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Study on the Use and Modification of a Sustainable Solid Waste Material for Carbon Dioxide Capturing

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Abstract

Carbon dioxide (CO_2) capturing by utilizing sustainable waste materials as an adsorbent is one of the emerging ideas in reducing air pollution nowadays. The abundance of these wastes generated on recurring bases from agricultural and forestry sectors (biomass) makes it to be sustainable. Moreso, biomass advantages for less pollution and low cost of production makes it a promising potential source for adsorbent. Empty fruit bunch (EFB) as one the most generated wastes from palm oil industry has been chosen for this study in order to assess its potential for CO_2 capture and de-capture. The raw EFB was first dried in roller oven under temperature condition of 100^oC for 24 hours, separated and stored in vacuumed desiccators. The dehydrated EFB was reduced with hydrogen and further treated with zeolite (sample 1) and stannum (sample 2) to improve or modify its affinity in CO_2 capturing. Both samples were introduced to a CO_2 flow of 100mL/ min for 3 hours in quartz bed. Then de-capturing of carbon dioxide were performed using nitrogen gas at a flow rate of 100mL/min as desorption agent under 1.6bars pressure and 100˚C temperature for 3 hours and the performances were compared. The FTIR results indicated the presence of CO_2 in the range of 950-1300cm^{-1} for sample 1 and 950-1300cm^{-1} for sample 2. It was also noticed that both adsorbents influenced the CO_2 capturing and de-capturing process with sample 1 having the best combination to capture CO_2 and Sample 2 appeared to be suitable for de-capturing of CO_2. These modified EFB sorbents can be a future potential source of adsorbents that would replace the existing/conventional adsorbents such as amine and activated carbon thereby reducing wastes generation annually as well as improving environmental air quality.

Keywords: Biomass, sustainable, carbon dioxide capture, empty fruit bunch (EFB), adsorbent

1. Introduction

Palm oil wastes or residues such as empty fruit bunch (EFB), fiber and shell kernel are the largest sources of biomass feedstock which can be obtained naturally. The resources are highly sustainable and provide vast opportunities to explore (Hussain et al, 2006). For example, Malaysia has been recognized as the largest hub of palm oil producer and exporter and indirectly contributes to the generation of wastes annually (Sulaiman et al, 2011). Carbon dioxide, (CO_2) was ranked as the major sources of greenhouse gas emission (GHG) and directly contributes to global climate changes and human's health (IPCC, 2007). In addition, penetration of fossil fuels in most parts of human activities which leads to CO_2 generation have aggravates this scenario. As example, a fossil fuel power plant which is coal-fired plant contributes approximately 40% of total CO_2 emission nowadays (Yang et al, 2008). The use of sustainable solid waste material such as almond shells (Plaza et al, 2009), industrial wastes (Kaithwas et al, 2012) and for carbon dioxide (CO_2) capturing is a new approach to reduce excessive amount of CO_2 nowadays. Conventionally, most methods for CO_2 capture are based on different physical and chemical processes such as adsorption, absorption, membranes and cryogenics (Pires et al, 2011). Application of a particular technique largely depends upon the characteristics of the gas stream from which CO_2 needs to be separated, which mainly depends on the power plant technology (Jacobson, 2009). Consequently, the necessity for zero emission associated with green lifestyle nowadays has boosted the concerted effort to find best solution to achieve it. The term 'zero emission' is a new concept that focusing on the utilization of natural resources within necessary limit and the emission generated should be within acceptable level (Kuehr, 2006).

Therefore, the aim of this paper is to study the use of reduced empty fruit bunch (EFB) as an adsorbent as well as its modification toward proper capturing of CO_2. Fourier transform infra-red (FTIR) technique was employed to evaluate the adsorption capacity of the porous unmodified and modified reduced EFB and the functional group effects. These modified EFB sorbents can be a future potential source of adsorbents that would replace the existing/conventional adsorbents such as amine and activated carbon thereby reducing wastes generation annually as well as improving environmental air quality.

