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Using power ultrasound for the regeneration of dehumidizers in desiccant air-conditioning systems: A review of prospective studies and unexplored issues

Ye Yao [a,b,*]

[a] Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, Shanghai 200240, China
[b] National Air Transportation Center of Excellence for Research in the Intermodal Transport Environment (RITE), School of Mechanical Engineering, Purdue University, West Lafayette, IN 47907-2031, USA

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ABSTRACT

Regeneration of dehumidizers is the most important stage in the working cycle of desiccant system. The lower regeneration temperature will be favorable for the energy efficiency of the whole system. Ultrasonic technology may be a promising method of dehydration applied to the regeneration of desiccant. As a non-heating method, the power ultrasonic may help lower the regeneration temperature and bring about energy savings. In the present paper, the mechanism of ultrasonic regeneration is set forth based on the ultrasonic theory as well as the mass transfer model in solid–gas and liquid–gas system. The recent studies related to ultrasonic dehydration are extensively reviewed, which is of significant reference to the study of desiccant regeneration assisted by power ultrasound. In addition, this work gives the basic ideas of ultrasonic dehydrator for solid/liquid-desiccant regeneration, which will promote the development of relevant equipments. Finally, some unexplored issues on this topic are addressed, including insight into the effects of ultrasonic on the regeneration, drying kinetics model for ultrasonic regeneration and the challenges possibly faced for the ultrasonic transducer development.
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Contents

1. Introduction

Dehumidification is an important air-handling process in air-conditioning system, which aims at reducing the level of humidity in the air, usually for health reasons, as humid air can easily result in mildew growing inside residence and cause various health risks [1]. It is also necessary in many industrial or agricultural occasions

* Correspondence address: Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University,Dong Chuan Rd. No.800, Shanghai, 200240, China.
Tel.: +86 13641943577; fax: +86 21 34206814.
E-mail address: yeyao10000@sjtu.edu.cn.

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where certain low level of air humidity is required to be maintained. Traditionally, the moist air is commonly dehumidified through refrigerant cooling method, i.e. the air is first cooled to below the dew-point temperature to condense moisture out, and then reheated to a desired temperature before it is delivered to the occupied spaces. This method not only results in additional energy dissipation due to the cooling–heating process, but also makes against the energy performance of chiller system because of the lower refrigerant evaporating temperature required. To improve the energy efficiency of the air-conditioning system, the independent humidity control system that integrates liquid/solid desiccant devices with a conventional cooling system has been developed to separate the treatment of sensible and latent load of moist air [2–4]. This system may bring about many chances of energy conservation, e.g. avoiding excess cooling and heating, utilizing waste heat rejected by machines [5] and solar energy [6] to accomplish the dehumidification. What is more, dehumidification with dehumidizers has been proved to be beneficial for improving IAQ (Indoor Air Quality) [7].

As shown in Fig. 1, the working cycle of desiccant method consists of the following three stages: (1) adsorption (from A to B); (2) regeneration or dehydration (from B to C); and (3) cooling (from C to A). During the repeated adsorption–regeneration–cooling cycle, the regeneration conditions will produce great influence on the performance of water vapor adsorption on dehumidizer [8]. Although higher regeneration temperature will contribute to increasing the desiccant volume of dehumidizer, it may be disadvantageous to the energy efficiency of desiccant system because high-temperature regeneration will not only consume large amount of thermal energy for heating the drying air, but also result in energy dissipation during the cooling process. In addition, the higher the regeneration temperature is, the more difficult it will be to utilize the low-grade energy sources widely existed in the nature. From this point of view, new types of dehumidizers [9,10] with lower regeneration temperature are attractive in this field application. In fact, the limitation of high regeneration temperature for the traditional solid desiccant may be overcome by some non-heating dehydration methods, such as pulsed corona plasma [11], pulsed vacuum [12], centrifugal forces [13], and electrical fields [14]. These non-heating methods enhance moisture transfer in materials through certain kind of physical force, and hence make it possible to apply to the drying of desiccant and lower the regeneration temperature.

