

ELECTRICAL SWING ADSORPTION OF CO₂ USING CARBON COMPOSITE MATERIALS

*Bo Feng, Hui An, Aitharaju Venkata, Jiang Chen, The University of Queensland, Australia
Ramesh thiruvengkatachari, Shi Su, CSIRO, Brisbane, Australia*

Abstract

The electrical swing adsorption (ESA) process, proposed by the Oak Ridge National Laboratory, was tested for CO₂ adsorption in our laboratory using carbon fibre composite material as CO₂ adsorbent. The composite material was fabricated using activated carbon or carbon fibre and phenolic resin (binder). The material was subsequently activated and tested the adsorption capacity. After adsorption, an electrical current passed through the material and the released amount of CO₂ was monitored. It was found that the adsorption capacity was more sensitive to the initial CO₂ partial pressure than the material composition. It was also observed that higher ratio of carbon fibre content relative to phenolic resin did not result in higher CO₂ adsorption capacity nor faster CO₂ desorption rate. The degree of desorption of CO₂ increased as the increase of electrical power. The energy required for CO₂ desorption was found to be about 45 MJ/mol with about 12 μmol/g loading, for both the activated carbon and carbon fiber composites. However the value was considerably lower (about 10 MJ/mol) when the loading was lower (6 μmol/g). The carbon fiber composite was also tested for the Young's Modulus after repeated cycles and it appears that it did not change after 50 cycles.

Introduction

The emission of carbon dioxide to the atmosphere has been a public concern and its control has been recognized to be necessary to remedy the global warming problem. Among the options, carbon capture and sequestration (CCS) seems to be the most effective one and thus a lot of research work is being conducted worldwide. Currently the barrier to the application of CSS is its high cost and this cost is mostly due to the capture process. Among the capture technologies adsorption using solid adsorbents is promising as it has the potential to reduce the cost of CO₂ capture significantly compared with the commercially available amine-based solvent technologies. In particular the electrical swing adsorption (ESA) process could possibly reduce the cost by 50%.

The concept of ESA was initially proposed by the Oak Ridge National Laboratory [1-3]. The process still consists of an adsorption process and a subsequent desorption process, like a conventional Thermal Swing Adsorption (TSA) or Pressure Swing Adsorption (PSA) process. Its unique feature is that in the desorption stage desorption is achieved by passing a current through the saturated electrically-conductive adsorbent, and this brings some advantages compared with TSA (desorption is achieved by heating up the adsorbent) and PSA (desorption is achieved by reducing the pressure of the system). Firstly, high energy efficiency can be achieved because direct heat is delivered to the adsorbent with no extra heat needed for heating of the ancillary equipment. Secondly, ESA allows independent control of the heating rate and the flow rate of the inert gas. Thus, both the heating rate and the flow rate can be optimised. Lastly, heating in ESA is not limited by the low heat capacity of the air and the heat transfer rate between the carrier gas and the adsorbent compared with the heating of TSA by hot air. Due to these reasons, ESA appears to be an attractive technology for CO₂ capture.

In order for ESA to work effectively, a good adsorbent meeting the following requirements is the key:

1. high selectivity and adsorption capacity for carbon dioxide.
2. adequate adsorption/desorption kinetics for carbon dioxide. The adsorbent must be electrically conductive and the desorption process must be fast.
3. stable adsorption and desorption behaviors of carbon dioxide after repeated adsorption/desorption cycles (or good reversibility).

4. adequate mechanical strength and attrition resistance of sorbent particles after repeated adsorption/desorption cycles.
 5. good regenerability. The regeneration efficiency as well as the energy efficiency should be high.
- In the literature, carbon composite materials such as activated carbon and carbon fibre composites have been used. Although a lot of work has been done [5-18], the suitability of this technology for CO₂ capture is still not clear. The objective of this work is to evaluate the feasibility of CO₂ capture using this technique, in particular the energy efficiency of desorption by electrical heating.

Experimental

The experimental system is shown in Figure 1. A mixture of CO₂ and N₂ was passed through an adsorption cell where CO₂ was captured by the carbon adsorbent (indicated by a decrease in CO₂ concentration). When the CO₂ concentration returned to its initial value or the adsorbent was saturated, an electrical voltage was applied on the adsorption cell. The CO₂ released was monitored as well as the temperature inside the adsorbent. The adsorption cell is shown schematically in Figure 2.

