

Synthesis and characterization of coconut pith char adsorbents for carbon dioxide capture

Abdul Rahman Abdul Rahim ^a, Keshyeeni Kuanaseaan ^a, Nasir Shehzad ^{a, b}, Nurul Ekmi Rabat ^{a, c}, Khairiraihanna Johari ^{a, c, *}, Hanapi Mat ^d

^a Department of Chemical Engineering, Faculty of Engineering, Universiti Teknologi PETRONAS, 32610 Bandar Seri Iskandar, Perak, Malaysia

^b Department of Chemical Engineering, COMSATS Institute of Information Technology, Defence Road, Off Raiwind Road, Lahore, 54000, Pakistan

^c Centre of Contamination Control (CenCo), Institute of Contamination Control Management (ICM), Universiti Teknologi PETRONAS, 32610 Bandar Seri Iskandar, Perak, Malaysia

^d Advance Materials and Process Engineering Laboratory, Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia

* Corresponding author: khairiraihanna.j@utp.edu.my

Article history

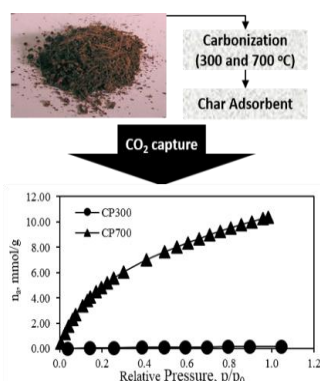
Received 1 December 2018

Revised 21 February 2019

Accepted 5 June 2019

Published Online 3 December 2019

Graphical abstract



Abstract

The emission of carbon dioxide (CO₂) from anthropogenic sources has become a public concern. Several effective and affordable post combustion CO₂ capture technology has been reported and one of the approaches is through adsorption process. This study focused the adsorption onto low-cost adsorbent that can be produced from waste biomass through carbonization method. Coconut pith (CP) was used as precursor and carbonized at temperature of 300 and 700 °C under ambient condition. The chemical and physical properties showed that the surface area, pore volume, ash, moisture and carbon content of chars increased, while the yield content decreased with increasing carbonization temperatures. The char adsorbent carbonized at higher temperature (CP700) showed the better performance with CO₂ adsorption capacity of 10.00 mmol/g at 25 °C. It was revealed that carbonization temperature greatly affects the properties of CP, hence influence the ability of the adsorbent to capture the CO₂. Hence, these unique properties and adsorption performance showed that char adsorbent enable to be used as an effective adsorbent for CO₂ capture and thus improving environmental quality and sustainability.

Keywords: Coconut, carbon dioxide, char, adsorbent, adsorption

© 2019 Penerbit UTM Press. All rights reserved

INTRODUCTION

Public concerns over the global warming and climate change have been widely reported due to the increasing of CO₂ concentration in the atmosphere. Major anthropogenic sources of CO₂ emission to environment are conventional fossil fuels such as coal, oil, and natural gas combustion (Leung *et al.*, 2014) for the purpose of electricity generation, transportation and industrial sector (Rashidi & Yusup, 2016). Due to these global concerns, strict regulations of CO₂ emission to the atmosphere have been imposed. Currently several available technologies for post-combustion capture of CO₂ were developed including wet absorption (Kim *et al.*, 2014), membrane-based technologies (Zhang *et al.*, 2013), cryogenics (Scholes *et al.*, 2013), and dry adsorption (Kim *et al.*, 2013) that are currently used in many industries. However, some of the methods need high operation cost and poor performance. Therefore, their applications becomes limited in a wide range of industries.

Adsorption is considered the most economic method for CO₂ removal using various types of adsorbents such as activated carbon, zeolites, hollow fibers, alumina, silica materials, metal organic frameworks (MOFs), and metal oxide-based adsorbents (Hornbostel *et al.*, 2013; Lee & Park, 2015). Extensive studies are still being carried out to produce low-cost, effective, and environment-friendly

adsorbents. The research has been directed towards the use of cheap adsorbent precursors such as agriculture wastes.

