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Thermodynamic analysis of an innovative liquid desiccant air conditioning system to supply potable water

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ABSTRACT

Liquid desiccant air conditioning systems are cost-effective, environmentally friendly and energy efficient techniques, especially in coastal areas. In the conventional liquid desiccant air conditioning system, the scavenging air is expelled into the atmosphere carrying a considerable amount of energy and water vapor. Thus, there is plenty of room to improve the system performance by recovering these losses. The proposed system consists of a conventional liquid desiccant air conditioning system plus a condenser. The aim of this study is to reduce the energy consumption by recovering the heat from the scavenging air using the condenser while also producing freshwater in addition to space cooling. Lithium chloride (LiCl) is used as the liquid desiccant for this study. The mathematical formulation for simultaneous heat and mass transfer between the condenser and the regenerator was developed to establish a comparison between the performance of the conventional and modified systems. Using the generated model, it is found that the modified system performance is 11.25% better than the conventional system and that it produces 86.4 kg of freshwater per hour as a by-product under the given conditions.

1. Introduction

The liquid desiccant systems are more energy efficient and provides an effective control of indoor air humidity and can provide as much dehumidification as needed for the ambient air [1]. This dehumidified air has many applications such as air conditioning, especially in humid areas, food preservation, storing chemicals and raw materials in the pharmaceutical industry, crop drying, etc. [2]. In the dehumidification process, the vapor pressure of the humid air is higher than the strong liquid desiccant solution and hence moisture transfer takes place [3]. The desiccant vapor pressure is increased as a result of moisture absorption making the liquid desiccant a weak solution. Regeneration is required to reconcentrate the weak desiccant solution to continue the cycle. The dehumidification and regeneration processes are equally important parts of the liquid desiccant system, but the regeneration process is the most critical part due to the association of energy consumption with it.

The liquid desiccant system can utilize any low-grade thermal energy such as exhaust gases from internal combustion (IC) engines, solar energy and waste heat, and is capable of overcoming electric consumption growth [4]. In this study, the main focus is on the regeneration process to lower its energy consumption by modifying the regeneration process in a conventional liquid desiccant system.

In the conventional liquid desiccant air conditioning system [5] as depicted in Fig. 1, the weak desiccant solution loses some of its energy and moisture content to the scavenging air. This air is thrown into the atmosphere carrying a considerable amount of energy and water vapor. The recovery of these potential losses is the key to the reduction of energy consumption. This paper proposes a new configuration for the liquid desiccant air conditioning system as shown in Fig. 2, in which both these losses are recovered.

Liquid desiccants have many advantages, the most important are that liquid desiccants require a low regeneration temperature which allows the use of the low-grade energy [4], in addition to the fact that concentrated liquid desiccants can be stored to be utilized later when the thermal energy source is unavailable [6]. The properties include surface vapor pressure, dynamic viscosity and the regeneration temperature control effectiveness of the liquid desiccant. Vapor pressure is the most influential parameter from among the aforementioned parameters and it represents the mass transfer potential in the regeneration process [7]. In general terms, liquid desiccants are non-toxic, non-corrosive, and odorless [8]. Different desiccant materials attract the moisture from the air at different capacities [9]. Frequently used liquid desiccants are glycols and solutions of halide salts which include lithium bromide

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Nomenclature

c_p	specific heat capacity at constant pressure (J kg^{-1} K^{-1})
h	specific enthalpy (J kg^{-1})
$\dot{H}$	total enthalpy rate (W)
$\dot{m}$	mass flow rate (kg s^{-1})
MR	desiccant-to-air mass flow rate ratio (–)
MRR	moisture removal rate (kg s^{-1})
$\dot{Q}$	heat input rate (W)
T	temperature (°C)
Greek	
Δ	difference
ε	effectiveness (–)
ξ	desiccant solution concentration (kg_s kg_{sol}^{-1})
ω	humidity ratio (kg_{H_2O} kg_{da}^{-1})
Subscripts	
1, 2, ...	desiccant solution stream state points
a, b, ...	air stream state points
da	dry air
f	dehumidifier
ht	heater
hx	heat exchanger
i	inlet
id	ideal
k	k = 1 for conventional system and k = 7 for modified system
max	maximum
min	minimum
n	condenser
o	outlet
opt	optimum
r	regenerator
s	desiccant
sol	solution
st	strong concentration
w	weak concentration

