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# CO<sub>2</sub> Capture Using Amine-impregnated Activated Carbon from *Jatropha curcas* Shell

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## ABSTRACT

A micro porous activated carbon (JAC) was synthesis from *Jatropha curcas* shell an agricultural waste by chemical activation using KOH. The JAC was modified with triethanolamine (TEA) to produce (JAC-TEA). The performance of both adsorbents in CO<sub>2</sub> capture study was evaluated in a cylindrical glass column equipped with a digital mass balance. The effect of adsorbent dosage (0.5-1.5 g) and temperature (30-60°C) as a function of time was investigated. The results showed that CO<sub>2</sub> adsorption capacities of the adsorbents increase on amine loading and adsorbent dosage (bed height), while the adsorption capacity decreases with increase in temperature. Adsorption capacity of JAC and JAC-TEA were 66 and 78 mg/g respectively. Crystallinity, morphological structure and surface functional groups of adsorbents were characterized using X-ray diffraction, Scanning electron microscopy and Fourier Transformed Infra red spectrophotometer respectively, while the surface areas and porosity were determined by Brunauer-Emmett-Teller. Both adsorbents had good crystallinity with a well-developed pore structures. The mechanism of CO<sub>2</sub> adsorption onto JAC and JAC-TEA is physisorption and that the adsorbent (JAC-TEA) can be used upto 7 cycles. The results of this study have revealed that a cost-effective high quality porous activated carbon can be prepared from a cheap carbonaceous material like *Jatropha curcas* shell and modified to improve its CO<sub>2</sub> adsorption capacity.

Keywords: *Jatropha curcas* shell; activated carbon; potassium hydroxide; Triethanolamine; CO<sub>2</sub> capture.

## 1. INTRODUCTION

Carbon (iv) Oxide (CO<sub>2</sub>) emission has been generally accepted to be a greenhouse gas with the potential of contributing to global warming; this has generated a lot of worries around the globe [1]. Presently, the emission of CO<sub>2</sub> into the atmosphere is on the increase. CO<sub>2</sub> emissions results from the burning of fossil fuel. Unfortunately, this additional carbon dioxide to the environment is causing havoc to the fragile balance that the earth manages naturally thereby negatively contributing to climate change and acidification of oceans [2]. The emission of carbon dioxide is also known to originated from a number of other sources which are on the increase daily as the world tends to become more industrialized [3].

According to [4], the Intergovernmental Panel on Climate Change (IPCC) third assessment stated that, the atmospheric concentration of CO<sub>2</sub> had increased globally by about 100 ppm (36%) over the last 250 years which falls within the range bracket of 275-285 ppm to about 379 ppm in 2005. The author added that between 1995 and 2005, the first highest average growth rate of CO<sub>2</sub> concentration (19 ppm increment) in to the atmosphere was recorded and this surpasses records of any decade since direct atmospheric CO<sub>2</sub> concentration measurement began in 1950. Currently as at March 2014, the

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average CO<sub>2</sub> concentration in the earth's atmosphere has risen to approximately 400 ppm by volume [5], about 21 ppm increment which has superseded previous records.

The most promising means of reducing CO<sub>2</sub> emissions is by post-combustion carbon capture and storage (CCS) methodologies [6]. Post-combustion capture of CO<sub>2</sub> from coal-fire power plant was mostly accomplished using liquid amine scrubbing [7]. Amongst others like cryogenic distillation and membrane purification [8,9], this is usually based on absorption processes using alkanolamine/water solutions [10] or chilled ammonia. However, this technique suffers from the harmful effects associated with the use of aqueous amine solvents, which includes equipment corrosion, alkanolamine toxicity, solvent loss and high energy consumption [11,12]. These challenges were proposed to be overcome by the use of solid adsorbents [12,13].

In recent time, intensive research has been going on in the development of low cost sorbent characterized with high CO<sub>2</sub> adsorption capacity, good adsorption/desorption kinetics, high CO<sub>2</sub> selectivity, good regenerable energy sorbents which can serve as alternative for capturing CO<sub>2</sub> [14,15,16,17]. A number of literature are available on the synthesis of CO<sub>2</sub>-philic sorbent materials, this include: Activated carbons [18,19], silicas [20], zeolites [21,22] and metal-organic frame works [23,24,25].

To achieve high CO<sub>2</sub> adsorption on activated carbon, lots of work has been carried out to regulate the pore structure of activated carbon in the preparation using different activation methods [26]. Knowledge about crystallinity is highly relevant in the development of activated carbon, as a crystalline form is usually preferred. In contrast to amorphous material, a crystal has well-defined properties (melting point, solubility). These parameters should be known in order to control final product. Crystalline adsorbent from different agricultural waste for CO<sub>2</sub> capture and storage have been documented. Only little reported works on the use of *Jatropha curcas* shell activated carbon for CO<sub>2</sub> capture and storage are available.

Amine-modified solid adsorbents make use of the amine groups grafted or loaded on the porous materials to adsorb CO<sub>2</sub>. CO<sub>2</sub> adsorption on these adsorbents is mostly a chemical process and the adsorption mechanisms mainly include: 1) under dry condition, primary and secondary amines form carbamate with CO<sub>2</sub> and tertiary amine works only as proton acceptor; 2) under humid condition, amines react with CO<sub>2</sub> to produce bicarbonate in the presence of water [27]. The amine-modified adsorbents can be prepared by two methods. One method is to physically impregnate amine into the porous materials, but the amines with low molecular weights (MW) can be leached easily in the adsorption and regeneration processes, resulting in bad reuse performance. Another method is to chemically graft amine onto the porous materials, and the adsorbents are stable in the reuse process. This method have reportedly been used for functionalization of AC from different agricultural wastes [27].

