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Research Paper

Experimental study on humidity control performance of diatomite-based building materials

Jiayi Zheng [a,b], Juan Shi [a], Qiang Ma [a], Xiaoli Dai [a], Zhenqian Chen [a,*]

[a] IIUSE, Key Laboratory of Energy Thermal Conversion and Control of Ministry of Education, School of Energy and Environment, Southeast University, Nanjing 210096, China
[b] School of Energy and Power Engineering, Nanjing University of Science and Technology, Nanjing 210094, China

HIGHLIGHTS

- The diatomite-based humidity control building materials are prepared.
- The porous structure parameters of DBHCBMs are characterized.
- Effect of surface energy on humidity control property of materials are analysed.
- Effects of temperature and humidity on performance of materials are examined.

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ABSTRACT

The humidity control performance of three types of diatomite-based building materials are experimentally studied. The distributions of the pores and matrix of the diatomite-based humidity control building materials (DBHCBMs) are visually characterized by micrographs and statistical analysis methods. The surface contact angle of the DBHCBMs is measured using an optical contact angle measuring device to evaluate the surface free energy. The saturated solution method is applied to measure the humidity control performance of the DBHCBMs. The effects of pores parameters (porosity, pore size distribution, surface contact angle), ambient temperature and relative humidity (RH) on the humidity control performance of the DBHCBMs are studied. The experimental results indicate that the humidity control performance of DBHCBMs is strongly affected by the pore parameters and surface contact angle. The DBHCBMs with tiny pore diameter, large amount of tiny pores and large surface contact angle have higher adsorption ability. The ambient temperature and the RH also have considerable influence on the adsorption performance of DBHCBMs.

1. Introduction

An excessively high or low relative humidity (RH) of the indoor air can cause various problems in the lives of people, such as the comfort of the occupants, the storage of goods, the durability of the building envelope and energy consumption. The Heating, Ventilating and Air Conditioning (HVAC) system is typically used to control the RH of indoor air and is a primary component of building energy consumption. A humidity control material (HCM) can adsorb or release moisture automatically without any power source or mechanical equipment due to its sensitivity to the variations of ambient RH. Thus, the use of a HCM is of great importance to the indoor environment, energy conservation and sustainable development of the ecological environment.

Since the use of a HCM was initially proposed by a Japanese scholar [1], it has received considerable interest, both at home and abroad. Various HCMs were developed, including biomass HCM [2–4], inorganic HCM [5–9], and organic HCM [10]. Horikawa et al. [2] studied the humidity control capacity of activated carbon from bamboo. The optimal treatment condition (bamboo activated at 873 K by K_2CO_3 with an impregnation ratio 1.0) for the highest humidity control capacity was obtained. Vu et al. [5] studied the humidity control materials by sintering a mixture of diatomite and volcanic ash with and without the addition of sodium perborate. The optimal sintered conditions and the best mixed portions were obtained to provide excellent humidity control performance for the building materials. Wang et al. [10] prepared an acrylate-based copolymer emulsion and investigated the humidity controlling characteristics in an interior wall coating.

The research studies described above experimentally characterized the HCM on the macroscopic scale, primarily examining the

* Corresponding author.
E-mail address: zqchen@seu.edu.cn (Z. Chen).

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original material selection, the optimal treatment and the best mixed portions of raw materials, as well as the humidity control performance measurement of the HCM. As a typical porous media, the micro-structure of HCM (e.g., porosity, pore size distribution, pores fractal dimension, and pores morphology) might have an influence on the humidity control performance of the HCM. To the best of our knowledge, there are only a small number of reports describing research in this area. Tomita et al. [11] investigated the humidity control ability of monolithic bimodal porous silica gel. The humidity control performance of the gel was controlled by changing its mesopore size. The presence of macrospores enabled the gel to respond to the humidity change quickly, due to the rapid gas diffusion in the monolithic gel body. Watanabe et al. [12] investigated the humidity control abilities of allophone, silica gel and gibbsite (which had mesopores). The results indicated that the mixture of gibbsite and clay minerals is appropriate for use as interior wall building materials, and these materials exhibit superior behavior for the removal of formaldehyde.

The above studies analyzed the humidity control abilities of HCM from the perspective of pore size. The results indicated that the humidity control performance of HCM varies with mesopore size. However, detailed micro-pore structure parameters which affected the heat or moisture migration in HCM need to be studied. Therefore, this work will prepare DBHCBMs by mixing mineral diatomite, cement, pulverized fuel ash, poplar cellulosine, mildew preventive and antimicrobial agents. The effects of the micro-pore structure, the pore-size distribution, and the surface free energy on the heat and moisture migration in DBHCBMs will be studied.

