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Recent developments in solar assisted liquid desiccant evaporative cooling technology—A review

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ABSTRACT

Cooling by solar energy is one of the key solutions to the global energy and environmental degradation issues. Solar liquid desiccant based on evaporative cooling is proposed as an eco-friendly alternative to the conventional vapour compression systems due to its huge untapped energy savings potential. In this paper, the recent works on solar assisted liquid desiccant cooling and its various applications combined with evaporative air-conditioning under different climates are reviewed and advantages the system may offer in terms of energy savings are underscored. A basic description of the principles of hybrid solar liquid desiccant with direct and indirect evaporative cooling is provided. Finally, solar regeneration methods and recent developments for the liquid desiccant air-conditioning system are presented.

Contents

1. Introduction

Conventional cooling technologies employing harmful refrigerants usually need more energy and lead peak loads which result in negative effect on the environment. As the energy and environmental issues have to be dealt with globally, developing and promoting environmentally benign sustainable systems emerge as an urgent need. Solar assisted desiccant cooling is one such encouraging system, given the fact that solar energy is abundant renewable source to meet the cooling load requirements. Furthermore, unlike other solar thermal applications such as heating, peak demand for cooling arises when the solar radiation is the most direct and intense.

The idea of a liquid desiccant evaporative cooling system is to combine liquid desiccant dehumidification with an evaporative cooling system in order to advance the overall system performance and utilize solar energy as a clean, renewable energy resource. In such a hybrid system, the desiccant dehumidification system is motivated to eliminate the latent load, while IEC system to provide the sensible heat load [1]. Further, as only low-grade energy is required for the regeneration process of the desiccant dehumidification system, solar energy as a renewable energy resource can handle running liquid desiccant air conditioning system [2].

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A number of studies can be found in literature investigating the low cost and low regeneration temperature of dilute desiccant solution, and the optimization of the combined liquid desiccant–evaporative cooling system. As the solar energy is a free energy source, the use of low grade solar thermal energy for the regeneration has been investigated extensively both by academia and industry in many applications. Although the initial cost of solar energy technology can be high like most developing concepts, it can lead to substantial savings in the long run. Moreover, evaporative coolers can act as mass exchange equipment in liquid desiccant systems rather than designing and manufacturing particular mass exchange equipment for such systems [3].

The objective of this study is to present a literature review over the recent empirical developments on solar assisted liquid desiccant–evaporative air conditioning systems and solar regeneration methods concerning various aspects of this technology.

2. Liquid desiccant dehumidification for solar cooling

A desiccant is a natural or synthetic substance that is capable of showing a strong attraction for water vapour. It is usually classified as either solid or liquid that is both commonly used in various applications where lower dew point temperature is needed. Each of solid and liquid desiccant material has their own advantages and shortcomings. To name a few, common solid desiccant materials are polymers, silica, zeolites, alumina, hydratable salts and mixtures etc. while commonly used liquid desiccant ones are lithium chloride (LiCl), calcium chloride (CaCl), lithium bromide (LiBr), tri-ethylene glycol (TEG) and calcium chloride–lithium chloride mixture. The liquid desiccants are expected to possess some important properties including low vapour pressure, low viscosity, low regeneration temperature, low crystallization point, high density and being cost effective [4] (Fig. 1).

A liquid desiccant system has three main components namely the regeneration heat source, dehumidifier and cooling unit. Today, packed bed is the most prevalent technology for these components. However, in order to avoid internal cooling, packed beds must operate with high desiccant flow rates to dehumidify effectively without any internal cooling. The dehumidification process is carried out by spraying the liquid desiccant into the process air to absorb the moisture out of the air then the liquid desiccant falls to a sump and pumped back to the nozzles to be sprayed back to the air again. The solution becomes diluted as a result of absorbing moisture out of the air stream. The concentration of desiccant solution decreases as the water content increases. Liquid desiccant is continuously circulated through the regenerator [5]. So, the desiccant is regenerated to remove the moisture content by using an external heat