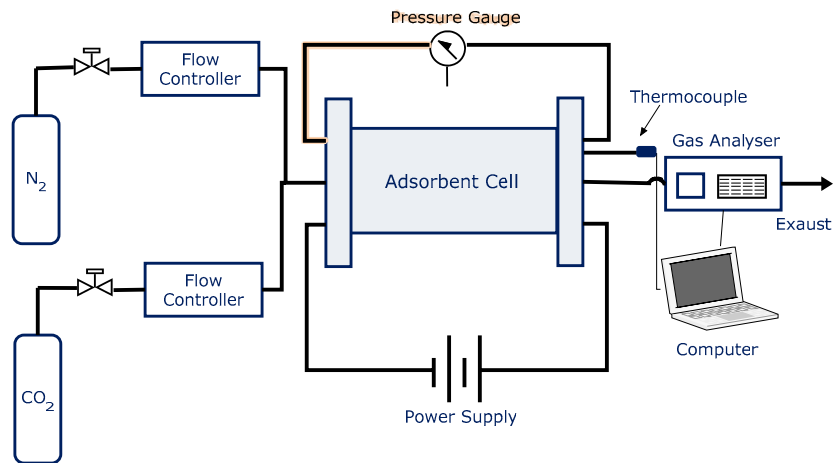


Figure 1 Experimental setup for Electrical Swing Adsorption (ESA)

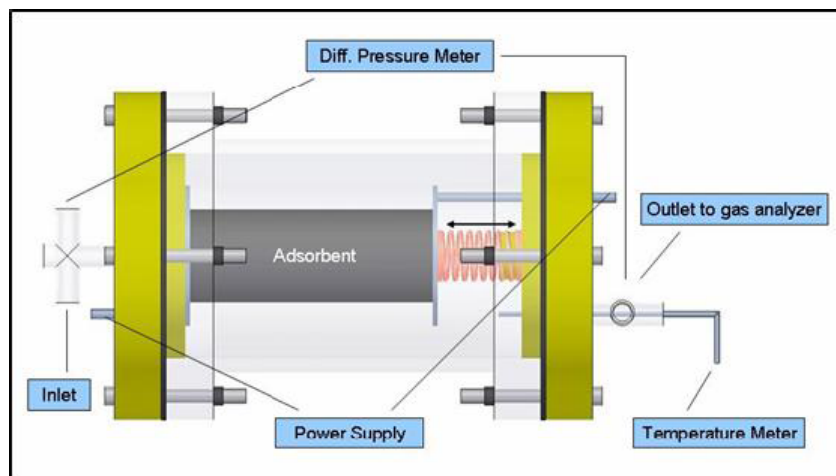


Figure 2 Schematic of the adsorption cell

The carbon composite adsorbent was fabricated using activated carbon or carbon fiber with phenolic resin. The procedure is shown in Figure 3. The ratio of carbon fiber to phenolic resin was 1:1 or 2:1 in weight. The ratio of activated carbon to phenolic resin was 27:21 or 30:60 or 30:70 in weight. The sample shown in Figure 3 was made from activated carbon and resin with a ratio of 30g to 70 g. The dimensions were about 42 mm in length and 30 mm in diameter after activation. It was observed that the carbon adsorbent made from activated carbon with a carbon-resin ratio of less than 2 was quite brittle and was not usable in the test. The results reported here were obtained using the sample with an initial carbon-resin ratio of 30 g to 70 g (The final weight was 14.6 g after activation). For carbon fiber, however, rigid samples were made with fiber-resin ratio of 1:1 (final weight of 8.16g) and 1:2 (final weight of 8.98 g) and the surface of the samples looked much smoother.

