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Experimental investigation on water migration mechanism of macroporous silica gel in the coupling process of moisture adsorption and electro-osmosis regeneration

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ABSTRACT

Electro-osmosis regeneration (EOR) of solid desiccant is a promising alternative method for dehumidification. Macroporous silica gel (MSG) has good performance on both moisture adsorption capacity and EO effect. In this paper an experimental bench is set up to investigate the water migration character and mechanism between the air and MSG in the coupling process of moisture adsorption and EOR. Through several continuous and oft-repeated experiments under different voltages, the experimental results validate that water can be transferred to a higher relative humidity environment through MSG by EO effect. It is found that the saturated water content around the anode decreases about 1.71% and 2.76% after twice EOR processes respectively. This phenomenon means the moisture re-adsorption capacity of MSG around the anode gets weaker after EOR. Based on the experimental results, the water migration mechanism of the coupling process is analyzed. Moreover, EO effect of MSG is studied from a new perspective. The water mass induced by EO has a near linear relationship with the electric charge transport with a certain EO starting value. The coefficient between the migration water mass and quantity of electric charge is about 0.0536 g/C under the experimental condition.

1. Introduction

Solid desiccant has been widely applied in many fields because of its good performance on moisture adsorption, such as air-conditioning [1–5], sea water desalination [6–8] and water extraction from atmospheric air [9,10]. Meanwhile, regeneration is a significant segment for solid desiccant to fulfill its cyclic utilization. Traditional heating regeneration consumes high energy and has complex system structure [11]. Ultrasound regeneration [12–16] and electro-osmosis regeneration (EOR) [17–24] are proposed lately as potential alternatives for lower energy consumption and compact system structure.

EOR is attracting more and more attentions due to its unique regeneration characteristic of lower temperature. This kind of micro/nano electro-osmosis flow (EOF) has many applications, such as EO pump [25–28], soil consolidation [29,30], and dewatering of sewage sludge [31,32]. The idea of regenerating the solid desiccant by EO effect was firstly proposed by Mina and Newell in 2004 [17]. They made theoretical research about this novel method and proved its feasibility. Then Zhang [18] carried out EOR experiments on zeolite, silica gel and active carbon solid desiccants in 2007. But there was no water discharged from the solid desiccants in his experiments when the air relative humidity (RH) was 80%. In 2010, Qi et al. [19–21] analyzed the EOR performance of zeolite in the air of 95% RH, and got water drop out of zeolite. At the same time, Li et al. [22,23] investigated EOR performance of zeolite and diatomaceous earth under different voltages, and considered EOR as a promising alternative for energy choice in dehumidification industrial field.

Based on these previous researches, the authors found that pore size and water content of the solid desiccant are also critical factors for EOR performance [24]. The authors chose macroporous silica gel (MSG) as EOR material based on its adsorption capacity, EO effect, and water distribution in the porous media. Experimental results proved that the pore size of MSG was big enough to form capillary condensation water during moisture adsorption, and this capillary condensation water could be transferred by EO. The

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Nomenclature

EOF	electro-osmosis flow
EOR	electro-osmosis regeneration
HR	humidity ratio (g/kg)
MSG	macroporous silica gel
RH	relative humidity (%)
a_m	mass diffusion coefficient of the porous media (m^2/s)
$a_{m,g}$	mass diffusion coefficient of the gas phase in porous media (m^2/s)
$a_{m,l}$	mass diffusion coefficient of the liquid phase in porous media (m^2/s)
d_e	humidity ratio of the enclosed space at the end of each process (g/kg)
d_s	humidity ratio of the enclosed space at the start of each process (g/kg)
E	electric field (V/m)
I	current during one time interval (mA)
k_e	electroosmotic permeability coefficient
m_1	stranded water mass among the MSG (g)
m_2	water mass due to increase of air humidity ratio of enclosed space (g)
m_3	water mass condensed on the surface of plexiglas slates (g)
m_{MSG}	half of MSG mass in the unit (g)
M	total migrated water of three EORs (g)
q_c	total quantity of electric charge transported by EO current (C)
r	water content of MSG (%)
r_1	water content of MSG around the anode (%)
r_2	water content of MSG around the cathode (%)
Δr_1	water content change of MSG around the anode (%)
Δr_1	water content change of MSG around the cathode (%)
Δt	period time of each process (s)
Δt_0	one time interval (s)
u_{mEO}	total mass flux during the coupling process (g/s)
u_{mMD}	mass flux migrated by molecular diffusion (g/s)
$u_{mEO,net}$	convection mass transfer driven by electro-osmosis (g/s)
V_O	volume of the enclosed space (m^3)
x	partial vapor pressure of the enclosed space (kPa)
δ	thickness of the coupling unit (mm)
ρ_e	air density of the enclosed space at the end of (g/m^3)
ρ_s	air density of the enclosed space at the start of each process (g/m^3)
ρ_s	density of porous media (g/m^3)