*Jatropha curcas* shell is a cheap carbonaceous material that is abundantly available and can easily be used to prepare high quality microporous carbon with well-developed pore structure. Some important features of *Jatropha curcas* shell that makes it a potential source of activated carbon includes; the shell's external surfaces which is full of cavities and low oxygen groups that suggest high surface area and hydrophobic characteristics [28]. Therefore, this study was designed to take advantage of some of these characteristics to further modify the activated carbon resulting from *Jatropha curcas* shell with the aim of improving its CO<sub>2</sub> adsorption capacity.

## 2. MATERIALS AND METHODS

### 2.1 Materials

Microporous activated carbon (JAC) produced from *Jatropha curcas* shell was used. Detail procedure and the properties of the JAC produced can be found in [29]. Potassium hydroxide (KOH), Hydrochloric acid (HCl), Triethanolamine (TEA) was purchased from PANLAC Chemicals while CO<sub>2</sub> was supplied by Nigerian Bottling Company CO<sub>2</sub> Production Plant, Kaduna State Nigeria and used without further purification.

### 2.1.1 Choice of TEA as modifier

TEA is a liquid amine belonging to the tertiary amine group which has proven to have a high absorption capacity and has been reported by other researcher to have been able to absorb CO<sub>2</sub> in molar ratio 1: 1 (that is, 1 mole of solvent to absorb 1 mole of CO<sub>2</sub>) which is quite high compared to its primary and secondary amine counterparts that falls around 2: 1 molar ratio [2]; these forms the bases of its choice in this research work as the amine to be used to modify the activated carbon produced, with the aim of improving the adsorption capacity of the activated carbon.

### 2.2 Synthesis of JAC-TEA

A known quantity (1.9 g) of JAC was placed in a flask containing TEA solution (0.1 g of 99% TEA + 19 g of ethanol stirred for 30 min). The mixture was stirred and heated for 2 hrs at 80°C and then dried at 80°C until the ethanol had volatilized completely [30]. The impregnated sample was designated as JAC-5 indicating that the Amine loading in the composites is 5 wt %. Loadings for 2.5 and 7.5 wt % were also conducted, while JAC-2.5 and JAC-7.5 were designated respectively. JAC-TEA was designated to generally describe all the amine loaded adsorbents that is, JAC-2.5, JAC-5 and JAC-7.5 respectively.

### 2.3 CO<sub>2</sub> Adsorption Experiment

The experiments were carried out in a cylindrical glass adsorption column with a length of 14 cm and an internal diameter of 1.2 cm. The adsorption column was packed with known amount of adsorbent, weighed on a digital weighing balance before placing it within a temperature-controlled water bath while CO<sub>2</sub> gas was passed through it for some time after which the column was pulled out from the water bath to be re-weighed. The amount of CO<sub>2</sub> captured by the adsorbent was determined by the difference in weight before and after the adsorption process, until the adsorbent was full to its capacity (until no further weight increase). The adsorption process was studied at different bed heights of adsorbent (2.7, 5.4 and 8.1 cm), amine loading on activated carbon (2.5, 5 and 7.5 wt %), adsorption temperature (30, 40, 50 and 60°C). The amount of CO<sub>2</sub> adsorbed (q, mg/g) was determine using equation (1) below.

$$\text{Amount of CO}_2 \text{ Adsorbed } \left( q, \frac{\text{mg}}{\text{g}} \right) = \frac{W_t(\text{mg}) - W_0(\text{mg})}{W_0(\text{g})} \quad (1)$$

Where:

W<sub>t</sub> is mass of adsorbent at time t

W<sub>0</sub> is original mass of adsorbent [31].

### 2.4 Adsorption Isotherm

Adsorption isotherm is a graphical representation of the relationship between the amounts of gas adsorbed by an adsorbent and the equilibrium pressure of the adsorbate at a constant temperature. In this work, the Langmuir [32] and Freundlich [33] isotherm models written in terms of pressure for gas adsorption (Equations 1 and 2) were used to analyze the experimental data obtained.

$$\frac{P}{\left(\frac{x}{m}\right)} = \left(\frac{1}{b}\right)P + \frac{1}{(ab)} \quad (2)$$

$$\log \left(\frac{x}{m}\right) = \log a + \left(\frac{1}{n}\right) \log P \quad (3)$$

where P (mmHg) is the pressure of gas, x (g) is the weight of gas adsorbed, m (g) weight of solid adsorbent and temperature and were evaluated from the slopes and intersects of the plots of P/(x/m) against P and log (x/m) against log P as shown in Figs. 7 and 8.

## 2.5 Adsorption Kinetics

The adsorption kinetic data of this work were fitted by the Lagergren pseudo-first-order and pseudo-second-order models [34]. To test the conformity of the experimental work,  $R^2$  values were analyzed [35,36].

$$\ln(q_e - q_t) = \ln q_e - k_1 t \quad (4)$$

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} t \quad (5)$$

Where  $q_e$  and  $q_t$  (mg/g) are the amounts of CO<sub>2</sub> adsorbed at equilibrium and at time  $t$  respectively,  $k_1$  ( $\text{min}^{-1}$ ) is the pseudo-first-order rate constant while  $k_2$  is the pseudo-second-order rate constant.  $k_1$  was obtained from the slope of the linear plot of  $\ln(q_e - q_t)$  against time while  $q_e$  and  $k_2$  were evaluated from the slope and intercept of the linear plot of  $t/q_t$  against time. The pseudo-first-order and pseudo-second-order kinetics are presented in Fig. 9 and Fig. 10 respectively.

