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Review of solar regeneration methods for liquid desiccant air-conditioning system

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ABSTRACT

Liquid desiccant air-conditioning system is a novel air-conditioner with good energy saving potential. For the liquid desiccant air-conditioning system, the energy consumption mainly relies on the regeneration process of desiccant solution. As the regeneration process of the liquid desiccant air-conditioning system only needs low-grade energy, solar energy (a kind of renewable energy) can be used to regenerate the desiccant solution and the solar desiccant regeneration system has attracted many attentions. In this paper, recent theoretical and experimental works on solar thermal regeneration method and solar electrodialysis regeneration method of the liquid desiccant air-conditioning system are extensively reviewed. Moreover, the comparison of solar TH regeneration method and solar electrodialysis regeneration method is discussed. The results showed that compared to the solar thermal regeneration system, the solar electrodialysis regeneration system is more energy-efficient but expensive.

Contents

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Nomenclature

Con	mass concentration (%)
F	faraday constant (C/mol)
I	electric current passing through the ED stack (A)
M_d	molecular weight of solute in the desiccant solution (kg/mol)
m	mass flow rate (kg/s)
N	the number of cell pairs in ED stack (no units)
P	electrical energy (kW)
Q	solar energy (kW)
q	solar energy for acquiring unit mass of strong desiccant (kW/kg)
r_0	heat of water vaporization (kJ/kg)
U	voltage of the ED stack (V)
z	valence of desiccant solution (no units)
α	ratio of the solar energy consumptions (no units)
β	conversion efficiency (%)
ζ	current utilization of ED stack (%)
η	regeneration efficiency (%)
$\eta_{collector}$	thermal efficiency of the solar collector(%)

Superscripts

c	concentrate cells in ED stack

Subscripts

ED	electrodialysis
i	at the entrance
o	at the exit
PV	PV cells
PV–ED	the PV–ED regeneration system
s	desiccant solution
TH	TH regeneration
w	water

1. Introduction

Seeking a comfortable living condition is a popular trend today, which leads to the wide-spread of air-conditioner. At present, the most widely used air-conditioner is the vapor compression cooling system, which is driven by electrical power. The dehumidification method of the vapor compression cooling system is to cool the air below its dew point, particularly for dew point requirements above 5 [1]. This approach is energy expensive as the air should be reheated after the dehumidification process to obtain the required temperature. On the other hand, the overuse of the vapor compression cooling system has a negative effect on the environment.

Besides the traditional dehumidification method (cooling the air below its dew point), the air may also be dehumidified by liquid desiccant. As a result, a novel liquid desiccant air-conditioning system has attracted many attentions [2–5], which uses liquid desiccant to dry the air by absorbing vapor in the air. Compared to the vapor compression cooling system, air in the liquid desiccant air-conditioning system is not needed to be cooled below the dew point temperature. Meanwhile, instead of CFCs and HCFCs, liquid desiccant is not harmful to the environment. Moreover, as only low-grade energy is needed in the regeneration process of the liquid desiccant air-conditioning system, renewable energy (such as solar energy) can be used to drive liquid desiccant air-conditioning system [6,7]. In summary, liquid desiccant air-conditioning system should be a promising choice for both cooling and wet supplies.

LiBr aqueous solution and LiCl aqueous solution are commonly used in the liquid desiccant air-conditioning systems. Liu et al. [8] compared mass transfer performance of LiBr solution and LiCl solution on the basis of the same solution temperature and surface vapor pressure. Compared to LiCl solution, LiBr solution has higher density and smaller specific heat capacity. In the condition of the same desiccant mass flow rate, the dehumidification performance of LiCl solution is better, and the regeneration performance of LiBr solution is a little better or almost the same as that of LiCl solution. In the condition of the same desiccant volumetric flow rate, the regeneration performance of LiBr solution is better and the dehumidification performance of LiCl solution is a little better or almost the same as that of LiBr solution. Moreover, LiCl solution costs 18% lower than LiBr solution at current Chinese price.

Besides traditional liquid desiccants (LiBr, LiCl and $CaCl_2$), new liquid desiccants which may be used in the liquid desiccant air-conditioning system have also attracted many researchers. Lychnos et al. [9] concerned the properties of the concentrated bittern solutions occurring as by-product from solar salt works, in relation to their potential use as liquid desiccants in cooling systems. An expression was provided for the equilibrium relative humidity of bitterns as a function of concentration relative to raw seawater. The vapor pressures of bittern solutions were found to be similar to those of solutions containing only magnesium chloride but having the same mass fraction of total salts. Davies and Knowles [10] explored the scope for exploiting the hygroscopic salts occurring in these by-products – such as magnesium, calcium and sodium chloride – as desiccant solutions in a greenhouse cooling system. The results show that except for sodium chloride, all six salts considered can be used as desiccant solutions in a greenhouse cooling system.

Besides investigation on the characteristic of liquid desiccant, there are also many literatures [11–27] shared with the experimental and theoretical investigations of the liquid desiccant air-conditioning systems. Longo and Gasparella [1] presented the experimental tests and the theoretical analysis of heat and mass transfer in a packed column dehumidifier/regenerator. The experimental tests and the theoretical analysis show that the dehumidification of air by hygroscopic salt solutions ensures consistent reduction in humidity ratio, which is suitable for applications to air conditioning or drying processes. Yin et al. [11–14] investigated the characteristic of the heat and mass transfer processes in the dehumidifier/regenerator experimentally and theoretically. Liu et al. [15–20] investigated the combined characteristic of the heat and mass transfer processes in the packed bed dehumidifier/regenerator experimentally and theoretically, and a handling zone dividing method in packed bed liquid desiccant dehumidification/regeneration process was proposed. Gandhidasan [21] presented the results from a simplified model of a packed bed regeneration process in which the desiccant solution is heated in any of the two ways. A closed form solution was obtained for both two ways of heating through two dimensionless performance parameters to estimate the water evaporation rate from the weak desiccant solution to the scavenging air stream in terms of known operating parameters. Aly et al. [22,23] presented the modeling and simulation of solar-powered desiccant regenerator used for open absorption cooling system. In order to evaluate the performance of the system under different operating conditions, Jain et al. [24] conducted an experimental investigation of a liquid desiccant dehumidification system using calcium chloride and lithium chloride as desiccants by varying parameters like inlet air conditions, hot water temperature and desiccant concentration.

Hybrid systems, which consist of desiccant cycle and vapor compression cycle, are also very attractive due to its energy-saving and its function to kill virus to make air clean. Ma et al. [28] presented the performance analysis on a hybrid air-conditioning system according to the hybrid building energy system of the green building demonstration project in Shanghai. In the hybrid system, the sensible cooling to the air is treated mainly by solar adsorption