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Experimental study of CO_2 adsorption kinetics onto activated carbon

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Abstract: *Kinetics measurement for adsorption of CO_2 on a highly porous commercially available activated carbon Maxsorb III is carried out in a thermogravimetric analyzer. The temperature selected for the study is 50 ºC. Two different heights of the loosely packed Maxsorb III sample are employed in the experiment: a) 0.9 mm and b) 25 mm. It is observed that the adsorption kinetics is strongly dependent on the height of the adsorbent used in the experiment. The lower sample height results in faster adsorption rate. The data obtained at two different pressure steps give identical result. This finding is significant in the design of an adsorption heat exchanger, as kinetics result obtained in the experiment may be quite different from that observed in a practical heat exchanger of an adsorption refrigeration system.*

Keywords: Activated carbon, adsorption, adsorbent height, CO_2.

1. INTRODUCTION

Adsorption based refrigeration system is gaining considerable attentions from the scientists due to its (i) ability to utilize low grade heat which would otherwise go as waste, (ii) its environment friendly nature. Several researchers work found in open literature on the measurement of adsorption kinetics parameters of different adsorption pairs [1]–[3]. Jribi et al. [4] measured the kinetics of CO_2 onto highly porous activated carbon Maxsorb III. Mitra et al. [5] numerically investigate the effect of adsorbent height on the adsorption dynamics for ethanol-Maxsorb III pair. All these kinetics parameters are used by the researchers and engineers in designing the adsorption heat exchanger. The motivation of the current study is to experimentally investigate the effect of adsorbent height in estimating the adsorption kinetics.

2. EXPERIMENT

The measurement of adsorption dynamics is conducted gravimetrically using magnetic suspension adsorption measurement unit supplied by Bel Japan. A schematic of the experimental setup is depicted in Figure 1.

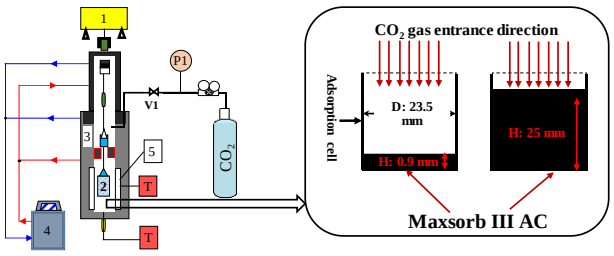


Fig. 1. Schematic of the magnetic suspension adsorption measurement unit. 1. Magnetic suspension balance; 2. adsorption cell; 3. Circulation oil jacket; 4. Isothermal circulation oil bath; 5. Sheathed heater.

The setup consists of a magnetic suspension balance; a sample cell to hold the sample; a circulation oil bath to control the adsorption temperature; a series of pumps, pressure sensors and thermocouples. The magnetic suspension unit contains a permanent magnet, sensor code and electronic control unit. The sample cell is surrounded by a circulation jacket so that the isothermal condition is maintained.

A CO_2 gas cylinder supplies the gas to be adsorbed by the sample at the adsorption cell. The pressure at the connecting tube can be adjusted by a control valve. The adsorbed amount is measured as weight by the magnetic suspension balance having a resolution of ±10μg. It needs mentioning that the buoyancy effect in the adsorbed quantity measurement is automatically considered by the software. The weight measurement repeatability of the balance is ±30μg with a relative error of ±0.002% of the reading. A pressure gauge of type Keller PAA-35X can measure pressure up to 10,000 kPa absolute with an uncertainty of ±0.1 of full scale.

3. RESULTS AND DISCUSSION

Experimental measurements are taken at an adsorption temperature of 50 ºC. The density of loosely packed Maxsorb III is measured as 170 kg/m^3. The adsorbents are placed in an adsorption cell having an inner diameter of 23.5 mm. Two different quantities of adsorbent are used in the investigation: 66 mg and 1850 mg, which give heights of the adsorbent as 0.9 mm and 25 mm respectively. It is obvious that with a higher mass, the absolute adsorbed quantity will be higher. Hence in the present study, normalized uptake is used to analyze the effect of adsorbent height on the adsorption dynamics. For the normalization, the following equation is used,

$$W_N = \frac{W - W_{in}}{W_{eq} - W_{in}} \quad (1)$$

where, W_N, W, W_{in} and W_{eq} are normalized uptake, instantaneous uptake, initial uptake and equilibrium

uptake, respectively.

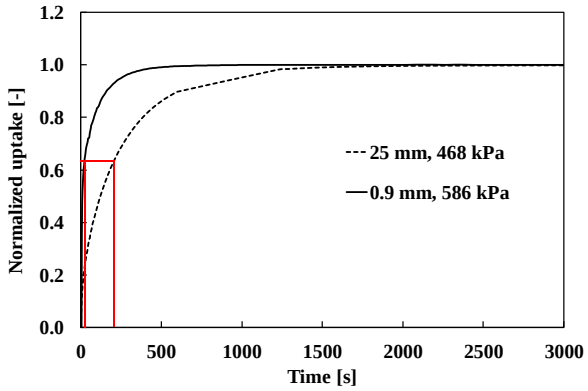
The adsorption rate can be estimated using the Linear Driving Force (LDF) equation,