## 2.6 Thermodynamics Studies

The magnitude of the activation energy ( $E_a$ ) is important in any of adsorption process due to the information it provides on the mechanism of the adsorption process. To calculate the activation energy of the adsorption process, the Arrhenius equation as shown in Equation 5 was applied [37].

$$\ln k = \frac{-E_a}{RT} + \ln k_0 \quad (6)$$

Where  $k$  is the rate constant of pseudo-second-order kinetic model (g/mg·min),  $E_a$  is the adsorption activation energy (J/mol),  $T$  is the adsorption temperature in Kelvin,  $R$  is the gas constant (8.314 J/mol·K), and  $k_0$  is the temperature independent factor (g/mg·min).

## 2.5 Isotheric Heat of Adsorption

The isotheric heat of adsorption ( $Q_{st}$ ) which is also known as the difference between the adsorption and desorption activation energy is the absolute value of the differential enthalpy of adsorption [38]. It represents the strength of the adsorbate-adsorbent interaction [39]. The  $Q_{st}$  ( $\text{kJmol}^{-1}$ ) of CO<sub>2</sub> adsorption onto JAC and JAC-TEA was evaluated from the Clausius-Clapeyron equation as stated below [40].

$$\frac{\delta(\ln P_{CO_2})}{\delta(1/T)} = \frac{-Q_{st}}{R} \quad (7)$$

Where  $P_{CO_2}$  is the CO<sub>2</sub> partial pressure (Pa),  $T$  is the absolute temperature (K), and  $R$  is the universal gas constant ( $8.314 \text{ Jmol}^{-1}\text{K}^{-1}$ ). The linearized form of the equation is;

$$(\ln P_{CO_2}) = \frac{Q_{st}}{R} (1/T) \quad (8)$$

The  $Q_{st}$  was then evaluated from the slope of the straight line graph of  $\ln P_{CO_2}$  against  $1/T$

## 2.7 Desorption Study

Thermal desorption technique was used to regenerate spent adsorbent. The spent adsorbent was weighed, introduced into a glass crucible, charged into an oven and heated. It was then removed, cooled and then reweighed. The desorption temperature and time of 100°C and 60 min were used respectively. 10 cycles of adsorption/desorption of CO<sub>2</sub> on adsorbent were conducted [29].

## 2.8 Characterization of the Activated Carbon

X-ray diffraction (XRD) measurements were carried out on a AXS Bruker advance-8 diffractometer using Cu K $\alpha$  radiation at a scan rate (2 $\theta$ ) of 0.04° per second recording from 12° to 90°. The accelerating voltage and applied current were 40 kV and 40 mA respectively. The micrographs of the morphological structure of the plain and amine impregnated adsorbent were taken using FEI Quanta 200 Scanning Electron Microscopy (SEM) with accelerating voltage of 20 kV. Brunauer-Emmett-Teller NOVA 4200e Quantachrome NovaWin© 1994-2013 instruments version 11.03 was used to determine the surface area and porosity of the adsorbent. The functional group of the activated carbon was determined using SHIMADZU FTIR-8400S Fourier Transform Infrared Spectrophotometer.

## 2.9 Degree of Crystallinity

Degree of crystallinity of samples was quantitatively estimated following the method of Ref. [41]. The equation used to calculate the degree of crystallinity is as follows:

$$X_c = \frac{A_c}{A_c + A_a}$$

Where  $X_c$  refers to the degree of crystallinity;  $A_c$  refers to the crystallized area on the X-ray diffractogram;  $A_a$  refers to the amorphous area on the X-ray diffractogram. (7)

## 3. RESULTS AND DISCUSSION

### 3.1 Characterization of the Activated Carbon

#### 3.1.1 XRD

Fig. 1 shows the XRD pattern of JAC and JAC-TEA. The appearance of CaCO<sub>3</sub> compound at 2 $\theta$  = 29° revealed the crystalline nature of both adsorbent [42]. The % peak area of the CaCO<sub>3</sub> compound for both JAC and JAC-TEA shows a relatively equal percentage crystallinity. The % peak area of Ca<sub>5</sub>(PO<sub>4</sub>)<sub>3</sub>OH compound at 2 $\theta$  = 38° - 48° that carries the hydroxyl group (OH) is observed to increase for JAC-TEA, this is one of the factors responsible for the increase in CO<sub>2</sub> adsorption capacity of JAC-TEA because -OH- functional groups enhances CO<sub>2</sub> capture [43]. The crystalline structure observed is a tremendous development impacted on the agricultural wastes upon activation [44].

#### 3.1.2 Scanning Electron Microscopic Analysis (SEM)

The percentage crystallinity of the JAC produced was found to be 49.9% which is higher than 2-9% reported in ref. [45] for all the activated carbon samples studied. This high crystallinity could be attributed to the presence of CaCO<sub>3</sub> as confirmed by XRD analysis result. High crystallinity is a measure of ordered pore structure which in turn is responsible for high adsorption characteristic exhibited by crystalline material.

#### 3.1.3 Scanning Electron Microscopic Analysis (SEM)

The SEM images of plain adsorbent (JAC), modified adsorbent (JAC-TEA) and spent adsorbent (JAC-A) are presented in Fig. 2a-2c.

Fig. 2a shows the morphological structure of JAC. It shows a well developed pore structure of a regular average dimensions as revealed by XRD pattern, while the pore structure of JAC-TEA shows a less regular dimensions due to TEA impregnated on its surface as shown in Fig. 2b. Fig. 2c is the morphological structure of a spent adsorbent JAC-A; the whitish appearance there signifies the presence of CO<sub>2</sub> adsorbed on the surface of the adsorbent.