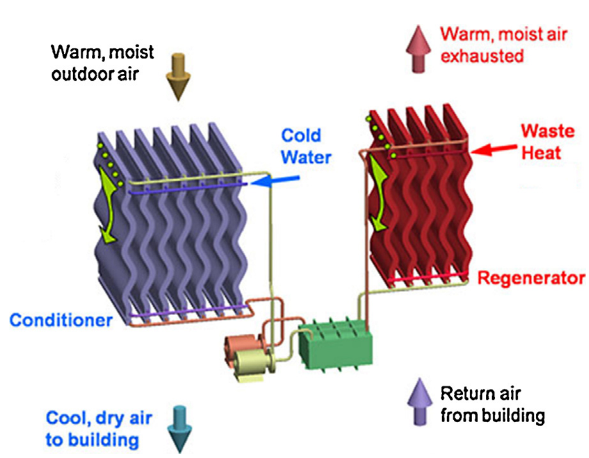

Fig. 1. Schematic of a desiccant cooling air conditioning [8].

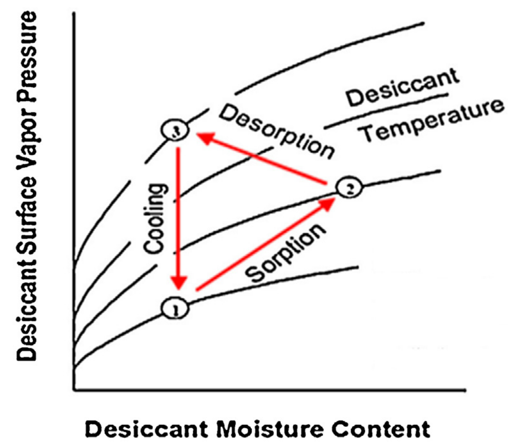

Fig. 2. Moisture removal process by desiccant [6].

source. Also, the desiccant solution is heated before any connection with air to adjust the partial pressure higher than that of the air. Thus, the moisture content of desiccant is transferred to the regeneration air (process 2–3 in Fig. 2). This regeneration air exits from the regenerator in a hot and humid condition. After the regeneration process, the liquid desiccant solution becomes concentrated and free from moisture content and is still at high vapour pressure and temperature. Before being sprayed into the process air again to complete the cycle, the liquid desiccant solution is cooled by a chiller or cooling tower to adjust the temperature to the desired level (process 3–1 in Fig. 2). Then, sensible cooling is provided via employing traditional vapour compression and vapour absorption, direct or indirect evaporative coolers [6]. For the regeneration, thermal energy required at a temperature as low as 40–50 °C that can be easily obtained by employing a flat plate collector [7]. In fact, being regenerated at lower temperatures below 80 °C is the one of the most favourable features of the liquid desiccant systems than the solid desiccant cooling systems due to the higher moisture mass transfer area. However, carry-over to the supply air is one of the main concerns of the liquid desiccant cooling systems. Besides, liquid desiccant materials are usually corrosive and simple handling of the working media is difficult. Thanks to fast advancement in the field, the potential of the liquid desiccant is remarkable [9,10].

Ever since Lof [11] investigated liquid desiccant solar cooling concept, a number of researchers have conducted number of studies on liquid desiccant dehumidification systems for solar cooling applications. Enteria et al. [10] studied solar assisted liquid desiccant air conditioning system. The study showed that increasing mass flow rate of the desiccant solution caused an increase in the performance of both the regenerator and the solar collector. Factors like initial air and solution temperatures, solar radiation as well as the climatic conditions were found to be having effects on the overall performance of the envisaged system. Henning et al. [12] conducted an experimental study of a combined solar aided liquid desiccant cooling system with a 20 m^2 flat-plate solar collector and a 2 m^3 hot water storage tank and claimed the primary energy savings up to 50% with a low overall cost. 54% of collector efficiency, 76% solar fraction between the solar heat and auxiliary heat provided and COP of 0.6 during typical summer conditions were also reported. Not only feasibility study but also comparative study over various systems for different climatic conditions were presented. Yutong and Hongxing [13] worked on to obtain the best configuration of an open cycle liquid desiccant air-conditioning system. The proposed system employed a counter flow type dehumidifier and solar collectors for the regeneration of dilute desiccant solution. There were two main loops designed for the system: liquid desiccant dehumidification loop and air dehumidification loop along