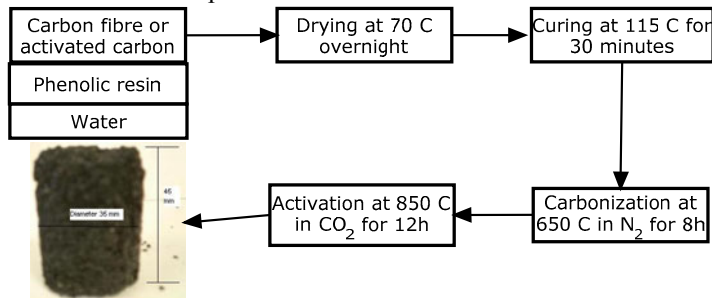


Figure 3 Procedure for sample preparation

The mechanical property, in particular Young's Modulus, was also tested for the carbon fiber samples after up to 50 cycles of adsorption and desorption. Five compression tests were conducted and each test was performed after 10 cycles of adsorption and desorption. The test was carried out according to ASTM C 1358 standard on Instron (a material testing machine) on compression mode. Before the test, the cross-section surfaces of the samples were polished by hands to guarantee a good contact with testing machine, This was important as rough or unparallel surface would cause the movement of the samples during the test, which could bring significant error to test results. In order to avoid fracture of the samples during the test, the maximum load was set at 10 N and the load-strain data was recorded at a rate of 50 points per second. Test data was output into computer to obtain the Young's modulus.

The desorption performance was assessed by two parameters: regeneration efficiency and energy efficiency. The regeneration efficiency is defined as the ratio of the amount of the adsorbate regenerated at the end of the electrothermal desorption process to the total amount of the adsorbate adsorbed during the adsorption process. The energy efficiency is described as the energy consumed per mole of the adsorbate desorbed. These parameters will be calculated to determine the desorption performance of each sample tested.

Results and Discussion

The experimental results are shown in Figs. 4-9.

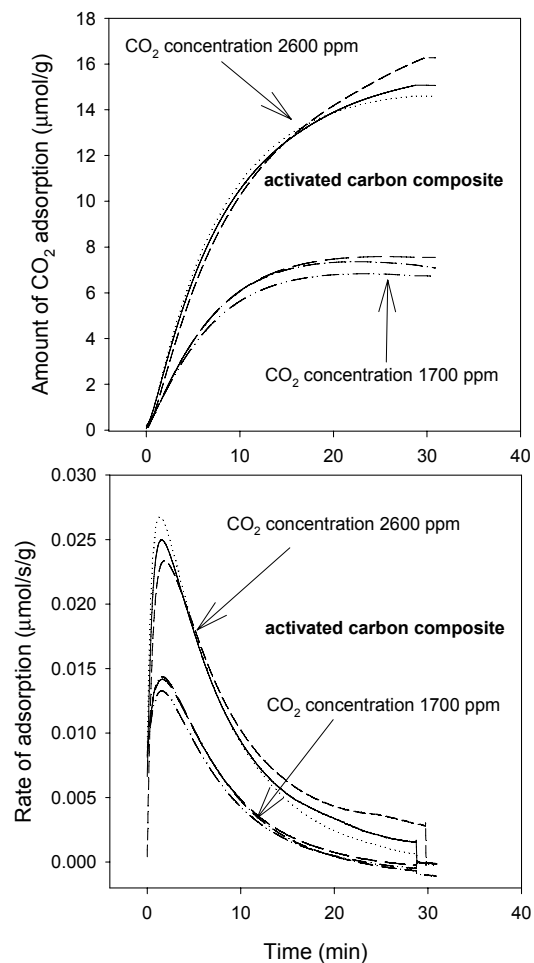


Figure 4 Adsorption of CO₂ on activated carbon composite. Pressure: atmospheric pressure, Temperature: room temperature 25 °C, gas flow rate 300 ml/min. The amount of CO₂ adsorption was found to be sensitive to the CO₂ partial pressure, as expected.

