification methods, including cooling coils, solid desiccant dehumidification and liquid desiccant dehumidification [2]. The traditional cooling coil system is inefficient in dealing with latent heat load. Furthermore, the air leaving the cooling coil is normally overcooled and needs to be re-heated to an appropriate supply temperature. Therefore, this combined process consumes a considerable amount of energy to cool (typically using a vapour compression system) and heat (using hot water or electricity) the supply air [6]. Liquid desiccant system has gained much progress recently due to the coherent virtues compared with others, for example high efficient without liquid water condensa-

tion. Liquid desiccant can be regenerated using low-grade heat such as solar energy, and the regenerated solution can be used as energy storage medium as well [7]. Membrane-based dehumidification stands out for its continuously working mode, reliability and non-direct contacting of air with working substance that avoids the problem of carry-over [8,9]. As a result, the membrane-based air dehumidification system has been studied extensively both experimentally and numerically. Several literature reviews have been conducted in this area [2,7,10]. Most of the reviews focus on the structures of liquid-to-air contractor, applications of membrane-based air dehumidification system, membrane materials and simple theory models. Numerical modelling methods of different types of membrane-based heat and mass exchanger have not been reviewed. This paper gives a comprehensive analysis of various numerical modelling methods to assess energy performance of the membrane-based heat and mass exchanger.

## 2. Performance evaluation

### 2.1. Designed operating parameters

Numerical and experimental investigations have revealed that the moisture removal rate and various effectiveness of the membrane-based heat and mass exchanger depend on its operating conditions significantly, so the main designed operating parameters are explored at first.

#### 2.1.1. Capacitance ratio ( $C_r^*$ )

Heat capacity rate  $C$  is defined as the product of specific heat capacity and mass flow rate ( $\text{W/K}$ ). Thus the heat capacities of desiccant solution and air can be calculated by Eqs. (1) and (2) [11].

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