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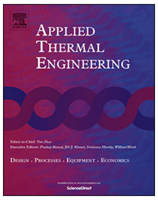

Research Paper

Extraction of heat transfer parameters in active carbon–ammonia large temperature jump experiments

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HIGHLIGHTS

- Heat transfer parameters in carbon–NH_3 large temperature jump tests were separated.
- Separated parameters are thermal conductivity, k and contact heat transfer coefficient, h.
- Thermal conductivity increased with bulk density.
- Contact heat transfer coefficient increased with bulk density.
- k is dominant for thicker adsorbent beds, while h is dominant for thinner beds.

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ABSTRACT

Experimental and theoretical analyses were carried out with the aim of developing a method of extracting heat transfer parameters from active carbon–ammonia large temperature jump data. The approach presented in this paper extracts two thermo-physical properties from the data as opposed to one overall property in previously employed techniques. Active carbon samples were tested using the large temperature jump technique with a step temperature increase from 40 °C to 70 °C. For a loose packed sample, which is about 8 mm thick, the obtained thermal conductivity (k) and heat transfer coefficient (h) were 0.2 W m^{-1} K^{-1} and 250 W m^{-2} K^{-1} respectively. The effect of changing bulk density through compression was also investigated. The thermal conductivity and contact heat transfer coefficient were found to increase with bulk density. The two physical properties obtained were combined into one single heat transfer figure and were compared to what was obtained using a previous method on the same set of data. Considering the assumptions made in the analytical process, these numbers were in reasonable agreement. A dominance of the thermal conductivity was observed in thicker beds, while contact heat transfer coefficient dominated in thin beds.

1. Introduction

Research into thermal based heating and cooling solutions has gained traction in recent years due to the environmental requirements of agreements such as the Kyoto Protocol, which calls for a progressive ban on CFCs and a reduction of GHG emissions. Adsorption systems among other thermally powered heating and cooling technologies have shown enormous potential. However, further research is required to deliver the desired performance worthy of competition with conventional systems. For adsorption systems, the associated sorption dynamics and cycle thermodynamics are two important factors that affect performance [1]. The large temperature jump (LTJ) is a methodology that has been used extensively [1–5] to study the dynamics of adsorption as it imitates conditions similar to the isobaric stages of the operation of an adsorption heat pump.

The underlying process involves keeping a sorbent sample at a steady temperature and then imposing a large step temperature change that induces the sorption process at constant volume and quasi-constant pressure. This emulates points 2 to 3 (desorption) or points 4 to 1 (adsorption) of the basic adsorption cycle in Fig. 1. Thus, large temperature jump experiments are a comparatively easy means of understanding the behaviour of various adsorbents/beds before spending time and effort testing them in full size adsorption heat pumps. In References 1–5, adsorption dynamics was the focus. Various adsorbent materials (Fuji silica RD, FAM-Z02, Carbon AC-35, SWS-1L) were tested on a range of vapours (H_2O, methanol, ethanol, ammonia) to ascertain the effects of the adsorbent nature, grain size, cycle boundary conditions, heating rate, isobar etc. on the adsorption dynamics. However, another product of the process in Reference 1 is the determination of an overall heat transfer parameter of the adsorbent bed, which treats the sample and it's carrier as one thermal entity.

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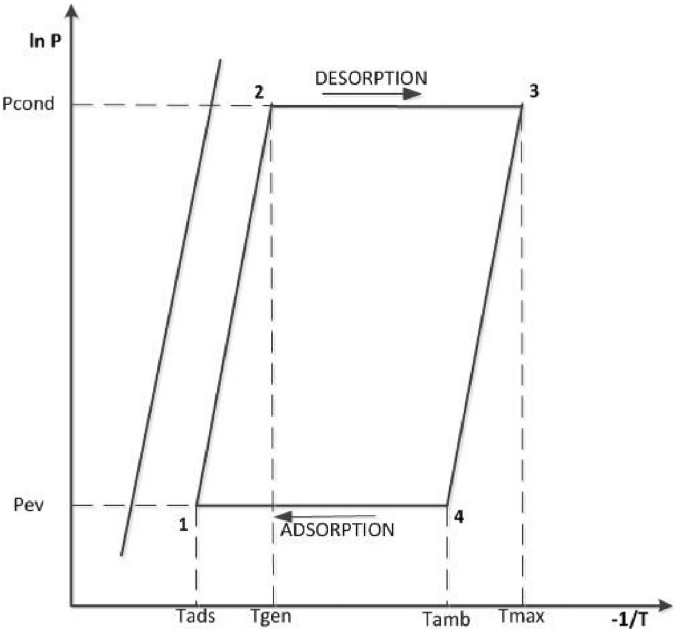

Fig. 1. A basic adsorption cycle.