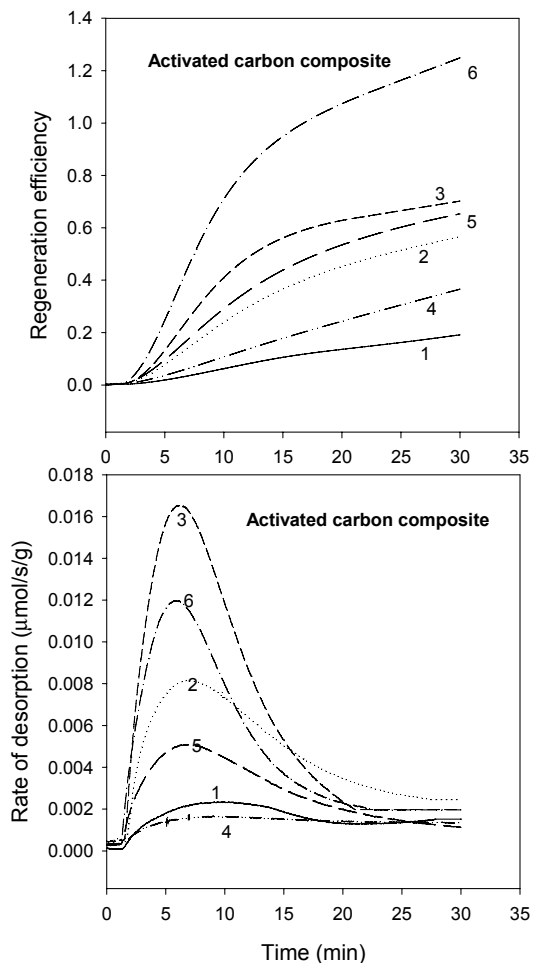


Figure 5 Desorption of CO₂ from activated carbon composite. Pressure: atmospheric pressure, gas flow rate 300 ml/min. 1, adsorption amount 3.66µmol, electrical power 0.25 W, 2, adsorption amount 3.55 µmol, electrical power 0.5 W, 3, adsorption amount 3.96µmol, electrical power 0.75 W, 4, adsorption amount 1.63µmol, electrical power 0.25 W, 5, adsorption amount 1.83µmol, electrical power 0.5 W, 6, adsorption amount 1.67µmol, electrical power 0.75 W.

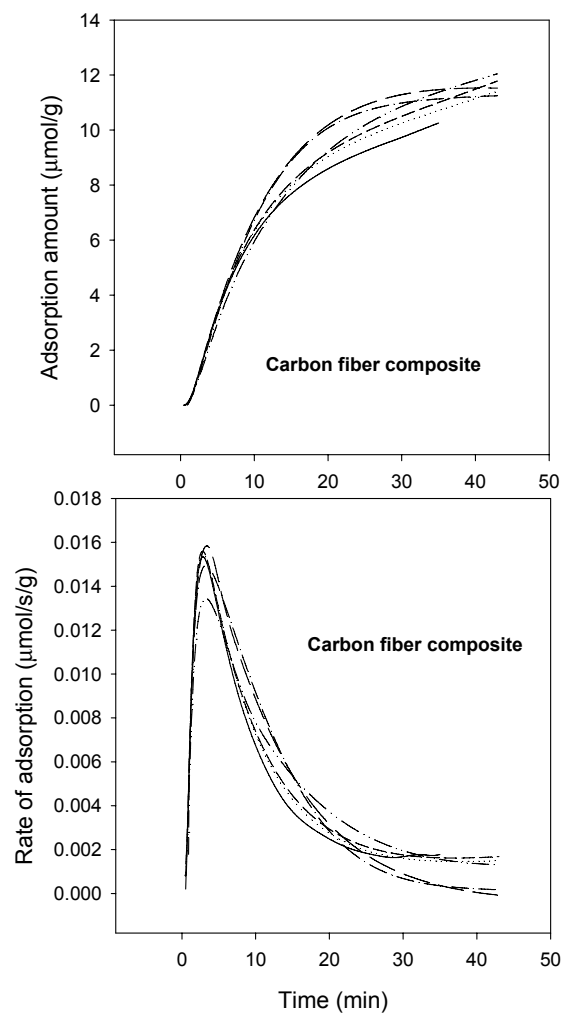


Fig. 6 Adsorption of CO₂ on carbon fiber composite. Pressure: atmospheric pressure, Temperature: room temperature 25 °C, gas flow rate 120 ml/min, initial CO₂ concentration 1900 ppm. It appears that the carbon-resin ratio did not affect the adsorption behavior significantly.