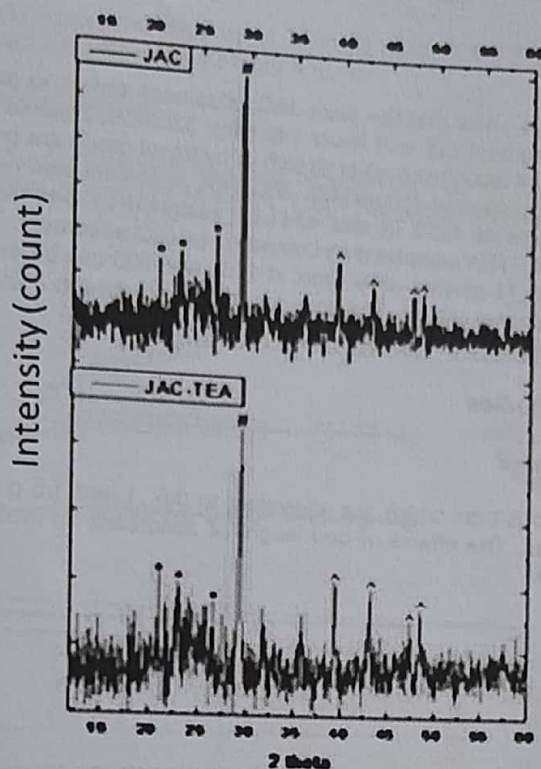


Fig. 1. XRD pattern of JAC and JAC-TEA compounds identified; \* = C<sub>2</sub>CaO<sub>4</sub>H<sub>2</sub>O; # = CaCO<sub>3</sub> and ^ = Ca<sub>5</sub>(PO<sub>4</sub>)<sub>3</sub>OH

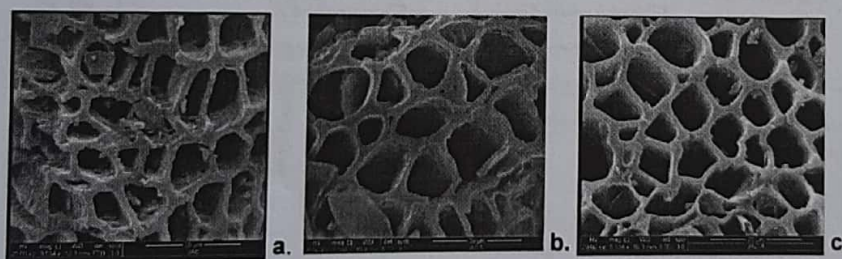


Fig. 2. SEM images of (a) JAC (b) JAC-TEA and (c) JAC-A image magnification: x5534

### 3.1.4 Brunauer-Emmett-Teller (BET)

The BET analysis of JAC surface area and porosity gave surface area of 689.41m<sup>2</sup>/g and pore volume of 0.35 cm<sup>3</sup>/g. This falls within the range of 0.2-0.6 m<sup>3</sup>/g for activated carbons with large pore volumes [46]. The nitrogen adsorption isotherm plotted suggested that the adsorbent is microporous in nature which is of the type I isotherm according to IUPAC classification [46]. Therefore, the large pore volume coupled with the microporous nature of the activated carbon produced from *Jatropha curcas* shell in this work can be said to be highly favourable for CO<sub>2</sub> adsorption. The significant surface areas recorded is an added advantage since the larger the surface area of an activated carbon, the better its adsorption capacity. In [29], it was shown that JAC has higher specific surface area than the activated carbons (AC-EFB, AC-CNS) [47], Synthesized from oil palm empty fruit bunch and coconut shells under the same experimental conditions.



### 3.1.5 FT-IR

In Fig. 3, the FT-IR spectra show that the plain JAC adsorbent seems to possess the entire surface functions of JAC-TEA adsorbent but with lower intensity. 3300-3500 bands assigned to amine N-H stretch and 3750-4000 band assigned to O-H stretch of hydroxyl group are predicted to enhance CO<sub>2</sub> adsorption in microporous carbon materials [48]. JAC-TEA adsorbent also possesses extra oxygen-containing functional groups at 4019.79 and 4341.91 assigned to O-H vibration which is also an advantage property for JAC-TEA adsorbent as compared to JAC adsorbent. The peak at 1625 can be assigned to type 1 and type 11 amines while peak at 1100 and 500 can be assigned to P-O stretching vibration in hydroxyl and phenol groups. The absence of peaks between 2000 and 250 is an indication that JAC and JAC-TEA are free from moisture and bound water content.

## 3.2 CO<sub>2</sub> Adsorption Studies

### 3.2.1 Effect of Bed height

Bed heights 2.7, 5.4 and 8.1 cm which are equivalent to 0.5, 1 and 1.5 g respectively of adsorbent dosage were investigated. The effects of bed height of adsorbent on the amount of CO<sub>2</sub> adsorbed were presented in Fig. 4.