2. Preparations of DBHCBMs

2.1. Optimization of the diatomite performance by calcination

Diatomite, a siliceous sedimentary rock abundant all over the world, is receiving significant attention due to its unique combination of physical and chemical properties (such as high porosity, high permeability, light weight, small particle size, high specific surface area, low thermal conductivity, chemical inertness and well-developed microcellular pore structure) [13]. Diatomite is widely used in the fields of chemical engineering, petroleum, building materials, food, environmental protection, etc [14–18]. Moreover, diatomite can be one of the raw materials for HCMs [19].

Fig. 1 shows micrographs of raw and calcinated diatomite taken using a scanning electron microscope (SEM). As shown in Fig. 1(a), the raw diatomite is observed to have a round plate structure with uniform pore size and distribution. It is found in Fig. 1(b), the micro-pore morphology of diatomite changes after performing calcination at 500 °C for 3 h. The pores become smaller, and the number of small pores increases. The minimum diameter of the pores can reach approximately 50 nm. In addition, cracks are found on the surface of the diatomite. As shown in Fig. 1(c) and (d), the energy spectra of impurity elements (Fe, Al) almost disappeared after calcination at 500 °C for three hours, which implies that the purity of diatomite increases after calcination.

Diatomite that exhibits small and dense pores after calcination can improve the humidity control performance of diatomite. A comparison of the adsorption and desorption performances between raw diatomite and calcinated diatomite are shown in Fig. 2. It is evident that the adsorption content in calcinated diatomite is higher than that in the raw diatomite, which shows that calcinated diatomite has superior ability to regulate and control the indoor RH for buildings. This ability is attributed to the fact that small and dense pores can provide higher capillary forces. Meanwhile, calcinated diatomite exhibits a slower speed to release excess moisture because small and dense pores promote water retention. The slow and uniform desorption speed can create a more comfortable indoor environment for people. Therefore, calcination can improve the adsorption and desorption performances of diatomite.

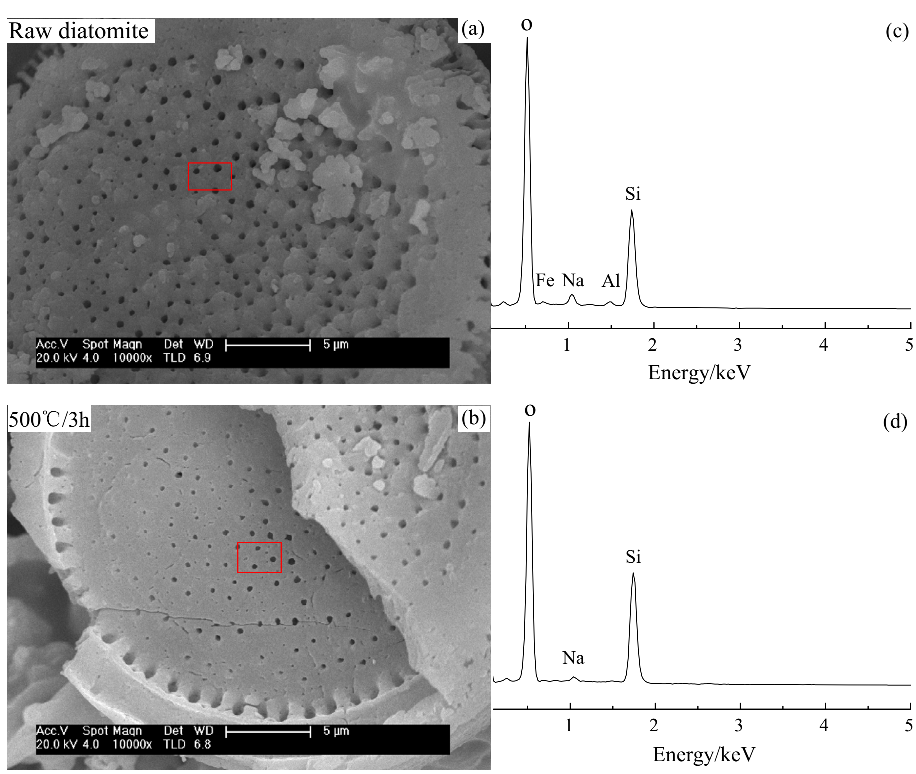

Fig. 1. SEM and EDS of raw and calcinated diatomites.