Energy and Buildings 62 (2013) 1–14

Contents lists available at SciVerse ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Review

Survey of liquid desiccant dehumidification system based on integrated vapor compression technology for building applications

Abdulrahman Th. Mohammad[a,b,*], Sohif Bin Mat[a], M.Y. Sulaiman[a], K. Sopian[a], Abduljalil A. Al-abidi[a]

[a] Solar Energy Research Institute, University Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia
[b] Department of Mechanical Engineering, Baqubah Technical Institute, Foundation of Technical Education, Baghdad, Iraq

ARTICLE INFO

Article history:
Received 21 August 2012
Received in revised form 22 February 2013
Accepted 1 March 2013

Keywords:
Vapor compression
Hybrid liquid desiccant
Vapor absorption

ABSTRACT

Conventional air conditioning systems based on the vapor compression principle are primary electricity consumers and their refrigerants have negative environmental impacts. The combined liquid desiccant dehumidification and vapor compression system, defined as hybrid liquid desiccant systems, was studied extensively to improve the performance of these systems. Different configurations of hybrid liquid desiccant systems and their components were investigated.

This paper reviews and surveys the available hybrid liquid desiccant air conditioning system technologies. Relevant information about the system characteristics, configurations, and performances are covered and presented in detail. Finally, conclusions and some important suggestions are presented according to the collected information about the systems.

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1. Introduction

The two most common types of refrigeration systems are vapor absorption and vapor compression. In a vapor compression system, an external source of shaft power is necessary to run the compressor. The vapor–compression cycle is the most widely used refrigeration cycle. In this cycle, a vapor is compressed and condensed into liquid. The pressure is dropped to allow fluid to evaporate at low pressure. The refrigeration cycle requires additional external work for its operation. The processes that constitute the cycle are: adiabatic compression, isothermal rejection of heat, adiabatic expansion, and isothermal addition of heat.

In recent years, many refrigeration vapor–compression systems were introduced and developed to increase the efficiency of power distribution and to utilize industrial waste heat and renewable clean energy. Yaqub et al. [1] applied the automatic hot gas bypass technique to reduce the capacity of refrigeration and air conditioning systems when operating at part load. Zubair [2] demonstrated the advantages of add-on sub cooler systems to improve the performance of refrigeration/air-conditioning systems. Chen and Jianlin [3] obtained better performance of a new refrigeration cycle for binary non-azeotropic mixed (R22/R134a). The performance of the new mixture in this new cycle is close to that which can be obtained with R22. The mixed COP of the system can be improved within a range of 8–9% of the conventional refrigeration cycle. Wang et al. [4] performed a thermodynamic and economic analysis of a novel

* Corresponding author at: Solar Energy Research Institute, University Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia. Tel.: +60 173672679; fax: +60 389214593.
E-mail address: abd20091976@gmail.com (A.Th. Mohammad).

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http://dx.doi.org/10.1016/j.enbuild.2013.03.001

Table 1
Main characteristics of liquid desiccants.

Characteristic	TEG	LiCl and LiBr	$CaCl_2$
Suitability of equilibrium	Moderate dehumidification when regenerated at 65–80 °C	Good dehumidification with regeneration temperatures above 80 °C	Poor dehumidification
Characteristics	Requires high circulation rate between dehumidifier and regenerator	Does not require high circulation rate between dehumidifier and regenerator	Regeneration possible at temperatures of about 60 °C Does not require high circulation rate between dehumidifier and regenerator
Loss desiccant through evaporation	Present (regeneration) Minimal (dehumidification)	No loss	No loss
Possibility of crystallization	Not	Present	Present – more than LiCl and LiBr
Corrosion hazard	Moderate requires inhibitors and PH control	High requires inhibitors and PH control	Moderate requires inhibitors and PH control
Toxicity of vapors	Not – toxic	Not – evaporate	Not – evaporate
Cost	High	High	Low

compressed-air energy storage refrigeration system; the system is a combination of a gas refrigeration cycle and a vapor compression refrigeration cycle. Liu Shengjuna et al. [5] performed a thermodynamics analysis of the actual air cycle refrigeration. The results of the study show that the pressure ratio, working temperature, and isentropic efficiencies of the rotors are effective on the performance of the actual cycle. Toublanc and Clausse [6] proposed a novel Carnot-type cycle to reach high performances for trans-critical and sub-critical applications. The coefficient of performance of the cycle is higher by 4–70% than the conventional cycle.