In the past few decades, the removal of organic and inorganic pollutants using carbon/char prepared from inexpensive and renewable sources such as from agricultural biomass residues (Johari *et al.*, 2015; Rashidi & Yusup, 2016; Tran *et al.*, 2016), woody biomass (Chen *et al.*, 2011; Fuente-Cuesta *et al.*, 2012), and industrial wastes (Li *et al.*, 2015) have gained considerable interests by many researches. The mutable properties of the chars depend upon several factors like biomass properties (e.g. type of biomass, moisture content, and particle size), reaction conditions (e.g. reaction temperature, reaction time, and heating rate), surrounding environment (e.g. types of carrier gas and flow rate), and other factors (e.g. catalyst and reactor type) (Qian *et al.*, 2016; Tripathi *et al.*, 2016).

The chars and activated carbons prepared from various precursors and conditions have been studied for the post combustion CO₂ capture (Rashidi & Yusup, 2016). The use of chars from a coconut pith (CP) for CO₂ adsorption has not been reported so far. The CP was selected as a char precursor since it has high carbon and oxygen contents (Rupesh *et al.*, 2015). It is also abundantly available in tropical countries and cheap. Thus, this study was focusing on the effect of carbonization temperature on CP towards physical and chemical

properties of derived chars and their effect towards CO₂ adsorption performance and mechanism.

EXPERIMENTAL

Coconut pith (CP) was collected from a local company (T&H Coconut Fiber Sdn. Bhd.) and was used as received. The preparation of char adsorbent was conducted similar to the method previously employed by Johari *et al.* (2016). The product was then dried in an oven at 105 ± 1 °C. The resulting char samples were denoted as CP'T' in which 'T' represents the pyrolysis temperature. The chemical and physical properties of char adsorbents were characterized and analyzed using proximate analysis (modified ASTM method (D1762-84, 2011)), CHNS/O analyzer (model FLASH, 2000; Thermo Scientific, USA), surface analyzer by nitrogen adsorption/desorption method (model NOVA-2000e; Quantachrome Corp., USA), and Fourier transform infrared (FTIR) spectroscopy (model PerkinElmer, 2000; USA). The evaluation of CO₂ adsorption capacity towards char adsorbent was carried out using the standard procedure of mini BELSORP volumetric adsorption measurement.

RESULTS AND DISCUSSION

The surface morphology of CP chars showed different pore openings. It was found that the pores of CP700 had wider opening compared to CP300. Carbonization at higher temperature shows the degree of roughness of the char surface due to the breaking down of biomass structures such as cellulose, hemicellulose, and lignin. Table 1 shows the results of the yield and proximate analysis for CP carbonized at temperature of 300 °C and 700 °C. It is apparent that increasing the carbonization temperature decreases the yield from 61.17 wt% to 31.42 wt%. In addition, the results obtained for moisture, ash, and fixed carbon increase with increasing of carbonization temperature while yields and volatile matter decreased. The major elements present in CP char adsorbents are carbon (C), oxygen (O₂), nitrogen (N₂), and sulphur (S). It can be observed that at high carbonization temperature, the percentage of carbon increases whereas the amount of hydrogen, nitrogen, sulphur, and oxygen decreases.

Table 1 Pyrolysis yields and properties of CP300 and CP700 adsorbents.

	CP300	CP700
Yields (wt. %)	61.17 ± 1.34	31.42 ± 1.39
Moisture (wt.%, dry basis)	1.37 ± 0.02	7.28 ± 0.15
Volatile matter (wt.%, dry basis)	54.69 ± 0.81	22.68 ± 0.96
Ash (wt.%, dry basis)	3.71 ± 0.39	4.42 ± 0.17
Fixed carbon (wt. %, dry basis)	40.23 ± 0.43	65.62 ± 0.98
Elemental analysis (wt.%, ash-free basis)		
Carbon (C)	59.74 ± 1.41	76.24 ± 0.40
Nitrogen (N)	4.46 ± 0.01	3.37 ± 0.09
Hydrogen (H)	3.72 ± 0.01	1.67 ± 0.04
Sulfur (S)	0.16 ± 0.03	0.15 ± 0.01
Oxygen (Oa)	32.91 ± 1.40	18.57 ± 0.04
Surface area (m ² /g)	3.98	315.06
Pore volume (cm ³ /g) x10 ³	4.39	2.40
Pore diameter (nm)	1.34	1.90