$$\frac{\partial W}{\partial t} = \frac{W_{eq} - W}{\tau} \quad (2)$$

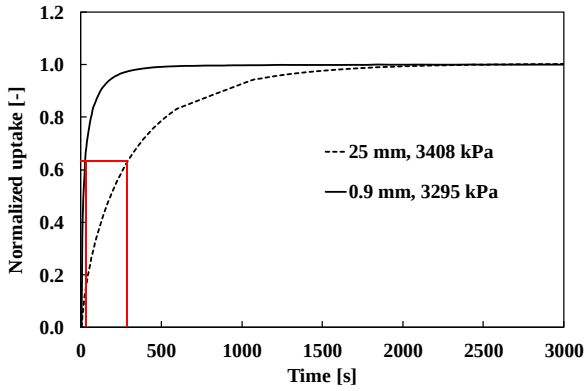
where, τ is the diffusion time constant which governs the rate of adsorption. This time constant provides an estimate of the intra-particle mass transfer resistance. It is dependent on the particle radius (r_p), diffusion constant of CO_2 gas through the adsorbent (D_s), activation energy (E_a) and the instantaneous temperature (T) by the following equation,

$$\tau = \frac{r_p^2}{15 D_s \exp\left(\frac{-E_a}{RT}\right)} \quad (3)$$

Hence, for a particular adsorbent of fixed particle size, the diffusion time constant is constant for adsorption in a particular temperature. But the adsorption rate is not constant for an adsorption cell containing different quantities of adsorbent, as can be seen in Fig. 2.



(a)



(b)

Fig. 2. Normalized uptake of CO_2 onto Maxsorb III powder at a temperature of 50 ºC at different pressures.

Fig. 2. presents the normalized uptake of CO_2 gas onto loosely packed Maxsorb III adsorbent of 2 different heights. The results are reported for 2 different pressure steps.

From Fig. 2, it is evident that a shorter height of adsorbent causes faster adsorption rate. To attain 63.2% of the maximum uptake, time required for adsorbent of 25 mm height are 208 s at 468 kPa and 292 s at 3408 kPa. On the other hand, Maxsorb III sample of 0.9 mm height requires only 22 s at 586 kPa and 26 s at 3295 kPa to attain the same percentage of its maximum uptake. This result indicates that the fastest kinetics can be obtained in the case of adsorption onto a monolayer adsorbent.

The reason for the deviation in the kinetics can be explained through mass transfer analysis within the adsorbent bed. Although the pressure applied is about the same in both the cases, the adsorbent with 25 mm height is not able to attain that pressure wholly due to higher resistance to mass transfer because of its larger height. As a result, the bottom part of that adsorbent experience lower pressure as compared to the adsorbent with 0.9 mm height.

The performance of an adsorption refrigeration system is strongly dependent on its cycle time which is determined based on the adsorption rate of refrigerant onto the adsorbent. In the adsorption heat exchanger, the adsorbents are packed within the fins and the height of adsorbent is essentially determined by the height of the fin. Hence, while designing such heat exchanger chamber, the kinetics parameters taken into calculation must consider the geometry of the adsorbent bed used in the experimental investigation. The adsorbent bed cannot be considered as a lumped model, since the isothermal and isobaric conditions are not maintained within a bed of large size. At the same time, the kinetics parameters reported after experimental investigation need mentioning of the geometry, used in the experiments.

4. CONCLUSION

Adsorption kinetics of CO_2 gas is analyzed for two different heights of Maxsorb III adsorbents at 50 ºC and at two different pressure steps. To maximize the performance of an adsorption refrigeration system, it is necessary to determine the optimum cycle time. The faster the adsorption rate, the lower can be the cycle time. It is observed that smaller height delivers faster adsorption rate as compared to the larger height. Hence in designing adsorption heat exchanger or in reporting the adsorption kinetics parameters, the height of the adsorbent must be taken into consideration. Furthermore, the adsorbent bed cannot be modeled using lumped capacitance equations as there is pressure and temperature variation within the bed.

5. REFERENCES

[1] I. I. El-Sharkawy, B. B. Saha, S. Koyama, and K. C. Ng, “A study on the kinetics of ethanol-activated carbon fiber: Theory and experiments,” *Int. J. Heat Mass Transf.*, vol. 49, no. 17–18, pp. 3104–3110, 2006.

[2] M. Ghazy, K. Harby, A. A. Askalany, and B. B. Saha, “Adsorption isotherms and kinetics of activated carbon/difluoroethane adsorption pair: theory and experiments,” *Int. J. Refrig.*, vol. 70, pp. 196–205, 2016.

[3] Y. I. Aristov, M. M. Tokarev, A. Freni, I. S. Glaznev, and G. Restuccia, “Kinetics of water adsorption on silica Fuji Davison RD,” *Microporous Mesoporous Mater.*, vol. 96, no. 1–3, pp. 65–71, 2006.

[4] S. Jribi, T. Miyazaki, B. B. Saha, A. Pal, M. M. Younes, S. Koyama, and A. Maalej, “Equilibrium and kinetics of CO2 adsorption onto activated carbon,” *Int. J. Heat Mass Transf.*, vol. 108, pp. 1941–1946, 2017.

[5] S. Mitra, M. Muttakin, K. Thu, and B. B. Saha, “Study on the influence of adsorbent particle size and heat exchanger aspect ratio on dynamic adsorption characteristics,” *Appl. Therm. Eng.*, vol. 133, 2018.