(LiBr), calcium chloride ($CaCl_2$) and lithium chloride (LiCl) [10]. The selection of a liquid desiccant material will have a direct effect on the dehumidification process and system performance. The absorption ability of LiBr is higher than $CaCl_2$ due to its relatively high vapor pressure [11]. However, $CaCl_2$ is common because of its availability and low cost. Liu et al. [12] performed a comparison between the performance of the LiCl and LiBr solutions; they found that the LiCl performance is better than LiBr due its low vapor pressure. Among the aforementioned aqueous salts, the absorption ability of calcium chloride ($CaCl_2$) is the least. In contrast, LiCl has very low vapor pressure and is the most stable. Thus, LiCl is used as the working liquid desiccant solution for this study.

The three major regeneration methods are thermal energy regeneration, regeneration by electrodialysis and reverse osmosis (RO) regeneration [13]. Since many liquid desiccants can be labeled as electrolyte solutions (such as LiBr, $CaCl_2$ and LiCl), electrodialysis could be a useful measure as a regeneration method [14]. Cheng et al. [15] investigated experimentally the performance of an electrodialysis regeneration unit of the liquid desiccant. In the electrodialysis method, the electric field transfers ions through a selective membrane. It is found that 55% of the maximum current was utilized by the system. The diluted solution can also be converted into a concentrated solution using the RO process. Al-Sulaiman et al. [16] proposed an RO system with an MFI zeolite membrane to separate the added moisture from the weak liquid desiccant solution. The most common regeneration method is the thermal energy regeneration method [17]. Either the air or the liquid desiccant can be heated using thermal energy regeneration. The regeneration unit works mostly as an adiabatic process. However, Yin and Zhang [18] proposed a system where the regenerator is internally heated and thermal energy is provided by a heating coil in order to maintain a constant solution temperature along the regenerator.

The recovery of both moisture and heat losses from the scavenging air in the conventional system has not been studied in

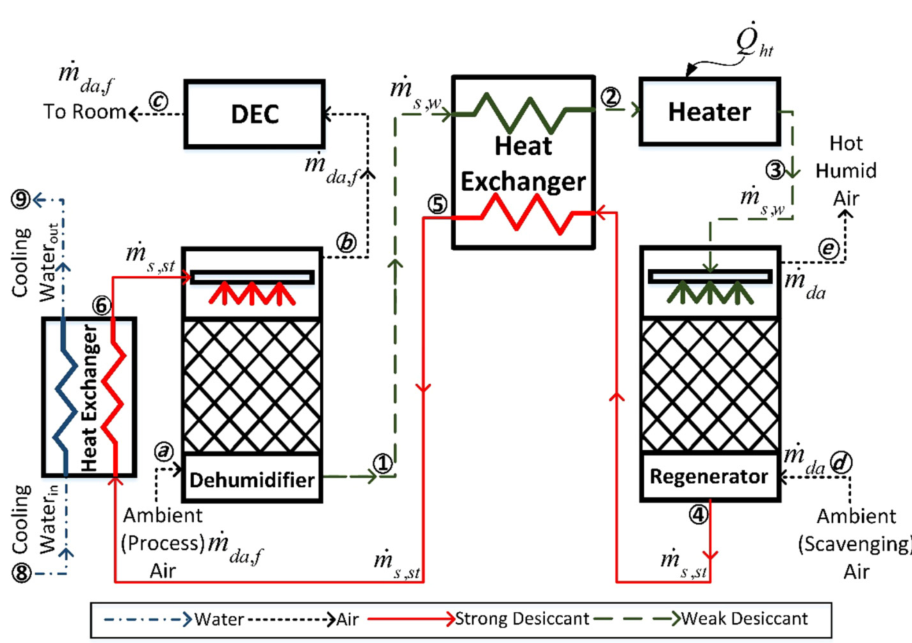

Fig. 1. Schematic of the conventional liquid desiccant air conditioning system.