Energy and Buildings 155 (2017) 475–483

Contents lists available at ScienceDirect

Energy and Buildings

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

Replication Studies

Experimental comparative research on electrodialysis regeneration for liquid desiccant with different concentrations in liquid desiccant air-conditioning system

Qing Cheng [a,*], Xiaosong Zhang [b], Shun Jiao [a]

[a] School of Energy Science and Engineering, Nanjing Tech University, Nanjing 211800, China
[b] School of Energy and Environment, Southeast University, Nanjing 210096, China

ARTICLE INFO

Article history:
Received 10 June 2017
Received in revised form
11 September 2017
Accepted 19 September 2017
Available online 20 September 2017

Keywords:
Liquid desiccant
Electrodialysis regeneration
Different concentrations
Comparative research
Experimental study

ABSTRACT

The issue of energy and environment is increasingly prominent, and air-conditioning system costs a lot of energy in the building. The liquid desiccant air-conditioning system is a novel air-conditioner with good energy saving potential, whose energy consumption mainly relies on the regeneration process of liquid desiccant. In this paper, an experimental system of electrodialysis (ED) regenerator was set up to confirm the stability of the ED regenerator for the regeneration of liquid desiccant with different concentrations and the regeneration performance of the ED regenerator for liquid desiccant with different concentrations was investigated. Moreover, the ideal COP of the liquid desiccant air-conditioning system and vapor pressure of the acquired strong desiccant at the exit of the ED regenerator were also evaluated to compare the characteristic of the ED regenerator for liquid desiccant with different concentrations. The result shows that besides high concentration, the low temperature is also very important for liquid desiccant to have high dehumidification capacity. Moreover, the excessive increase of current will be more harmful to the dehumidification capacity of the acquired strong liquid desiccant when liquid desiccant concentration is around 35%. Furthermore, when liquid desiccant concentration is around 35%, the ED regenerator needs more power to achieve liquid desiccant with the same dehumidification capacity.

1. Introduction

The issue of energy and environment is increasingly prominent, and energy saving is an important project nowadays. Industry, transportation and building energy consist of the main consumption factor, among which building-related energy consumption contributes to 48% of the total social energy consumption [1]. Besides lighting and plug load, air-conditioning system costs a lot of energy in the building, which gives a huge pressure on social energy.

At present, the most widely used air-conditioner is the vapor compression cooling system, which is driven by electric power and causes a large number of fossil fuels consumption, resulting in energy crisis and serious environmental problems [2,3]. The dehumidification process of vapor compression cooling systems is to cool the air below its dew point, which consumes much electrical energy, especially when the air should be reheated after this process. Besides the normal air dehumidification method (cool the air below its dew point), liquid desiccant can also be used to dry the air [4–6]. Based on liquid desiccant dehumidification, the liquid desiccant air-conditioning system (LDAS) is a novel air-conditioner with good energy saving potential [7–10], which is environmentally friendly and driven by low-grade thermal energy.

The energy consumption of the liquid desiccant air-conditioning system mainly relies on the regeneration process of the desiccant solution, which increases the concentration of liquid desiccant and gives it a powerful dehumidification ability. At present, thermal energy is widely used for the desiccant regeneration process, condensing thermal energy regeneration [11,12] and solar thermal regeneration [13–17] are most popular. She et al. [11] considered the distribution ratio (R) on the regeneration air and solution to improve the condensation heat utilization efficiency, the maximum COP 5.5 and the maximum performance improvement 17.6% can be obtained both in Mode 1 and Mode 3 systems. Lu et al. [13] conducted the simulation of solar-assisted LDAC in five cities of four main climate regions and results showed that the system's performance was seriously affected by ratio of building's sensible and latent cooling load. Fabio Armanasco et al. [14] used available heat

* Corresponding author.
E-mail address: chengqingny@njtech.edu.cn (Q. Cheng).

http://dx.doi.org/10.1016/j.enbuild.2017.09.055
0378-7788/

Nomenclature

C	Concentration (%)
COP	Ideal performance coefficient
F	Faraday constant (C/mol)
I	Current of the ED regenerator (A)
ICC	Income-cost coefficient of the ED regenerator (Pa/W)
m	Flow rate of the concentrated desiccant (g/s)
m_{de}	Desiccant flow rate out of the dehumidifier (g/s)
M_d	Molecular weight (g/mol)
n	Number of the independent measured variables
N	Number of cell pairs
p	Vapor pressure of desiccant solution (Pa)
p_{air}	Vapor pressure of air (Pa)
P	Energy consumption of the ED regenerator (W)
Q_{rc}	Refrigerating capacity (J)
r_w	Latent heat of water vaporization (kJ/kg)
r_α	Parameter ratio
U	Voltage of the ED regenerator (V)
x_i	Independent measured variable
y	Calculated variable
z	Valence
α	Parameter
$\triangle m_w$	Water transfer in dehumidifier (g/s)
$\triangle p$	Vapor pressure difference between desiccant solution and air (Pa)
ζ	Current efficiency (%)
δy/y	Relative uncertainty (%)