2. Materials and methods

2.1. Sample Preparation

The raw empty fruit bunch (EFB) used in the experiment was supplied by oil palm Koperasi from Johor, Malaysia. The raw EFB was first dried in roller oven under temperature condition of 100^{o}C for 24 hours, separated and stored in vacuumed desiccators. The purpose of the drying process was to remove moisture content. In fact, raw EFB was proven to have contained about 60 wt% water (Abdullah et al., 2010). 5g dehydrated EFB was later ground and crushed into the required finer size in order to provide the surface area for contacting with carbon dioxide. The dehydrated EFB (250μm) was then reduced using hydrogen gas under the operating conditions of 100˚C and 1.5 bars temperature and pressure respectively for 3 hours as shown in Figure 1. The reduced EFB was then modified using zeolite or stannum as shown in Table 1. The schematic of CO_2 capturing and de-capturing processes is shown in Figure 2.

(a) (b)

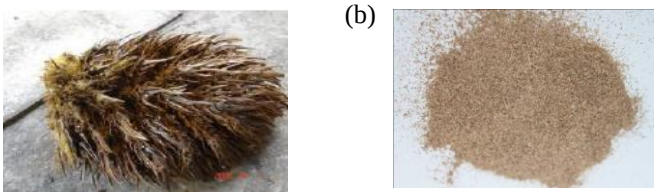

Figure 1. (a) fresh EFB and (b) reduced EFB sieved 250μm

Table 1: Modification of reduced EFB for CO_2 capture and de-capture

Type of sample	Mass percentage (%)
Sample 1	50 wt% of reduced EFB + 50 wt% of zeolite
Sample2	50 wt% of reduced EFB +50 wt% of stannum

2.2 CO_2 capture and de-capture

The samples prepared as shown in Table 1 were subjected to CO_2 gas at a flow of 100mL/min for 3 hours under 1.6bars pressure and temperature range of 35˚C to 65˚C. Then de-capturing of carbon dioxide were performed using nitrogen gas at a flow rate of 100mL/min as desorption agent under 1.6bars pressure and 100˚C temperature for 3 hours. Heating rate of 7˚C/min was supplied for 5min to reach 100˚C temperature and cooling rate of 7˚C/min was supplied for 5min to reach ambient temperature.

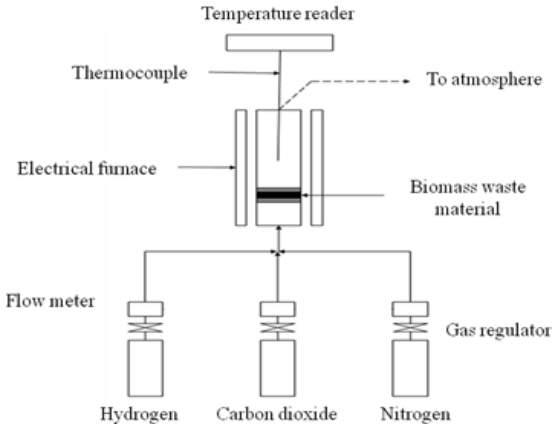

Figure 2. Schematic diagrams of CO_2 capturing and de-capturing processes

2.3 Samples characterization using Fourier Transform Infrared Spectroscopy (FTIR)

FTIR analysis was used to qualitatively identify the chemical functionality of the samples. This was performed using a Perkin Elmer Spectrum One series model instrument at wave numbers range of 400-4000cm^{-1}. The transmission spectra of the samples were recorded using KBr pellets containing 0.1% of carbon. A blank test was carried out first to eliminate the buoyancy effect (Dantas et al, 2011).

