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A solar desiccant pre-treatment electrodialysis regeneration system for liquid desiccant air-conditioning system

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ABSTRACT

The liquid desiccant air-conditioning system (LDAS) has attracted more and more attentions in recent years. As a kind of renewable energy, solar thermal energy can be used to regenerate the desiccant solution in LDAS. One problem of the solar TH energy regeneration system for LDAS is that solar energy will depend on weather conditions, which means that the solar TH energy regeneration system cannot meet the dehumidification requirements all the time. In this paper, a new solar desiccant pre-treatment ED regeneration system is proposed in order to improve the reliability of solar desiccant regeneration system. The solar desiccant pre-treatment ED regeneration system makes comprehensively use of the solar energy and can work reliably under the condition without plenty of solar energy. Analysis of the solar desiccant pre-treatment ED regeneration system, the solar TH regeneration system and the PV-ED regeneration system is made and the influential factors of the performance of the solar desiccant pre-treatment ED regeneration system are investigated. The results reveal that the solar desiccant pre-treatment ED regeneration system will be more energy efficient than the solar TH regeneration system and the PV-ED regeneration system by setting up the parameters in reason.

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 electric power. The liquid desiccant air-conditioning system (LDAS) is a novel air-conditioner with good energy saving potential [1–4]. Compared to the vapor compression cooling system, the liquid desiccant air-conditioning system has attracted more and more attentions in recent years due to its environmentally friendly technology and promising utilization of low-grade thermal energy.

The energy consumption of liquid desiccant air-conditioning system mainly relies on the regeneration process of the desiccant solution. In general, the liquid desiccant air-conditioning system is driven by thermal energy, which can be obtained from low-temperature heat sources [5,6]. As a kind of renewable energy, solar energy can be used to regenerate the desiccant solution for the liquid desiccant air-conditioning system. There are many literatures shared with the investigation of the performance of the solar liquid desiccant air-conditioning system [7–9]. However, one problem of the solar energy regeneration system is that solar energy will depend on weather conditions, which means that the solar energy regeneration system cannot meet the dehumidification requirements all the time. Therefore, it is necessary to find a new regeneration system for the liquid desiccant air-conditioning system under the condition without plenty of solar energy.

Electrodialysis (ED) is a technology based on the transport of ions through the selective membranes under the influence of an electrical field [10–12]. 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 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 some cells of the electrodialyzer will increase, and the others will decrease.

Based on the ED technology, Li et al. [13,14] developed a new regeneration system for the liquid desiccant air-conditioning system. In the new regeneration system, the regenerator was designed as an ED stack, and photovoltaic (PV) generator supplied electric power for the regeneration process of the desiccant solution. The regeneration system was named as photovoltaic-electrodialysis (PV-ED) regeneration system. Based on the PV-ED regeneration system, Cheng et al. [15] developed a new double-stage photovoltaic/thermal ED regeneration system (PVT-ED). Analysis of the

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Nomenclature

Con	mass concentration (%)
F	faraday constant (C/mol)
G	water evaporation rate of desiccant solution (kg/s)
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 (%)
η	regeneration efficiency (%)
$\eta_{collector}$	thermal efficiency of the solar collector(%)
η_E	electrical efficiency of the solar cells (%)
η_T	thermal efficiency of the solar cells (%)
ζ	current utilization of ED stack (%)

Superscripts

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

Subscripts

dP	comparison between the PV-ED regeneration system and the solar desiccant pre-treatment ED regeneration system
dT	comparison between the solar TH regeneration system and the solar desiccant pre-treatment ED regeneration system
dpre	the desiccant pre-treatment unit
dpre-ED	the solar desiccant pre-treatment ED regeneration system
ED	electrodialysis
heat	thermal energy in PV/T components
i	at the entrance
loss	energy loss
o	at the exit
PV	PV cells
PV-ED	the PV-ED regeneration system
PV/T	the PV/T components
s	desiccant solution
s,c	concentrated desiccant solution in the ED regenerator
s,c,i	desiccant solution at the entrance of concentrate cells in ED regenerator
s,c,o	desiccant solution at the exit of concentrate cells in ED regenerator
TH	TH regeneration
w	water

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 liquid desiccant air-conditioning system. The PV-ED regeneration has higher performance and reliability than the solar TH regeneration method by using solar photovoltaic components to drive an ED regeneration process [15]. However, the PV-ED regeneration will waste a large amount of solar thermal energy as the conversion efficiency of the PV cells is low.

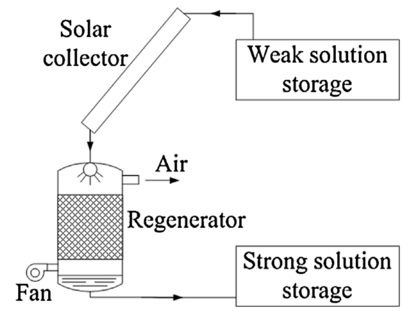

Fig. 1. Typical solar TH regeneration system for LDAS.

In this paper, a new solar desiccant pre-treatment ED regeneration system is proposed in order to improve the reliability of solar desiccant regeneration system for liquid desiccant air-conditioning system. The solar desiccant pre-treatment ED regeneration system will be built by combining it with solar PV/T components, a desiccant pre-treatment unit and an ED regenerator. The solar desiccant pre-treatment ED regeneration system makes comprehensively use of the solar energy and can work reliably under the condition without plenty of solar energy. What's more, the new regeneration system can be appropriate for energy-storage in a night operation mode when the electric power supply is at its valley. Analysis of the solar desiccant pre-treatment ED regeneration system, the solar TH regeneration system and the PV-ED regeneration system is made and the results reveal that the solar desiccant pre-treatment ED regeneration system will be more energy efficient than the solar TH regeneration system and the PV-ED regeneration system under the ideal operational condition.

2. Materials and methods

2.1. Solar TH regeneration system

2.1.1. System description of solar TH regeneration system

A typical solar TH regeneration system for LDAS is shown in Fig. 1. Weak desiccant solution in the weak solution storage is sent from the dehumidifier in LDAS. The weak desiccant solution flows into the solar collector and absorbs the solar thermal energy, which leads to the increase of the temperature of the weak desiccant solution. Then the hot weak desiccant solution flows into the regenerator and contacts with the passing air. As a result, water in the hot weak desiccant solution is absorbed by the passing air and the weak desiccant solution is regenerated. By this way, strong desiccant solution is acquired. Finally, the strong desiccant solution will be sent to the dehumidifier from the strong solution storage.

2.1.2. Energy consumption of solar TH regeneration process

In the solar TH desiccant regeneration process, the energy-consuming component is the solar collector. As the weak desiccant solution absorbs the solar thermal energy in the solar collector, the energy consumption of the solar TH desiccant regeneration process mainly relies on the solar thermal energy. The energy consumption of the desiccant pump and the fan is neglected in the following simulation as it is much less than the energy consumption in the solar