The work documented here seeks to complement literature by separating heat transfer parameters in large temperature jump experiments. It is useful to obtain more heat transfer information from large temperature jump tests as this could ultimately help design better packed adsorbent beds for adsorption machines. Moreover, poor heat transfer has been widely identified as one of the major problems in packed adsorbent beds [5,6]. This work uses the large temperature jump as described in Reference 2 excluding the components for the creation and maintenance of water vapour since ammonia is used in this case and it remains as gas for the range of temperatures involved in the experiments performed [7]. The LTJ experiments were carried out for a range of bed thicknesses and densities. The density was varied by compressing the carbon with a compression testing machine. Data from the tests conducted were analysed with the aim of extracting two distinct thermo-physical properties. These properties are the thermal conductivity (k) and the contact heat transfer coefficient (h).

Similar works have been performed in the past. However, most previous works found in literature propose methods of determining the thermal conductivity of the bed as the sole heat transfer parameter without paying attention to the contact heat transfer resistance. Some of these methods [8] are steady state and only involve measuring the instantaneous temperature gradient between two known distances within the bed, although transient approaches like the hot wire and probe [9] methods also exist in literature. Rivero-Pacho et al. [10] used the hot transient tube method to obtain the thermal conductivity and contact resistance of a close packed mixture of active carbon grains and powder samples in the presence of air. The probe method [9] identifies thermal conductivity by fitting a model to transient temperature measurements obtained from a probe inserted into the sample.

Sharafian et al. [11] used the simultaneous solution of thermal balances in two experimental scenarios (two thickness method) on the guarded hot plate apparatus to determine two thermal parameters (conductivity and contact heat transfer coefficient). However, this was performed in the presence of a vacuum and not with gas flow and as such does not represent the actual condition in adsorption machines. The contact wall resistance accounted for 26% of the bulk resistance of the adsorbent-metal composite in Reference 11. This further highlights the importance of being able to investigate the conductivity and contact resistance separately.

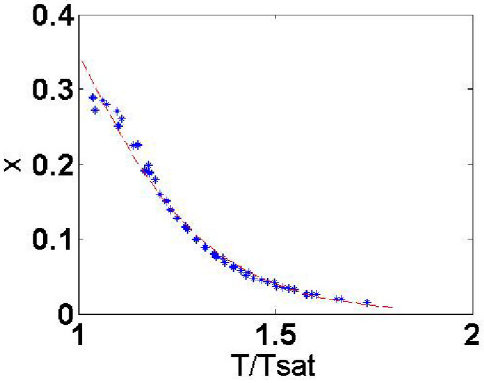

Fig. 2. Plot of concentration (x) vs T/Tsat for the adsorbent used.

The approach presented in this work deduces one dimensional heat transfer characteristics of the bed by fitting a relatively simple numerical model to the pressure evolution over the sample by varying the thermal conductivity and contact heat transfer coefficient values. The samples were made with a low height to diameter ratio (0.1 at most) in mind so as to minimise the effects of radial heat transfer. It is important to note that the approach presented here is only valid for cases where ammonia is used as adsorbate. In this case, the temporal evolution of the pressure over the sample greatly depends on the heat transfer parameters (k and h) separated in this work. For a given cooling power, the gas velocities for ammonia are much lower compared to those of lower density gases such as water. Thus the pressure drop across the packed bed based on Ergun equation [12] is very low and the assumption of constant pressure throughout the bed is valid. Tamainot-Telto and Critoph [13] also find that pressure drop for a monolithic carbon–ammonia generator bed is insignificant.

2. Experiment

2.1. Characterisation of active carbon

The adsorbent used was granular activated 208C carbon with a mesh size of 12 by 30 supplied by Chemviron Carbon. A Rubotherm magnetic suspension balance was used to characterise the porosity of the active carbon sample used, and the following was obtained for the plot of x vs $\frac{T}{T_{sat}}$.

As seen in Fig. 2, the data have a poorer fit towards the left hand side of the graph. This is due to the presence of capillary condensation as the sample approaches saturation [14]. Capillary condensation is a phenomenon in which the pores of the samples are filled with condensed gas in which condensation occurs below the saturation vapour pressure due to the pressure exerted by the meniscus between the liquid–vapour interfaces. Therefore, it is important to operate within the area of good curve fit.

The values of the constants (x_0, K and n) obtained from the characterisation were 0.3431 kg/kg, 4.4854 and 1.17 respectively. They are used in the modified Dubinin Astakhov equation (equation (1)) to obtain the adsorbate concentration in the adsorbent.

$$x = x_0 \exp\left(-K\left(\frac{T}{T_{sat}}-1\right)^n\right) \quad (1)$$

This form of the Dubinin Astakhov equation is obtained from the original form by making a direct comparison between the adsorbed phase and a saturated liquid at the same temperature [15].