Power ultrasonic is another non-heating technology that can improve the dehydration process of moist material, and becomes a promising dehydration method for desiccant regeneration [15]. Much literature [16–20] has reported that the high-intensity ultrasound can well enhance the regeneration of some adsorbents (used for water treatment), such as activated carbon and resins of different sorts (e.g. polymeric, NKA-II and CL-TBP). It is widely admitted that the regeneration enhancements attribute to some special effects (e.g. cavitation and miro-oscillation) induced by ultrasound that can overcome the affinity of the adsorbed species with the adsorbent surface and accelerate the molecular transport towards and from the adsorbent surface. The regeneration of the adsorbents for water treatment is made in solid–liquid system where the mass transfer occurs on the interface between solid and liquid. While, the desiccant regeneration usually happens in either solid–gas or liquid–gas environment. It is a brand new field for ultrasonic applications.

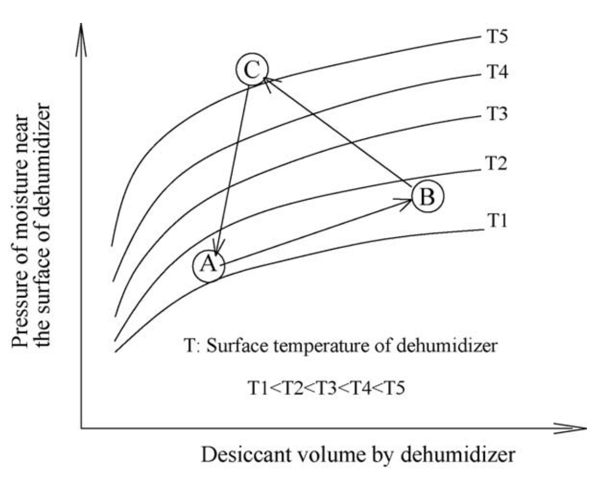

Fig. 1. Working cycle of dehumidification using dehumidizer.

The primary aims of this paper are to make clear the mechanism of mass transfer enhancement by ultrasonic in solid–gas and liquid–gas system based on an extensive review of relevant literature, and identify some unexplored issues for the future research. In order to provide a context for the main body of the review, we will begin by introducing the fundamental knowledge about ultrasound and its several special effects. Then, the mass transfer models in solid–gas and liquid–gas system are presented to illustrate the possible mechanism of enhancement by ultrasonic. Next, the recent studies on ultrasonic dehydration are summarized and reviewed. Meanwhile, some basic ideas about ultrasonic dehydrator for the regeneration of solid/liquid desiccant are put forward. Finally, some unexplored issues on the regeneration by power ultrasonic are addressed for the future study. These include the insight into the effects of ultrasonic on the improvement of desiccant regeneration, the drying kinetics model for ultrasonic regeneration, the development of ultrasonic transducer for this application and the other problems like the environmental impact and economic benefit.

2. Theoretical investigations

2.1. Fundamental knowledge about ultrasound

Sound, as a special form of energy, propagates through pressure fluctuations in elastic media. According to the frequency of pressure pulsation, sound can be classified as infrasound (lower than 20 Hz), audible sound (normally from 20 Hz to 20 kHz) and ultrasound (above 20 kHz) [21]. High-intensity ultrasound can cause some special effects, typically like cavitation, micro-oscillation and heating. The cavitation refers to the formation and subsequent dynamic behavior of vapor bubbles in liquids. It occurs when the high-intensity sound waves are coupled to the liquid surface, which results in the propagation of alternating regions of compression and expansion, and thus in the formation of micro-size vapor bubbles. If the bubbles grow up to a critical size, they may implode violently, releasing energy in the form of instant impulses with high local point temperature (attains 5000 K) and pressure (attains 1000 atm) [22]. Since the impulse time is very short (less than 0.1 s), the temperature of the bulk of the liquid hardly have a change. The micro-oscillation is due to the pressure fluctuation caused by the sound wave which makes the particles in medium alternately flex in the similar frequency of sound. Although the amplitude of vibration of the particles is very small, the acceleration may be as high as ten thousand times of the gravity [22]. The thermal effect of ultrasound can be illustrated by the following facts: on the one hand, part of ultrasonic energy is directly absorbed by medium during the transmission of ultrasonic wave; on the other hand, the oscillation caused by the sound wave intensifies the friction among particles, and ultimately converts into heat.

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