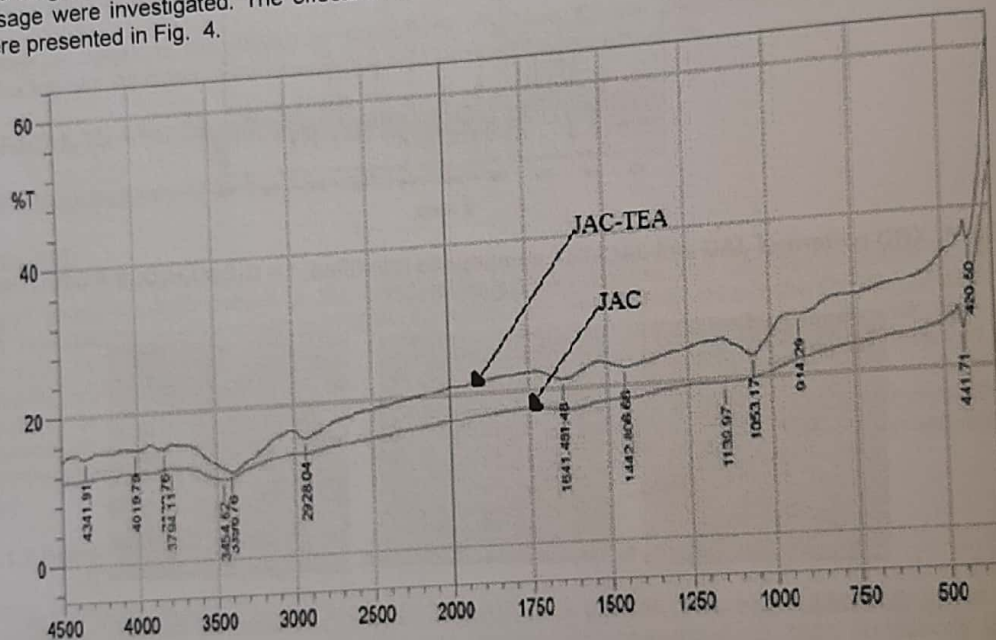


Fig. 3. FTIR Spectra of JAC and JAC-TEA

It was observed that an increase in the bed height of adsorbent leads to a corresponding increase in the adsorption capacity of CO<sub>2</sub>. Bed heights of 2.7 cm and 5.4 cm of JAC adsorbent captures 36 mg/g and 66 mg/g of CO<sub>2</sub> respectively. The increase in the amount of CO<sub>2</sub> adsorbed was due to the increase in the active sites of the adsorbent, thus improving interaction between CO<sub>2</sub> molecules and adsorbent active sites. This observation shows appreciable consistency with the report of [49].

### 3.2.2 Effect of amine loading on activated carbon

The effect of amine loading (2.5, 5, and 7.5 w%) on CO<sub>2</sub> adsorption of the JAC is presented in Fig. 5.

From the concentration range studied, it was observed that adsorption capacity increased with increase in amine loading. This observation is similar to that of the other researchers who also reported an increase in CO<sub>2</sub> uptake with corresponding amine loading increase [30]. The JAC-5

adsorbent gave higher CO<sub>2</sub> adsorption capacity of 78 mg/g as compare to the plain adsorbent JAC which was 66 mg/g and JAC-7.5 which was 62 mg/g (Fig. 5).

### 3.2.3 Effect of adsorption temperature

Adsorption was tested under the temperature range between 30 – 60°C; this range covers the post-combustion flue gas temperature range of 35 – 45°C [10]. The results are presented in Fig. 6.

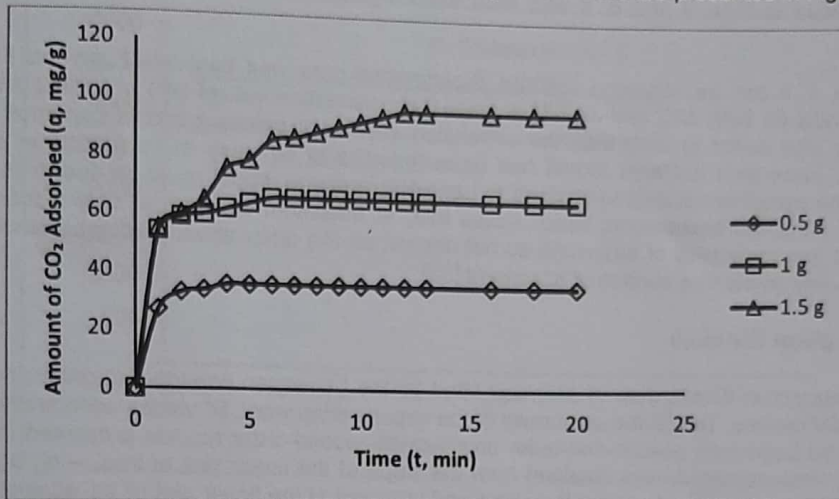


Fig. 4. Effect of adsorbent dosage (bed height) on the amount of CO<sub>2</sub> adsorbed

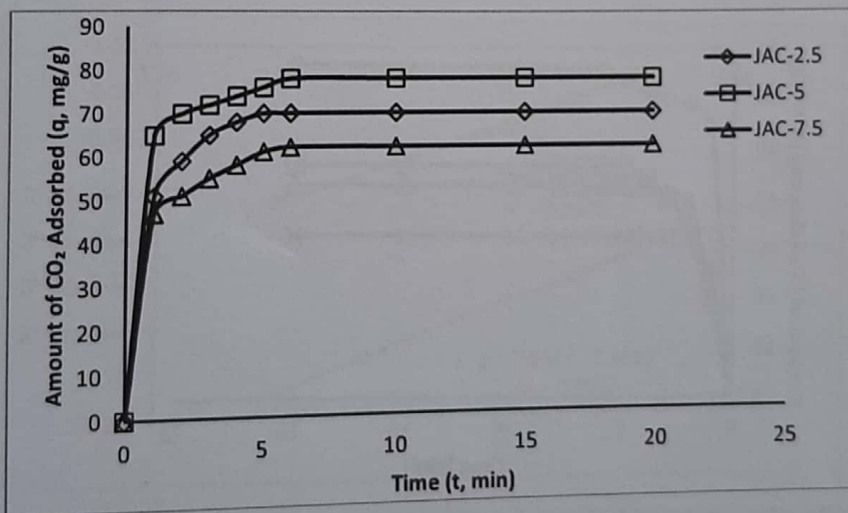


Fig. 5. Effect of amine loading on activated carbon on the amount of CO<sub>2</sub> adsorbed

The adsorption capacity of the adsorbent JAC was observed to be decreasing as the temperature increases from 30°C - 60°C. This is a peculiar phenomenon in physisorption. Reference [48] reported that physisorption process involves high surface adsorption energy and molecule diffusion at elevated temperatures, which results in instability of the adsorbed gas on the surface of activated carbon and consequently, desorption process will occur. In physisorption unlike chemisorptions only weak van der Waals forces exist between the adsorbed molecules of CO<sub>2</sub> and carbon surfaces; any increase in temperature easily breaks this bond that was why a decrease in CO<sub>2</sub> capacity was observed as

temperature increases. This shows that the adsorption is more controlled by the physical characteristics of the adsorbent [49].

