Applied Energy xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

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

Experimental investigation on adsorption and electro-osmosis regeneration of macroporous silica gel desiccant

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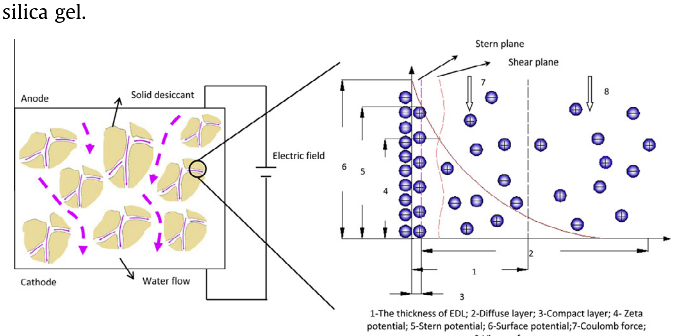
HIGHLIGHTS

- Electro-osmosis regeneration of solid desiccant is one potential method.
- Theoretical analysis is based on adsorption mechanism and water distribution.
- The property of macroporous silica gel is tested.
- Experiment verify feasibility of macroporous silica gel electro-osmosis regeneration.

GRAPHICAL ABSTRACT

In this paper, the electro-osmosis, adsorption, and the water distribution in porous media were discussed first. The macro-porous silica gel has optimal diameter of electro-osmosis flow. Free water exists in it, which indicates that it is feasible to form electro-osmosis flow. Then the adsorptive property of the macro-porous silica gel was tested by surface area and pore size analyzer. The electro-osmosis regeneration experiment bench of the macro-porous silica gel with different initial moisture content was designed. The experimental results demonstrated preliminarily the electro-osmosis could reduce the moisture content of unsaturated macro-porous silica gel and achieved the purpose of regeneration.
Capillary condensation takes place in the medium relative humidity and water exists in the state of liquid in the pore of 2–50 nm. Moreover, the electro-osmosis flow increases with the capillary diameter 8–20 nm. Therefore, the larger the pore size of the solid desiccant, the greater feasibility of the electro-osmosis regeneration is.
The most probable pore size of the macro-porous silica gel is 17.6 nm. The saturated moisture content of macro-porous silica gel is 113% in 300 K temperature and 95% relative humidity, and its zeta potential is −10.92 mV. These data shows that it both has electro-osmosis and moisture absorption characteristic. As for 105% initial moisture content of the macro-porous silica gel, the *D*-value of moisture content between the upper and bottom half of the sample box with the voltage was higher than that without voltage. Meanwhile, there was no visible condensing water droplet on the inside surface of the plastic film. However, for the 110% initial moisture content, there were lots of visible condensing water droplets on the inside surface of the plastic film. Both the electro-osmosis flow rates of these two groups both were not linearly proportional to the voltage due to feedback electric field and Joule heating effect. Moreover, the maximum electro-osmosis flow rates of 105% and 110% initial moisture content are 1.0E–8 kg m^{-1} s^{-1} V^{-1}, 3.4E−8 kg m^{-1} s^{-1} V^{-1} respectively.
The feasibility research proved that the electro-osmosis regenerated method was a potential method of macro-porous silica gel.



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http://dx.doi.org/10.1016/j.apenergy.2014.04.087

Please cite this article in press as: Zhang G et al. Experimental investigation on adsorption and electro-osmosis regeneration of macroporous silica gel desiccant. Appl Energy (2014), http://dx.doi.org/10.1016/j.apenergy.2014.04.087

ARTICLE INFO

Article history:
Received 13 December 2013
Received in revised form 17 April 2014
Accepted 26 April 2014
Available online xxxx

Keywords:
Electro-osmosis
Adsorption
Moisture content
Regeneration
Macroporous silica gel

ABSTRACT

In this paper, the possibility on electro-osmosis regeneration of macro-porous silica gel (MSG) desiccant has been investigated by testing the adsorption and electro-osmosis characteristic. The measured saturated moisture content of MSG is 113% in 300 K temperature and 95% relative humidity. Its zeta potential is −10.92 mV, which shows it has both good moisture absorption and electro-osmosis characteristic. The experiment bench is built to test the electro-osmosis regeneration performance on MSG by means of changing initial moisture content (105% and 110%) and applied voltage (40 V, 50 V and 60 V) respectively. The *D*-value of moisture content between the bottom and upper half with voltage is much higher than that without voltage. For the 110% initial moisture content, there are many visible condensing water droplets on the inside surface of plastic film under the cathode. Based on experimental results, it can find electro-osmosis flow exists when the moisture content is lower than the saturated moisture content. Besides, the electro-osmosis regeneration is one potential method of MSG desiccant when it is applied in dehumidification.