3.0 Results and Discussion

3.1 FTIR Spectra of Reduced EFB

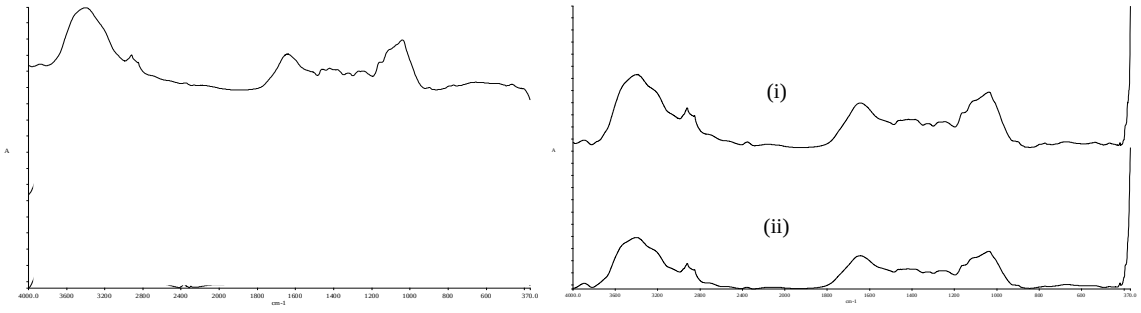

Figure 3. IR spectra of reduced EFB (a) before CO_2 capture (b) after (i) CO_2 capturing and (ii) de-capturing

The characteristics of the IR spectrum in Figure 3 are summarized in Table 2.

Table 2. Comparison of reduced EFB (a) before and (b) after CO_2 capturing process

Wave number range (cm^{-1})	Group	Compound	Peak wave number before capturing process (cm^{-1})	Peak wave number(cm^{-1}) after	
				CO_2 capturing	CO_2 de-capturing
3600-3300	O-H	Phenols, alcohols	3409.00	3396.23	3406.45
3000-2800	C- H	Alkanes	2921.57	2922.52,2849.31	2920.59,2853.22
2348	**CO_2stretch**		-	**2352.25**	**2367.90**
1675-1575	C=C	Alkenes	1642.95	1643.45	1642.87
1460-1350	C-H	Alkanes	1460.24,1421.08, 1323.35	1417.95	1417.75
1300-950	C –O	1, 2,3 alcohol, phenol, ester	1247.12, 1161.03, 1042.95	1321.39, 1247.43, 1162.98	1329.62, 1163.50,1037.08
900- 650	C –H	Aromatic compound	-	771.86,674.17	899.65, 672.76
578-667	**CO_2 bending,**		-	**674.17**	-

3.2 FTIR Spectra of modified reduced EFB

The characteristics of IR spectra for reduced EFB with zeolite (sample 1) and that with stannum (sample 2) for CO_2 capturing and de-capturing process are shown in Figure 4 (a) and (b). The comparison of IR spectra for both samples is summarized in Table 3.

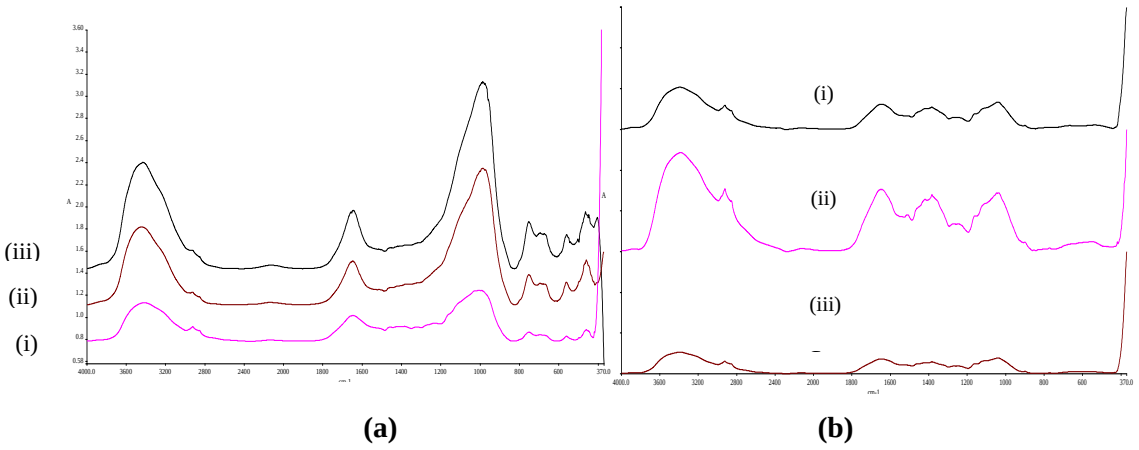

Figure 4. IR spectra of modified reduced EFB (a) sample1 (b) sample 2, before CO_2 capture and after CO_2 capturing and de-capturing