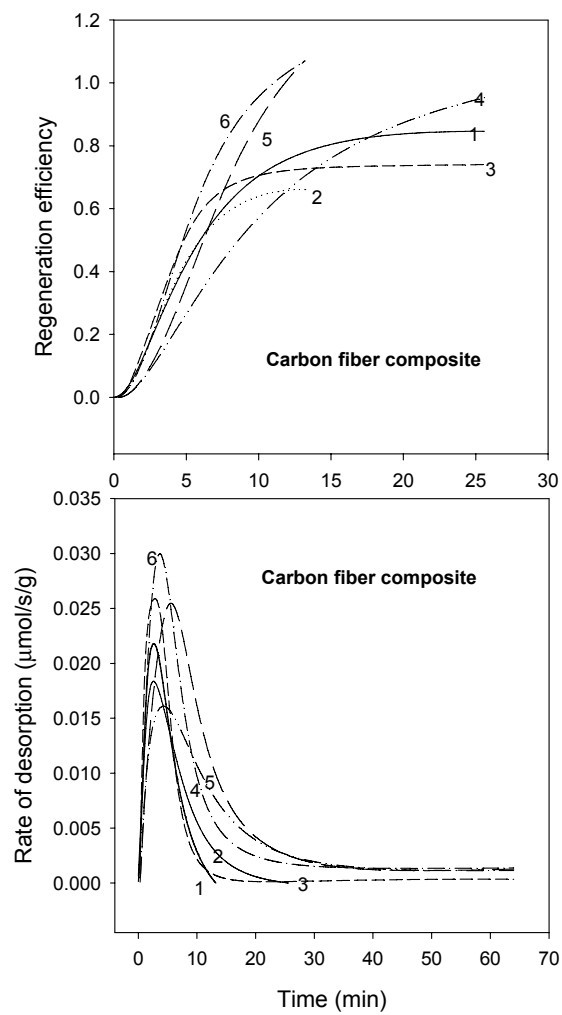


Fig. 7 Desorption of CO₂ from carbon fiber composite. Pressure: atmospheric pressure, gas flow rate 120 ml/min. 1-3, carbon-resin ratio of 1:1, 4-6, carbon-resin ratio of 2:1. 1, electrical power 2.07 W, 2, electrical power 3.64 W, 3, electrical power 5.4 W, 4, electrical power 2.73 W, 5, electrical power 4.0 W, 6, electrical power 5.92 W.

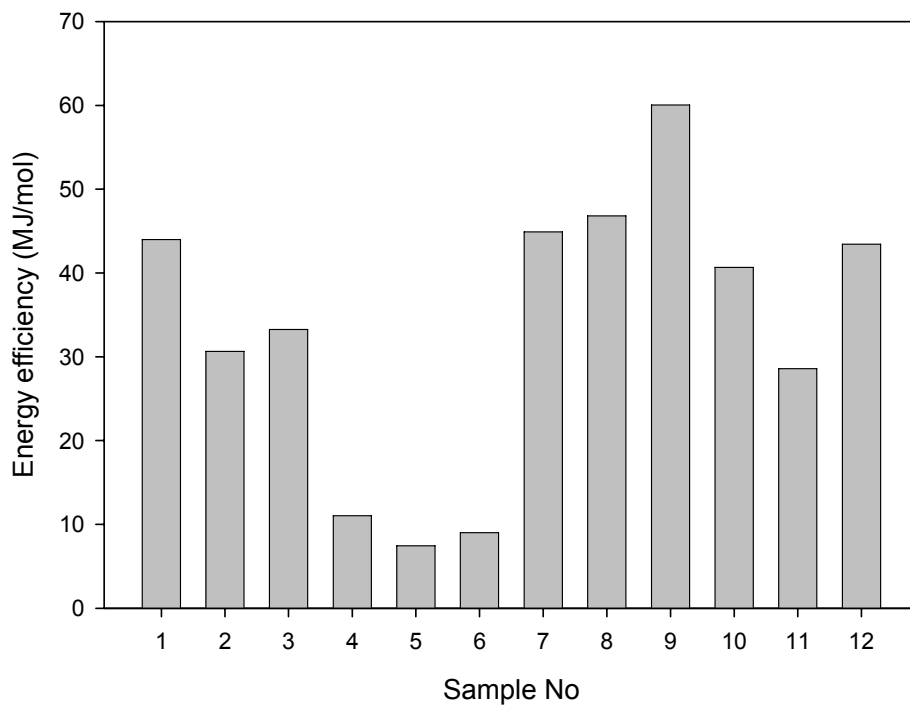


Fig. 8 Energy required to desorb CO₂ from carbon composites. 1-6, activated carbon composites, the same as samples 1-6 in Figure 5. 7-12, carbon fiber composites, the same as samples 1-6 in Fig. 7.