### 3.3 CO<sub>2</sub> Adsorption Isotherms

Langmuir and Freundlich Adsorption Isotherms for JAC and JAC-TEA at room temperature (28°C) were presented in Figs. 7 and 8. It was from these figures that data presented in Table 1 were generated.

From Table 1, it can be observed that the experimental data was best fitted into the Freundlich isotherm model for both JAC and JAC-TEA since their correlation values ( $R^2$ ) of 0.9962 and 0.9945 respectively was closer to unity than the correlation coefficient values found in Langmuir isotherm model [50]. Freundlich isotherm model has been reported to be easy to fit adsorption data [51]. Failure of the experimental data to conform to Langmuir isotherm model could be due to its failure to conform to Langmuir assumption, which states that, at maximum adsorption, only a monolayer is formed and that molecules of adsorbate do not deposit on the other already adsorbed molecules of adsorbate, only on the free surface of adsorbent [32].

### 3.4 Adsorption Kinetics

The CO<sub>2</sub> adsorption kinetic data of JAC was fitted by the Lagergren pseudo-first-order and pseudo-second-order models. To test the conformity of the experimental work,  $R^2$  values were analyzed. From the linearized Lagergren pseudo-first-order and pseudo-second-order models presented in Equation (4) and (5) respectively,  $k_1$  was obtained from the slope of the linear plot of  $\ln(q_e - q_t)$  against time while  $q_e$  and  $k_2$  were evaluated from the slope and intercept of the linear plot of  $t/q_t$  against time. The pseudo-first-order and pseudo-second-order kinetics are presented in Figs. 9 and 10 respectively which were further used to generate data presented in Table 2.

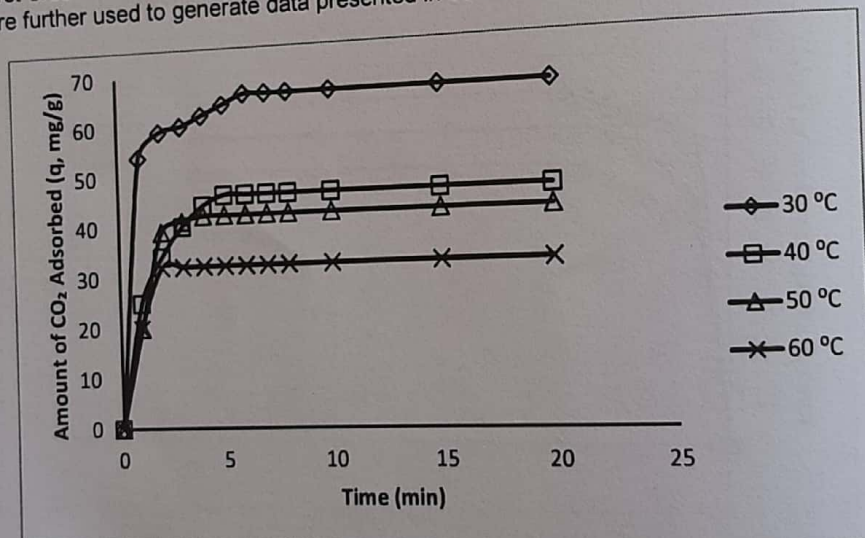


Fig. 6. Effect of adsorption temperature on the amount of CO<sub>2</sub> adsorbed

Evaluating the correlation coefficient ( $R^2$ ) obtained in both pseudo-first-order and pseudo-second-order kinetics models for the adsorption of CO<sub>2</sub> onto JAC and JAC-TEA, it can be clearly observed that the correlation coefficients of 0.999 and 0.9994 obtained from pseudo-second-order kinetic model indicates that these systems conformed more to pseudo-second-order kinetics model [49]. The significance of its conformity can be observed from the  $q_e$  values of pseudo-second-order model, which shows the actual CO<sub>2</sub> adsorption capacity of the adsorbents as compared to the  $q_e$  values of pseudo-first-order model [31]. The resulting parameters of both models for the systems studied are presented in Table 2.