Table 3. IR characteristics of reduced EFB for sample 1 and 2, CO_2 capture and de-capture

Wave number range (cm^{-1})	Group	Compound	Peak wave number (cm^{-1}) before capturing		Peak wave number (cm^{-1}) for CO_2 capture		Peak wave number (cm^{-1}) for CO_2 de-capture	
			Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2
690-515	C-Br stretch	Alkyl halide	560.46	543.85	563.18	555.85	560.59	556.24
850-550	C-Cl stretch	Alkyl halide	751.65	-	753.78		753.59	

1000-650	=C-H bend	Alkene	-	-	987.13		986.40	
1300-1150	C-H	Alkyl halide	-	1269.50	-	1267.44	-	1270.45
1320-1000	C-O stretch	Alcohol, Carboxylic acid, ester, ether	1006.78	1035.98	-	1035.98	-	1034.50
1650-1580	N-H bend	Primary amine	1647.01	-	1647.00	-	-	-
1680-1640	-C=C- stretch	Alkene	1647.01	1646.78	1647.00	1650.49	1643.08	1646.29
3000-2850	C-H stretch	Alkane	2922.62	-	-	2921.19	-	2922.82
3300-2500	O-H stretch	Carboxylic acid	2922.62	2922.62	-	2921.19	-	2922.82
3500-3200	O-H stretch, H-bonded	Alcohols, phenol	3415.17	3383.08	3442.62	3380.90	3430. 16	3391.43

The performances of both samples as indicated on the IR spectra shoed that for the CO_2 capturing study, there was significant change in range of 950 to 1300cm^{-1} for C=O stretching and O-H stretching in range of 3300 to 3600cm-1 that represent the bonding of bicarbonate to O-H bond. Reduced EFB with zeolite (sample 1) has significant character to capture CO_2 compare to reduced EFB with stannum (sample 2). Starting with OH bond in peak range of 3200 to 3500cm^{-1} as seen on the spectra, it showed significant change in term of peak and wide. This proves that bicarbonate compound has been stick onto the surface of reduced EFB with zeolite than reduced EFB with stannum. However, during de-capturing of CO_2 study, reduced EFB with stannum showed more changes than that with zeolite deposited. The significant changes happened at peak range of 3200 to 3500cm^{-1} where bicarbonate was easily leaving the structure. The changes in peak range of 1000 to 1300cm^{-1} showed that C=O stretch had occurred strongly. As a result, modified reduced EFB with zeolite (sample 1) has greater potential possibility for a commercialized adsorbent due to its affinity to adsorb CO_2 and as such it can significantly replace the conventional/existing CO_2 capturing technologies which are very expensive and energy intensive.

Conclusions

The necessity for zero emission associated with green lifestyle nowadays has boosted the concerted effort to find best solution to achieve such motive. As such, modification of EFB as adsorbent for CO_2 capture is an alternative option for a better and improved CO_2 capturing process since it showed a significant improvement on the capturing process. It was noticed that both adsorbents influenced the CO_2 capturing and de-capturing process with sample 1(zeolite modified EFB) having the best combination to capture CO_2 and Sample 2 (Stannum modified EFB) appeared to be suitable for de-capturing of CO_2.These modified EFB sorbents can be a future potential source of adsorbents that would replace the existing/conventional adsorbents such as amine and activated carbon thereby reducing wastes generation annually as well as improving environmental air quality.

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