Surface functional groups over the CP300 and CP700 can be observed in the FTIR spectra within the range of 4000–400 cm⁻¹ (Fig. 1). It can be seen that the major peaks of O-H (~3420 cm⁻¹), C=O (~1620 cm⁻¹), and C-H (~1400 cm⁻¹) groups confirm the presence of cellulose, hemicelluloses, and lignin which are the typical characteristics of natural fiber (Rout *et al.*, 2001). The strong absorption peaks at 3416 and 3426 cm⁻¹ are attributed to the presence

of hydroxyl group (O-H) and amine (N-H) groups. The weak peak at ~2930 cm⁻¹ shows the presence of C-H stretching from CH₂ groups. This is derived from the hemicellulose and lignin structures (Johari *et al.*, 2016). The peaks at ~1624 and 1634 cm⁻¹ are assigned to the O-H bending while the peak at 1401 cm⁻¹ is attributed to C-O-H bending. Similar peak intensities around 3416–3426 cm⁻¹ indicating the constant moisture contents (1.37–7.28 wt.%) of CP300 and CP700 adsorbents. The decrease of intensities at peaks 1624 cm⁻¹ (CP300) to 1634 cm⁻¹ (CP700) mean that with the increase of pyrolysis temperatures, nearly all hemicellulose and cellulose decompose at temperatures of 300 °C and higher (Min *et al.*, 2011).

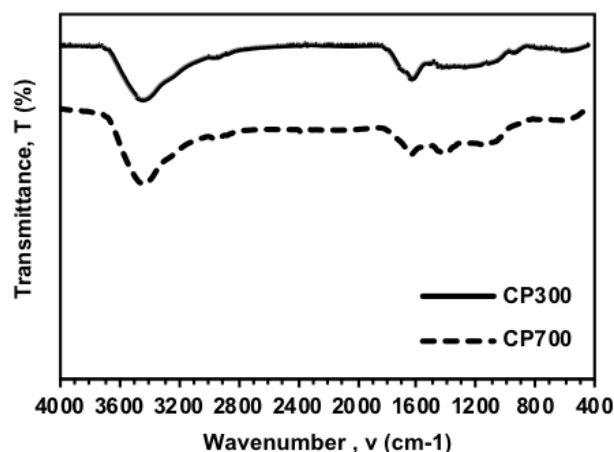


Fig. 1 FTIR spectra of CP300 and CP700 adsorbents.

The variation of CO₂ adsorption capacity of char adsorbents is illustrated in Fig. 2. It was found that CP700 (10.00 mmol/g) performed better adsorption capacity compared to CP300 adsorbent (0.18 mmol/g). The highest CO₂ adsorption of CP700 adsorbent was relatively high compared to previous literature, especially on CO₂ removal by coconut-based adsorbent (Creamer & Gao, 2016; Ello *et al.*, 2013). In addition, the adsorption rate increased rapidly at the beginning of relative pressure due to the presence of vacant pores being available for adsorption. As relative pressure increased, the rate of adsorption started to decrease. It means that the adsorption process is exothermic in nature, which corresponds to the CO₂ gas adsorbed on the surface of char adsorbent by intermolecules (van der Waals) forces (Singh & Kumar, 2016). In this study, high CO₂ adsorption capacity by CP700 adsorbent was attributed by high carbon content and large surface area (315.06 cm²/g), even without activation. The high surface area of the char helped in enhancing the CO₂ adsorption capacity. This is consistent with the finding of previous studies using chars from carbonization or pyrolysis of raw biomass (Creamer & Gao, 2016; Wang *et al.*, 2011).