Subscripts

add	Increase
entrance	Desiccant at the entrance of regenerate rooms
exit	Desiccant at the exit of regenerate rooms
h	High desiccant concentration in experiment 2
l	Low desiccant concentration in experiment 1

driven cooling technologies in combination with solar thermal collectors to reduce the load caused by air conditioning on the electric utilities and to reduce the environmental impact, and experimental tests run during summer showed an average primary energy ratio and a primary energy saving index of about 1.6 and 30%, respectively. Peng and Zhang [15] validated a group of modified heat and mass transfer models based on thermal balance of the glazing of solar collector/regenerator to reflect solution regeneration process more truly. The results showed that preheating solution increased the regeneration efficiency to reach twice that of preheating air stream and the regeneration efficiency reached a maximum value of about 4 m and shorter or longer solar C/R failed to increase solution regeneration efficiencies. Abdel-Salam et al. [16] proposed and investigated a solar membrane liquid desiccant air conditioning (S-M-LDAC) system, which could eliminate the problem of desiccant droplets carrying over in supply and exhaust air streams. Results showed that the use of a solar thermal system (STS) to provide the thermal energy required for the regeneration of the dilute desiccant solution increased the initial costs but decreased the annual operating costs, compared to the non-solar systems. However, one problem of the solar thermal energy regeneration system is that solar energy will depend on weather conditions, the dilute desiccant needs more solar thermal energy and higher operational temperature when the outside air is hot and wet, which means that the solar thermal energy regeneration system cannot meet the dehumidification requirements all the time, and this shortage will limit the widely application of the liquid desiccant air-conditioning system based on solar thermal energy regeneration.

Besides solar thermal energy regeneration, electrodialysis (ED) regeneration is also a reliable choice to achieve the strong desiccant, which is a technology based on the transport of ions through the selective membranes under the influence of an electrical field [18–21]. Tufa et al. [18] tested a salinity gradient power-reverse electrodialysis (SGP-RE) unit for the production of electrical energy by exploiting the chemical potential of real brackish water and exhaust brine from a solar pond. Based on the ED technology, Li et al. [22,23] developed a new photovoltaic-electrodialysis (PV-ED) regeneration system for the liquid desiccant air-conditioning system, which has less energy consumption and can work steadily and meet the dehumidification requirements anytime. In addition to that, there are many literatures shared with the investigation of the performance of the electrodialysis regeneration system [24–28]. Among these researches, the performance of the ED regenerator for the regeneration of liquid desiccant with low concentration (below 30%) was studied [25,28]. However, when the air needed to handle is very hot and wet (such as the summer in Nanjing), the dehumidifier in the liquid desiccant air-conditioning system needs quite strong desiccant (exceed 35%) to dry the air. As a result, the reliability of the ED regenerator for liquid desiccant with high concentration (around 35%) should be experimentally validated.

In order to confirm the stability of the ED regenerator for the regeneration of liquid desiccant with different concentrations, an experimental system of the ED regenerator was set up in this paper and the regeneration performance of the ED regenerator for liquid desiccant with different concentrations was investigated. Moreover, the ideal COP of the liquid desiccant air-conditioning system and vapor pressure of the acquired strong desiccant at the exit of the ED regenerator were also evaluated to compare the characteristic of the ED regenerator for liquid desiccant with different concentrations. The results in this paper will clarify the performance of the liquid desiccant air-conditioning system based on ED regeneration with high concentration liquid desiccant and promote the application of LDAS based on ED regeneration in the buildings, especially the application in hot and wet area.

2. Material and method

2.1. Experimental system

The experimental system is combined with an ED regenerator, a concentrated desiccant storage, a dilute desiccant storage, an electrode solution storage and a rectifier. In the ED regenerator, the cation-exchange membranes and the anion-exchange membranes are placed alternately between the cathode and the anode. Liquid desiccant in the concentrated desiccant storage flows into regenerate rooms (b in Fig. 1) of the ED regenerator, while liquid desiccant in the dilute desiccant storage flows into dilute rooms (a in Fig. 1) of the ED regenerator. In the experimental system, the ED regenerator is driven by the rectifier, the anions and the cations in the cells of the ED regenerator will move to the anode and the cathode under the electrical field. In the migration process, the cations will pass through the cation-exchange membrane and be retained by the anion-exchange membrane. Likewise the anions will pass through the anion-exchange membrane and be retained by the cation-exchange membrane. Finally, the concentration of liquid desiccant in regenerate rooms is improved and that in dilute rooms is reduced. Then the concentrated liquid desiccant in regenerate rooms flows into the concentrated desiccant storage, while the dilute liquid desiccant in dilute rooms flows into the dilute desiccant storage. As a result, the strong liquid desiccant, which is needed in the liquid desiccant air-conditioning system, can be