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Review

Enhancement of mass transfer by ultrasound: Application to adsorbent regeneration and food drying/dehydration

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ABSTRACT

The physical mechanisms of heat and mass transfer enhancement by ultrasound have been identified by people. Basically, the effect of 'cavitation' induced by ultrasound is the main reason for the enhancement of heat and mass transfer in a liquid environment, and the acoustic streaming and vibration are the main reasons for that in a gaseous environment. The adsorbent regeneration and food drying/dehydration are typical heat and mass transfer process, and the intensification of the two processes by ultrasound is of complete feasibility. This paper makes an overview on recent studies regarding applications of power ultrasound to adsorbent regeneration and food drying/dehydration. The concerned adsorbents include desiccant materials (typically like silica gel) for air dehumidification and other ones (typically active carbon and polymeric resin) for water treatment. The applications of ultrasound in the regeneration of these adsorbents have been proved to be energy saving. The concerned foods are mostly fruits and vegetables. Although the ultrasonic treatment may cause food degradation or nutrient loss, it can greatly reduce the food processing time and decrease drying temperature. From the literature, it can be seen that the ultrasonic conditions (i.e., acoustic frequency and power levels) are always focused on during the study of ultrasonic applications. The increasing number of relevant studies argues that ultrasound is a very promising technology applied to the adsorbent regeneration and food drying/dehydration.

Contents

1. Introduction

The power ultrasound has been found to be helpful to enhance heat and mass transfer process, and hence, improve systems efficiency. These owe to some special effects induced by power

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ultrasonic waves when traveling across a medium. Major effects of ultrasound for heat and mass transfer enhancement are acoustic 'cavitation' and acoustic streaming [1,2]. There exist other subsequent effects such as 'heating effect' due to dissipation of the mechanical energy and 'sponge effect' due to alternative compressions and expansions generated by the ultrasonic waves. The heating effect can increase mass diffusivity in a solid medium and promote mass transfer process. The sponge effect produces the release of liquid from the inner part of the particle to the solid surface, and the forces involved in this mechanism can be higher than the surface tension which maintains the water molecules inside the capillaries of the material, creating microscopic channels and making the interchanges of matter easier [3]. From a general viewpoint, all these effects produced by ultrasound could be interesting in applications involving heat or mass transport, decreasing both the external and internal resistance to transport.

As the typical application of power ultrasound in the heat and mass transfer enhancement, the ultrasound-assisted regeneration of adsorbents and food processing have been intensively studied in recent years. The objectives of this paper are to review and discuss recent studies on these topics.

2. Regeneration of adsorbents by ultrasound

2.1. Regeneration of desiccant

Regeneration of desiccant is a key process in an air dehumidification cycle with the adsorption/absorption method. The air-dehumidification system repeats the adsorption–regeneration–cooling cycle, in which the regeneration conditions will produce great influence on the performance of water vapor adsorption on desiccant [4]. The conventional regeneration method by heating is admitted to be of low energy efficiency due to the relatively higher regeneration temperature of some traditional desiccant materials like silica gel, molecular sieve and so on. The higher regeneration temperature, on one hand, results in more energy dissipation during the cooling process, and on the other hand, it is disadvantageous for the utilization of low-temperature energy sources (such as solar energy and waste heat). To reduce the regeneration temperature of desiccant, some non-heating methods have been put forward for the desiccant regeneration in recently years including ultrasound-assisted method [5–18], electro-osmotic method [19–22] and plasma method [23,24]. This section only presents the recent studies performed in our laboratory on the ultrasound-assisted regeneration of desiccant.

2.1.1. For solid desiccant

An experimental set-up (as shown in Fig. 1 [6,7]) has been built to investigate the effect of ultrasound on the regeneration of silica gel (an often-used desiccant). The silica gel packed bed is a concentrically cylindrical container. The regeneration air first enters into the inner cylindrical shell, then passes through the silica gel in the bed and finally exhausts outside from the orifices of the outer cylindrical shell.

To evaluate the benefits brought by the power ultrasound, several indicators are suggested for the study. These are the moisture ratio in the silica gel (q_s), the regeneration degree (RD), the enhanced ratio of regeneration (ER) and the energy-saving rate (ESR), which are defined, respectively, as below [6]:

$$q_s = \frac{m_{s,wet} - m_{s,dry}}{m_{s,dry}} \tag{1}$$

$$RD = \frac{m_{w,loss}}{m_{w,ini}} \tag{2}$$

$$ER = \frac{(MRS)_U - (MRS)_{NU}}{(MRS)_{NU}} \tag{3}$$

In Eqs. (1) through (3), $m_{s,wet}$ and $m_{s,dry}$ denote the mass of the wet and the dry silica gel, respectively, in kg; $m_{w,loss}$ and $m_{w,ini}$ denote the mass of moisture desorption and the initial mass of moisture in the sample, respectively, in kg; MRS denotes the mean regeneration speed (kg/s), i.e., the average moisture desorption rate in a period of regeneration time. The subscript '*U*' and '*NU*' denote the case in the presence and absence of ultrasonic radiation, respectively.

$$ESR = \frac{E_{NU}(RD) - E_U(RD)}{E_{NU}(RD)} \tag{4}$$

where, E (RD) denotes the energy consumption (J) used for obtaining certain RD of silica gel.

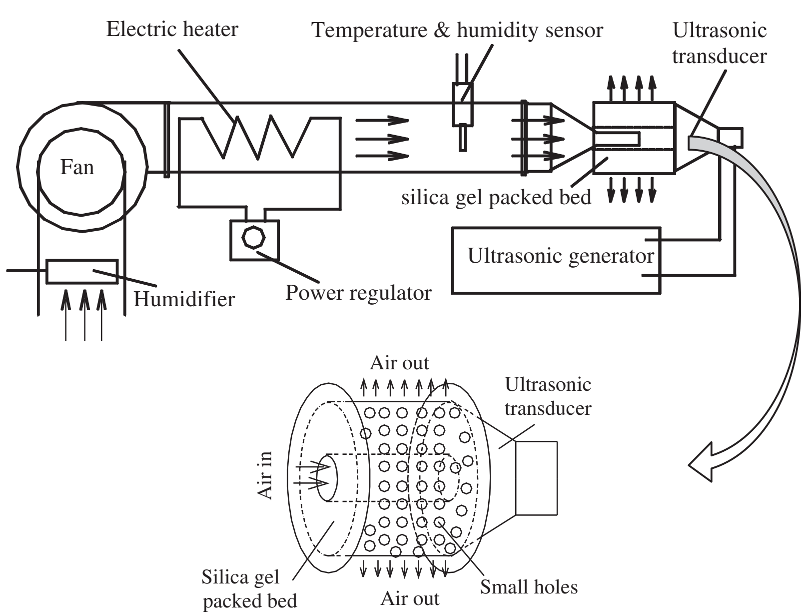

Fig. 1. The schematic diagram of the setup for the experiment [6,7].