Table 1. Parameters obtained from adsorption isotherms for JAC and JAC-TEA

Adsorbent	Langmuir isotherm model			Freundlich isotherm model		
	a (mmHg <sup>-1</sup> )	b (g/g)	R <sup>2</sup>	a (g/g)	1/n	R <sup>2</sup>
JAC	3.10 × 10 <sup>-4</sup>	1.01	0.4766	3.97 × 10 <sup>-4</sup>	0.944	0.9962
JAC-TEA	1.07 × 10 <sup>-3</sup>	0.3988	0.909	6.28 × 10 <sup>-4</sup>	0.8912	0.9945

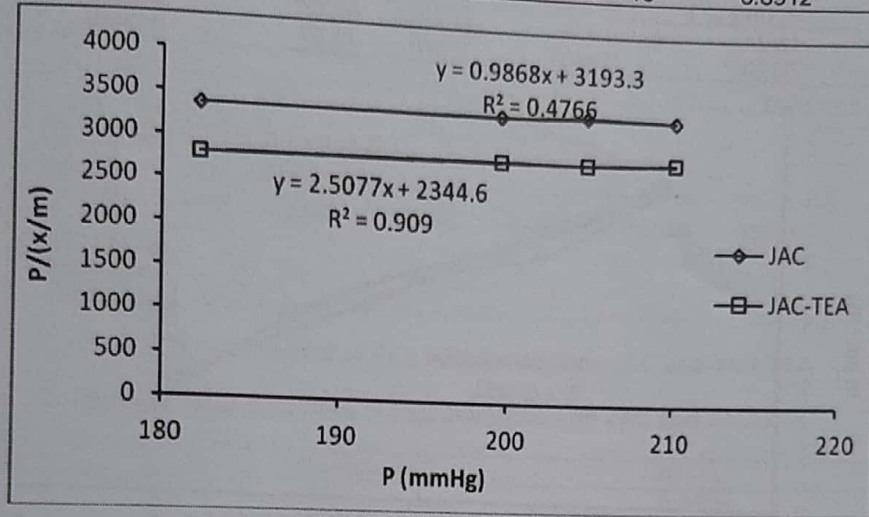


Fig. 7. Langmuir adsorption isotherms for JAC and JAC-TEA at room temperature (28°C)

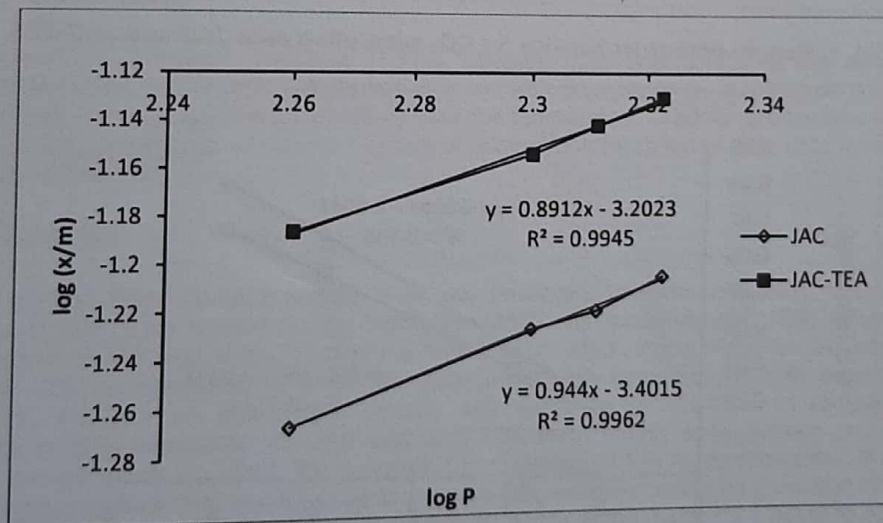


Fig. 8. Freundlich adsorption isotherms for JAC and JAC-TEA at room temperature (28°C)

### 3.5 Thermodynamics Study

Using Arrhenius equation as shown in equation 5, the activation energy for JAC was found to be 5.177 kJ/mol while that of JACTEA was found to be 3.0 kJ/mol. The positive value of  $E_a$  indicates that the CO<sub>2</sub> adsorption is endothermic [38]. The low activation energy found in this work implies that the adsorbents adsorption onto JAC and JACTEA is a diffusion-controlled process. This suggests the adsorbents might have a good desorption capability [35,31]. However, the  $E_a$  of JACTEA is lower than that of

JAC indicating that the bond formation between CO<sub>2</sub> and JAC-TEA is weaker as compared to that of JAC.

Table 2. Parameters for CO<sub>2</sub> adsorption kinetics on JAC and JAC-TEA

Adsorbent	Pseudo-first-order kinetics			Pseudo-second-order kinetics		
	q <sub>e</sub> (mg g <sup>-1</sup> )	k <sub>1</sub> (min <sup>-1</sup> )	R <sup>2</sup>	q <sub>e</sub> (mg g <sup>-1</sup> )	k <sub>2</sub> (min <sup>-1</sup> )	R <sup>2</sup>
JAC	18.24	0.414	0.9593	66.67	0.0549	0.999
JAC-TEA	20.78	0.4437	0.978	79.37	0.0496	0.9994

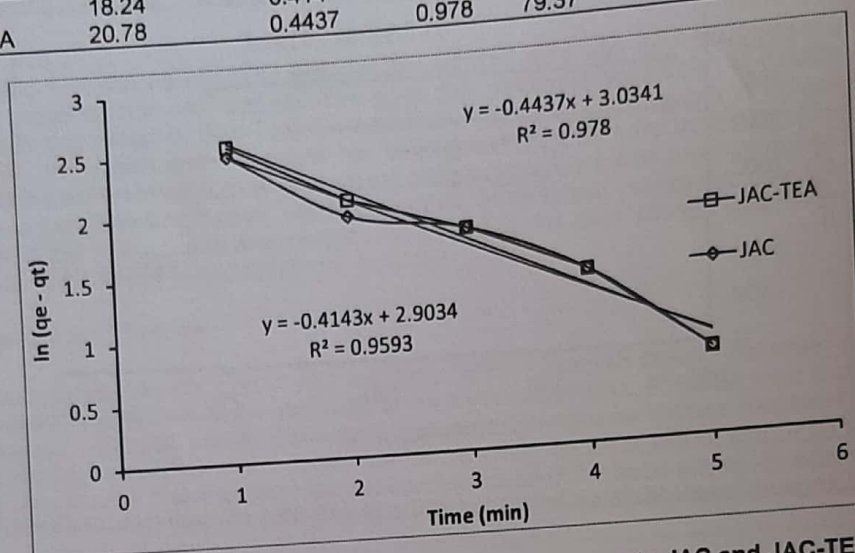


Fig. 9. Pseudo-first-order kinetics for CO<sub>2</sub> adsorption onto JAC and JAC-TEA