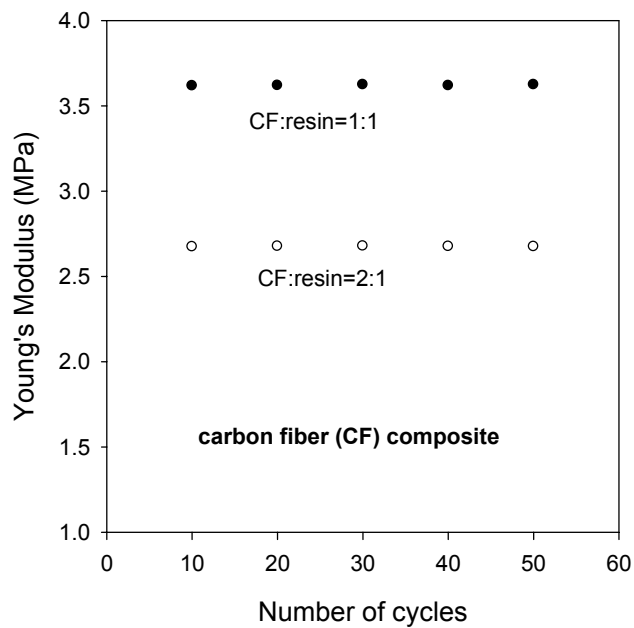


Fig 9. Young's modulus of the samples after cycles of adsorption and desorption

Conclusions

The following observations may be made:

1. There seems to be little difference between activated carbon composites and carbon fiber composites. This did not confirm the literature results, thus needing further work.
2. The adsorption capacity was sensitive to the initial CO₂ concentration.
3. The regeneration efficiency can be improved by increasing the power input. Higher power input results in faster desorption rate.
4. The energy required for CO₂ desorption was found to be about 45 MJ/mol for the composites with loading of about 12 μmol/g (about 1000 times of the heat of adsorption). The energy reduces if the loading decreases. This has implications in the application of the technique.
5. The carbon fiber composites remained its Young's modulus after 50 cycles of adsorption and desorption.

Acknowledgement

The authors acknowledge the financial support of the University of Queensland and the CSIRO flagship program.

References

- [1] A. Subrenat and P. Le Cloirec, *Journal of Environmental Engineering-Asce* 129 (2003) 1077.
- [2] P. D. Sullivan, M. J. Rood, K. J. Hay, and S. Qi, *Journal of Environmental Engineering-Asce* 127 (2001) 217.
- [3] P. D. Sullivan, M. J. Rood, G. Grevillot, J. D. Wander, and K. J. Hay, *Environmental Science & Technology* 38 (2004) 4865.
- [4] L. A. Luo, D. Ramirez, M. J. Rood, G. Grevillot, K. J. Hay, and D. L. Thurston, *Carbon* 44 (2006) 2715.
- [5] J. L. Cook, in *Proceedings of the 10th Annual Symposium of the new mexico Section of ASME*, Albuquerque, NM, USA, 1970, p. 143.
- [6] G. C. Wei and J. M. Robbins, *American Ceramic Society bulletin* 64 (1985) 691.
- [7] T. D. Burchell and R. R. Judkins, *Energy Conversion and Management* 37 (1996) 947.
- [8] T. D. Burchell, R. R. Judkins, M. R. Rogers, and A. M. Williams, *Carbon* 35 (1997) 1279.
- [9] T. D. Burchell and R. R. Judkins, *Energy Conversion and Management* 38 (1997) S99.
- [10] T. D. Burchell, R. R. Judkins, and M. R. Rogers, in *Proceedings of the 12th Annual Conference on Fossil Energy Materials*, Oak Ridge National Lab, Tennessee, 1998.
- [11] T. D. Burchell, O. Omatete, N. C. Gallego, and F. S. Baker, *Adsorption Science & Technology* 23 (2005) 175.
- [12] T. Burchell and M. Rogers, in *Government/Industry Meeting*, Washington, D.C., 2000.
- [13] T. D. Burchell, J. Howe, A. Gabbard, and M. Rogers, in *Proceedings of the 48th International SAMPE Symposium*, Vol. 48, 2003, p. 1855.
- [14] S.-H. Moon and J.-W. Shim, *Journal of Colloid and Interface Science* 298 (2006) 523.
- [15] A. Jayaraman, A. S. Chiao, J. Padin, R. T. Yang, and C. L. Munson, *Separation Science and Technology* 37 (2002) 2505.
- [16] G. Marban, T. Valdes-Solis, and A. B. Fuertes, *Chemical Engineering Science* 61 (2006) 4762.
- [17] F. D. Yu, L. Luo, and G. Grevillot, *Chemical Engineering and Processing* 46 (2007) 70.
- [18] F. D. Yu, L. A. Luo, and G. Grevillot, *Journal of Environmental Engineering-Asce* 130 (2004) 242.