Nomenclature

EDL	electric double layer (–)
EOF	electro-osmosis flow (–)
MSG	macroporous silica gel (–)
D	dielectric constant (–)
K	electric conductivity (S m^{-1})
I	current (mA)
R	saturated moisture content (%)
r	moisture content (%)
U	voltage (V)
A_c	cross sectional area (m^2)
E_z	electric field intensity (V m^{-1})
P_{Ad}	adsorption pressure (Pa)
$Q_{net,eo}$	net electro-osmosis flow rate without condensation water (kg m^{-1} s^{-1} V^{-1})
$Q'_{net,eo}$	net electro-osmosis flow rate with condensation water(kg m^{-1} s^{-1} V^{-1})
P_{De}	desorption pressure (Pa)
ΔE	streaming potential (mV)
ΔP	pressure difference (Pa)
Δt	experimental period (s)
r_i	initial moisture content (%)
m_{ex}	water quantity removed under voltage (kg)
m_{gr}	water quantity removed by gravity (kg)
m_{con}	water quantity condensing on the plastic (kg)
V_c	specific cumulative pore volume (cm^3 g^{-1})
μ	dynamic viscosity (Pa S^{-1})
ρ	density of water (g cm^{-3})

1. Introduction

The desiccant dehumidification makes use their affinity for water to reduce the humidity of the air. This humidification system gets more and more applications because of the higher demand of thermal comfort and energy-saving in the buildings. The desiccant dehumidification can easily realize independent control of sensible and latent heat load, reduce the use and leak of chlorofluorocarbons [1–3], and satisfy the demand of the fewer energy consumption and higher efficiency [3–6].

To realize cyclic utilization of solid desiccant, the desiccant should be regenerated after absorbing the moisture from high humidity air. The present method is heating regeneration whose temperature is much higher than the boiling point of water. Besides, this method consumes much thermal energy, and has complex structure [7–9]. Therefore, low-energy consumption and simple structure solid desiccant regeneration methods are urgent needed.

Electro-osmosis flow (EOF) is formed when the electric field applies on the porous media or the micro-channel. It has many applications such as electro-osmosis pump [10–13], soil consolidation [14,15], sludge dewatering [16–19], biological electro-osmosis [19,20], the capillary electro-chromatography [21,22] and electro-osmosis regeneration [23–28]. The electro-osmosis regeneration had been put forward first by Mina and Newell [23] in 2004. They conducted theoretical research about this novel method and found this method was feasible. They got the results based on the relative humidity *D*-value between two pressure-tight chambers. The electro-osmosis dehumidifier connected these two chambers. The water flow rate was 2.31 g m^{-2}. In 2007, Zhang [24] did electro-osmosis regeneration experiment with zeolite, silica gel and active carbon as solid desiccants. The moist air flowed over the solid desiccants surface. The electric field applied through the solid desiccant. But there was no water discharged from these solid desiccants. Qi et al. [25–27] did the electro-osmosis regeneration of zeolite in relative humidity of 95% and made performance analysis and optimization for the electro-osmosis regeneration system. The maximum regeneration rate was 1.1×10^{-7} kg m^{-1} s^{-1} V^{-1}. Li et al. [28,29] did the electro-osmosis experiment of zeolite in the way of adding water flow with constant weight. The final EOF rate was 0.953 g m^2 s^{-1}. They also established the heat and mass transfer model in porous medium. The present researches in this field mainly focused on electro-osmosis. However, the combination with different adsorption mechanisms and electro-osmosis is a gap. The considered parameter was the particle size of solid desiccant rather than the pore size of them, which was core part for adsorption dehumidification. The adsorbed moisture exists in the pore of solid desiccant makes the solid desiccant have certain moisture content. The electro-osmosis regeneration experiment of solid desiccant with certain initial unsaturated moisture content is also blank.