Energy and Buildings 66 (2013) 1–15

Contents lists available at ScienceDirect

Energy and Buildings

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

Performance analysis of a new desiccant pre-treatment electrodialysis regeneration system for liquid desiccant

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ARTICLE INFO

Article history:
Received 13 March 2013
Received in revised form 21 June 2013
Accepted 9 July 2013

Keywords:
LDAS
Liquid desiccant
Desiccant regeneration
Desiccant pre-treatment

ABSTRACT

Liquid desiccant air-conditioning system (LDAS) is a novel air-conditioner with good energy saving potential. As a renewable energy, solar thermal energy (TH) can be used to regenerate desiccant for LDAS. One problem of the solar regeneration system is that solar energy will depend on weather conditions, which means that the solar regeneration system cannot meet the dehumidification requirements all the time. In this paper, a new desiccant pre-treatment electrodialysis (ED) regeneration system is proposed in order to improve the reliability and the performance of solar desiccant regeneration system for LDAS. The new system makes comprehensively use of solar energy and can work reliably under the variable conditions. Moreover, the new system can be used in the deep dehumidification field, which is required in industrial air-conditioning. Analysis of the new system, the solar TH regeneration system and the PV-ED regeneration system is made and the results reveal that the new system will be more energy efficient than others under the ideal operational condition. Among all factors, the most influential one is the concentration of desiccant at the entrance of concentrate cells in the ED regenerator, and the new system should be running under the ideal operational condition as possible.

1. Introduction

In today's world, finding ways to produce comfortable living conditions in buildings is a popular and needed trend, which leads to the widespread use of air-conditioner. At present, the most widely used air-conditioner is the vapor compression cooling system, which is driven by electric power. However, the overuse of the vapor compression cooling system is harmful to the energy power supplying and the environment. As a result, many new types of air-conditioners are developed to solve the problems accompanying with the overuse of the vapor compression cooling system. Among all new air-conditioners, the liquid desiccant air-conditioning system (LDAS) is a novel air-conditioner with significant energy-saving potential [1–4]. It is also a promising technology that can meet the needs of space cooling and moisture management in artificial building spaces.

The energy consumption of liquid desiccant air-conditioning system mainly relies on the regeneration process of the desiccant solution. At present, thermal energy (TH) is widely used for desiccant regeneration in liquid desiccant air-conditioning systems. This energy is usually obtained from low-temperature heat sources [5,6]. As a renewable energy source, solar thermal energy has many advantages and can be used to power this type of air-conditioning systems. There are many literatures shared with the investigation of the performance of the solar liquid desiccant air-conditioning system. Audah et al. [4] studied the feasibility of using a solar-powered liquid desiccant system to meet both building cooling and fresh water needed in Beirut humid climate using parabolic solar concentrators as a heat source for regenerating the liquid desiccant. Kabeel [7] investigated the regeneration of liquid solution using cross flow of air stream with flowing film of desiccant on the surface of a solar collector/regenerator. The results showed enhancement of regeneration efficiency for the forced cross flow compared with the free regeneration. Katejanekarn et al. [8] carried out an experiment of a solar-regenerated liquid desiccant ventilation pre-conditioning system. The results showed that the evaporation rate at the regeneration process was always greater than the moisture removal rate at the dehumidification process, which indicated that the concentration of the desiccant in the system would not decrease and so the performance would not drop during continuous operation. However, one problem of solar TH regeneration systems is that solar energy is cyclical and heavily dependent on weather conditions. This means that the system cannot always meet the

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http://dx.doi.org/10.1016/j.enbuild.2013.07.034

Nomenclature

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

Superscripts

c	concentrate cells in ED stack
$'$	parameters in the desiccant pre-treatment ED regeneration system
i	under the ideal operational condition

Subscripts

TH	TH regeneration
w	water
s	desiccant solution
i	at the entrance
o	at the exit
$PV\text{-}ED$	the PV-ED regeneration system
ED	electrodialysis
PV	PV cells
PV/T	the PV/T components
$dpEr$	the desiccant pre-treatment ED regeneration system
$heat$	thermal energy in PV/T components
$loss$	energy loss
dp	the desiccant pre-treatment unit
c	concentrate cells of the ED regenerator
d	dilute cells of the ED regenerator
dT	Comparison between the solar TH regeneration system and the desiccant pre-treatment ED regeneration system
dP	Comparison between the PV-ED regeneration system and the desiccant pre-treatment ED regeneration system

dehumidification requirements. Therefore, it is imperative to find a backup way for solar desiccant regeneration when the solar energy cannot produce enough desiccant regeneration.

Electrodialysis (ED) method is a technology based on the transport of ions through the selective membranes under the influence of an electrical field [9–11]. In the electrodialyzer, the cation-exchange membrane and the anion-exchange membranes are placed alternately between the cathode and the anode. The anions and the cations in the cells of the electrodialyzer will move to the anode and the cathode under an electrical field. In the migration process, the anions and cations can go through the anion-exchange membrane and the cation-exchange membrane, respectively. However, the anions and cations cannot go through the cation-exchange membrane and the anion-exchange membrane, respectively. Finally, the concentration of liquid desiccant in some cells of the electrodialyzer will increase, and the others will decrease.

Based on the ED technology, Li et al. [12,13] developed a new regeneration system for LDAS. The regeneration system was named as photovoltaic-electrodialysis (PV-ED) regeneration system. Based on the PV-ED regeneration system, Cheng et al. [14] developed a new double-stage photovoltaic/thermal ED regeneration system (PVT-ED). Analysis of the single-stage and double-stage regeneration system was made and the results showed that the double-stage PVT-ED regeneration system will be more applicable than the single-stage PV-ED regeneration system for LDAS.