Absorption systems are similar to vapor compression systems, except for the pressure used in each stage [7]. Absorption systems use heat energy to produce refrigeration; water is used as a refrigerant and lithium bromide is generally used as the absorber of refrigerant [8]. Ammonia water and water lithium bromide are often used absorption refrigeration systems, whereas ammonia–water systems are used in condensers [9]. The required heat source temperature for this system is approximately 300 °F.

Commercially, two types of absorption systems are available, single effect and double effect. The main purpose for increasing the effect cycle is to increase the system performance at high heat source [10].

2. Principle of liquid desiccants

The dehumidifier and the regenerator are the main components of a liquid-desiccant dehumidification system. The most common technology for a dehumidifier/regenerator is the packed bed. However, packed beds must work with high desiccant flow rates to achieve good dehumidification levels without internal cooling [11]. The main purpose of the desiccant is to attract the water vapor from the air; thus, it can be classified it into solid and liquid desiccant. Several types of solid materials can hold of water vapor; they are silicas, polymers, zeolites, aluminas, hydratable salts, and mixtures. Other available liquid desiccants are calcium chloride, lithium chloride, lithium bromide, tri-ethylene glycol, and a mixture of 50% calcium chloride and 50% lithium chloride. These liquid desiccants have general properties, but their requirements are not fully answered by any single desiccant. These requirements include low vapor pressure, low crystallization point, high density, low viscosity, low regeneration temperature, and low cost. Several works were done to investigate the characteristics of single and mixtures of two liquid desiccants, these characteristic can be represented in Table 1.

Liquid desiccants can be regenerated at low temperatures, approximately 50–80 °C [12]. Thus, the regeneration process could be driven by heat sources with relatively low temperature, around 70 °C, such as solar energy, waste heat, and geothermal power. Few of researchers have performed experimental studies on the desiccant mixture to improve the thermal properties of desiccants, especially their surface water vapor pressure. The lower vapor pressure promotes the mass transfer process and gives better dehumidification effect. Liu et al. [13] compared the mass transfer of LiBr and LiCl aqueous solution including dehumidification and regeneration performance. The comparison depends of the liquid desiccant is the same inlet temperature and vapor pressure. From the experimental results, the same desiccant flow rate condition in the dehumidification process shows the LiCl solution better mass transfer than that LiBr solution. While in the regeneration process, the LiBr solution shows better mass transfer than that LiCl solution. The COP of the system was a similar in two cases, while the cost of LiCl solution was 18% lower than LiBr solution at current Chinese price. Ertas et al. [14] have analyzed the thermal properties of a new liquid desiccant solution-lithium chloride and calcium chloride. There were five different combinations according to the changed LiCl/$CaCl_2$ ratio: 100% LiCl, 100% $CaCl_2$, 70% LiCl and 30% $CaCl_2$, 30% LiCl and 70% $CaCl_2$, and 50% LiCl and 50% $CaCl_2$. The results showed that the 100% LiCl group was the lowest vapor pressure under different temperature. In Ahmed et al. [15] study, simple mixing rules used for predicting the thermophysical properties of 50% concentration of LiCl and 50% $CaCl_2$. The properties include vapor pressure, viscosity, and density. The results show that the interaction parameter works very well for calculating the viscosity of the mixture but doesn't work well for calculations vapor pressure and density.

Hassan and Salah [16] proposed a desiccant with a mixture of 50% of the weight of water calcium chloride and 20% calcium nitrate. They studied the physical properties of the mixture, such as viscosity, vapor pressure, density as well as the heat and mass transfer process. As compared with vapor pressure of 50% $CaCl_2$ solution, the results of the study show a significant increase in vapor pressure of approximately 14.7, 20.6, 34.4, and 47.3 mmHg at 30, 40, 50, and 60 °C, respectively. Li et al. [17] proposed a novel method that mixes LiCl and $CaCl_2$. In their work, they divided the liquid desiccant into five groups: Group 1 (pure LiCl with mass fraction 39%), Group 2 (mixed LiCl–$CaCl_2$ solution with mass fraction of 5% for $CaCl_2$), Group 3(35% LiCl and 10% $CaCl_2$), Group 4 (33% LiCl and 15% $CaCl_2$), and Group 5(31.2% LiCl and 20% $CaCl_2$). Through the experiments, the inlet air temperature for dehumidification was controlled as 30 ± 0.5 °C and the humidity ratio was regulated as 10 g/kg_{air}, 11 g/kg_{air}, and 12 g/kg_{air} The experimental results show that the fifth groups have the best dehumidification effect. As compared to Group 1(Pure LiCl solution), Group 5 was improved the dehumidification amount by 25%, 25.3%, and 24.3% under three conditions, respectively, while the cost added only takes up 4.5% of the original cost in Group 1.