experimental results also indicated that unsaturated MSG could be regenerated by EO effect. As for EOR, the higher the water content of MSG, the stronger the EO effect is. Therefore, feasibility of EOR for MSG at 300 K in temperature and 95% in RH is verified.

Authors have studied the EOR performance of MSG on certain initial water content without moisture adsorption [24]. However, the process of solid desiccant moisture adsorption and regeneration is usually coupled and cyclic in practical application. Water migration characteristic is complicated during the coupling process especially under the action of EO.

The purpose of this paper is to investigate water migration characteristic and mechanism in the coupling process of moisture adsorption and EOR of MSG, and study its EOR performance.

2. Experimental setup

2.1. Experimental mechanism

Moisture inside of the solid desiccant adsorbed from the air exists in the form of hydration water, surface water, interstitial water such as capillary condensation water, and free water. Interstitial water and free water can be removed by EO effect [33]. EOF forms from the anode to cathode in solid desiccants along with moisture adsorption, when voltage is applied. Then, water is released out of the solid desiccant through the cathode into the air.

The EOR unit coupling with moisture adsorption used in the experiment is shown in Fig. 1. The test unit includes two wire mesh electrodes, and solid desiccant which has both moisture adsorption properties and EO effect. Direct current field is applied between two electrodes. Processed air is passing over the anode. In order to measure the water mass migrating out of MSG, the air beside the cathode is enclosed. Moreover, temperature and RH of the air in the enclosed space represents the regeneration air to some extent. Humidity ratio (HR) increased in enclosed space indicates water migration. When the air in the enclosed space is supersaturated and its surface temperature is lower than the air's dew point, the water condenses. This is coupled running process of moisture adsorption and EOR of MSG. Coupled application is operated alternatively to measure the water content change of MSG before and after EOR. On the basis of these analyses, experimental bench is designed.

2.2. Experimental bench

The schematic of experimental bench testing coupling performance of EOR and moisture adsorption of MSG is shown in Fig. 2. The experimental bench includes an environment chamber (12) maintaining certain temperature and humidity, a test box (16), and some measuring apparatuses. The air, which is supplied to environment chamber by a fan, is reprocessed by a heater and a humidifier with On/Off operating logic to control the air on set condition as 300 K in temperature and 95% in RH. The test box is composed of two plexiglas slates propped up by four rectangle columns. Anode electrode and cathode electrode, made by titanium wire mesh and stainless wire mesh respectively, are embedded in columns. MSG is incased between the electrodes. Distance between the two electrodes is 5 mm. Four EOR units coupling with moisture adsorption make up the test box. Temperature and humidity sensor is inserted into the test box from bottom plexiglas

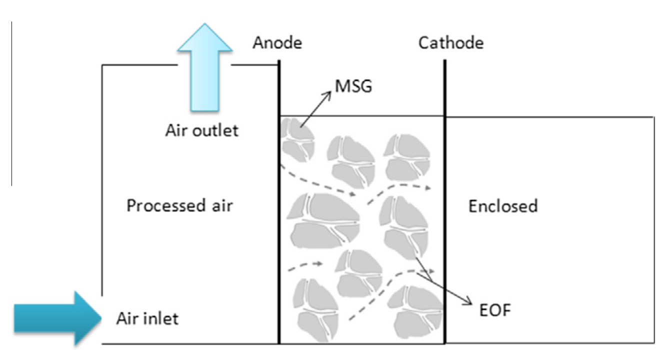

Fig. 1. Schematic diagram of EOR coupling with moisture adsorption.