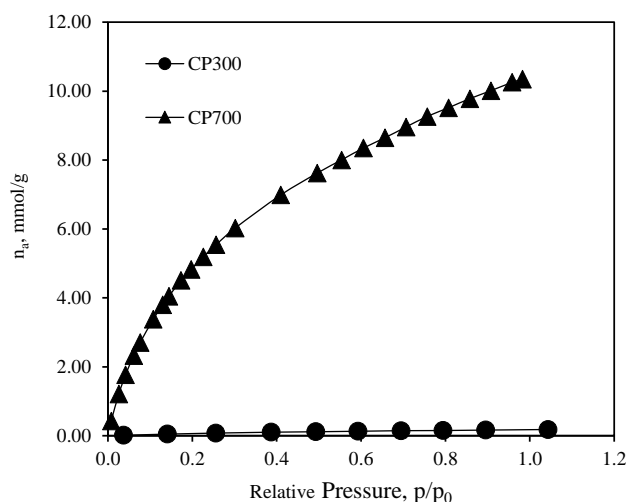


Fig. 2 CO₂ adsorption of CP300 and CP700 adsorbents.

CONCLUSION

The coconut pith chars were successfully synthesized and characterized to be used as an adsorbent for CO₂ gas removal. It can be observed that as the carbonization temperature becomes higher (700 °C), the properties of char such as surface area, moisture, ash, and carbon content of chars increased, while the yield content decreased. The carbonization temperature has a significant effect on the structural changes in CP char which resulted in different pore texture and chemical reactivity, as well as the CO₂ adsorption performances. The CP char carbonized at higher temperature (CP700) showed the better performance with CO₂ removal capacity of 10.00 mmol/g. Thus, with the unique properties and high adsorption performances, CP char adsorbent could be a cost-effective and environmental-friendly adsorbent for CO₂ capture.

ACKNOWLEDGEMENT

The financial supports from the Universiti Teknologi PETRONAS for Short Term Internal Research Fund (STIRF) are gratefully acknowledged.

REFERENCES

- Chen, X., Chen, G., Chen, L., Chen, Y., Lehmann, J., McBride, M. B., & Hay, A. G. (2011). Adsorption of copper and zinc by biochars produced from pyrolysis of hardwood and corn straw in aqueous solution. *Bioresource Technology*, 102(19), 8877–8884.
- Creamer, A. E., & Gao, B. (2016). Carbon-based adsorbents for postcombustion CO₂ capture: A critical review. *Environmental Science and Technology*, 50(14), 7276–7289.
- ASTM International. (2011). *Standard test method for chemical analysis of wood charcoal (D1762-84)*. Retrieved from <https://www.astm.org/>
- Ello, A. S., De Souza, L. K. C., Trokourey, A., & Jaroniec, M. (2013). Coconut shell-based microporous carbons for CO₂ capture. *Microporous and Mesoporous Materials*, 180, 280–283.
- Fuente-Cuesta, A., Diaz-Somoano, M., Lopez-Anton, M. A., Cieplik, M., Fierro, J. L. G., & Martínez-Tarazona, M. R. (2012). Biomass gasification chars for mercury capture from a simulated flue gas of coal combustion. *Journal of Environmental Management*, 98, 23–28.
- Hornbostel, M. D., Bao, J., Krishnan, G., Nagar, A., Jayaweera, I., Kobayashi, T., & Dubois, L. (2013). Characteristics of an advanced carbon sorbent for CO₂ capture. *Carbon*, 56, 77–85.
- Johari, K., Alias, A. S., Saman, N., Song, S. T., & Mat, H. (2015). Removal performance of elemental mercury by low-cost adsorbents prepared through facile methods of carbonisation and activation of coconut husk. *Waste Management & Research*, 33(1), 81–88.
- Johari, K., Saman, N., Song, S. T., Cheu, S. C., Kong, H., & Mat, H. (2016). Development of coconut pith chars towards high elemental mercury adsorption performance - Effect of pyrolysis temperatures. *Chemosphere*, 156, 56–68.
- Kim, K., Son, Y., Lee, W. B., & Lee, K. S. (2013). Moving bed adsorption process with internal heat integration for carbon dioxide capture. *International Journal of Greenhouse Gas Control*, 17, 13–24.
- Kim, Y. E., Moon, S. J., Yoon, Y. I., Jeong, S. K., Park, K. T., Bae, S. T., & Nam, S. C. (2014). Heat of absorption and absorption capacity of CO₂ in aqueous solutions of amine containing multiple amino groups. *Separation and Purification Technology*, 122, 112–118.
- Lee, S. Y., & Park, S. J. (2015). A review on solid adsorbents for carbon dioxide capture. *Journal of Industrial and Engineering Chemistry*, 23, 1–11.
- Leung, D. Y. C., Caramanna, G., & Maroto-Valer, M. M. (2014). An overview of current status of carbon dioxide capture and storage technologies. *Renewable and Sustainable Energy Reviews*, 39, 426–443.
- Li, G., Shen, B., Li, F., Tian, L., Singh, S., & Wang, F. (2015). Elemental mercury removal using biochar pyrolyzed from municipal solid waste. *Fuel Processing Technology*, 133, 43–50.
- Min, F., Zhang, M., Zhang, Y., Cao, Y., & Pan, W. (2011). An experimental investigation into the gasification reactivity and structure of agricultural waste chars. *Journal of Analytical and Applied Pyrolysis*, 92(1), 250–257.
- Qian, L., Zhang, W., Yan, J., Han, L., Gao, W., Liu, R., & Chen, M. (2016). Effective removal of heavy metal by biochar colloids under different pyrolysis temperatures. *Bioresource Technology*, 206, 217–224.
- Rashidi, N. A., & Yusup, S. (2016). An overview of activated carbons utilization for the post-combustion carbon dioxide capture. *Journal of CO₂ Utilization*, 13, 1–16.
- Rout, J., Tripathy, S. S., Nayak, S. K., Misra, M., & Mohanty, A. K. (2001). Scanning electron microscopy study of chemically modified coir fibers. *Journal of Applied Polymer Science*, 79(7), 1169–1177.
- Rupesh, S., Muraleedharan, C., & Arun, P. (2015). A comparative study on gaseous fuel generation capability of biomass materials by thermo-chemical gasification using stoichiometric quasi-steady-state model. *International Journal of Energy and Environmental Engineering*, 6(4), 375–384.
- Scholes, C. A., Ho, M. T., Wiley, D. E., Stevens, G. W., & Kentish, S. E. (2013). Cost competitive membrane-cryogenic post-combustion carbon capture. *International Journal of Greenhouse Gas Control*, 17, 341–348.
- Singh, V. K., & Kumar, E. A. (2016). Measurement and analysis of adsorption isotherms of CO₂ on activated carbon. *Applied Thermal Engineering*, 97, 77–86.
- Tran, H. N., You, S.-J., & Chao, H.-P. (2016). Effect of pyrolysis temperatures and times on the adsorption of cadmium onto orange peel derived biochar. *Waste Management & Research*, 34(2), 129–138.
- Tripathi, M., Sahu, J. N., & Ganesan, P. (2016). Effect of process parameters on production of biochar from biomass waste through pyrolysis: A review. *Renewable and Sustainable Energy Reviews*, 55, 467–481.
- Wang, Q., Luo, J., Zhong, Z., & Borgna, A. (2011). CO₂ capture by solid adsorbents and their applications: Current status and new trends. *Energy and Environmental Science*, 4(1), 42–55.
- Zhang, X., He, X., & Gundersen, T. (2013). Post-combustion carbon capture with a gas separation membrane: Parametric study, capture cost, and exergy analysis. *Energy and Fuels*, 27(8), 4137–4149.