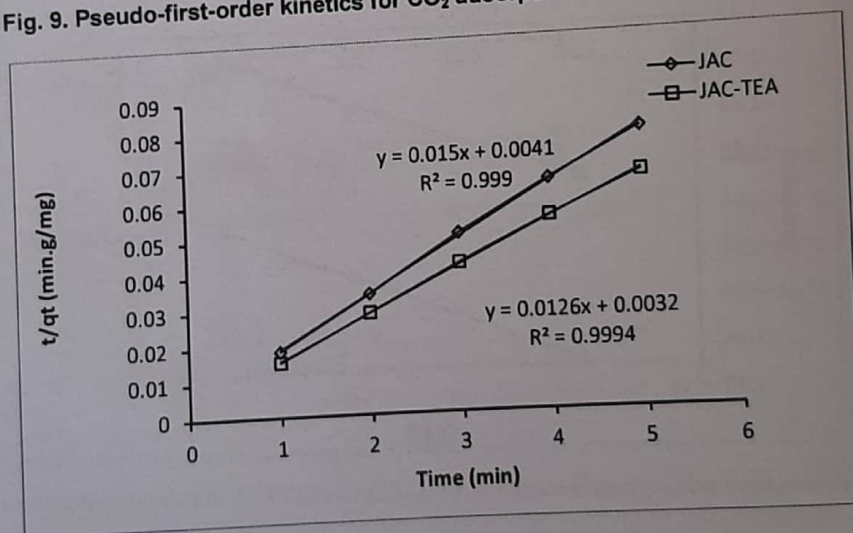


Fig. 10. Pseudo-second-order kinetics for CO<sub>2</sub> adsorption onto JAC and JAC-TEA

Fig. 11 shows isosteric heat of adsorption.  $Q_{st}$  and  $R^2$  values generated from Fig. 11 are tabulated in Table 3. It can be observed from the figure that  $Q_{st}$  became more negative with plain adsorbent (JAC) showing a more physical adsorbate-adsorbent interaction [52].

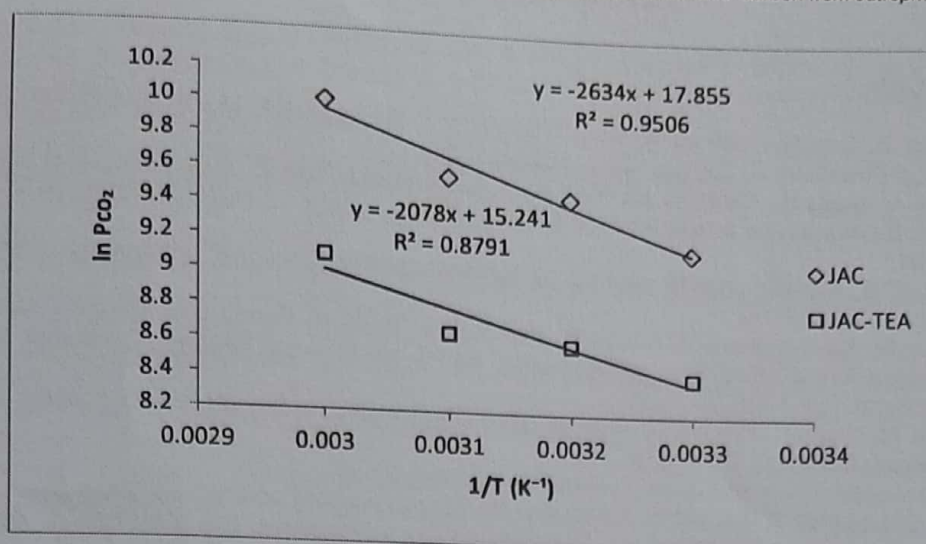


Fig. 11. Isosteric heat of CO<sub>2</sub> adsorption onto JAC and JAC-TEA

Table 3. Isosteric heat of CO<sub>2</sub> adsorption on JAC and JAC-TEA

Adsorbent	Q <sub>st</sub> (kJmol <sup>-1</sup> )	R <sup>2</sup>
JAC	-21.9	0.9506
JACTEA	-17.3	0.8791

### 3.6 Desorption Study

The desorption temperature and time (100°C, 60 min) used was similar to the adsorbent pre-treatment temperature and time; this method is in line with other report by researchers who were able to successfully carry out a desorption study with the temperature used for pre-treatment [47]. JAC-TEA adsorbent was able to withstand 7 cycles of adsorption/desorption of CO<sub>2</sub> onto it which reveals the stability of the JAC.

## 4. CONCLUSION

Activated carbon from *Jatropha curcas* shell was produced, modified with TEA, after which CO<sub>2</sub> adsorption studies were carried out on both plain (JAC) and modified (JAC-TEA) adsorbents. The surface nature of JAC was changed after the modification, which made JAC-TEA adsorbed a higher amount of CO<sub>2</sub> as compared to JAC. The CO<sub>2</sub> adsorption capacities of both adsorbents were observed to increase on bed height increase and decrease on increase in temperature. The mechanism of CO<sub>2</sub> adsorption on JAC and JAC-TEA were mainly physisorption possessing low activation energy which is suitable for desorption. The results of this study shows that a high quality porous activated carbon that can be used to mitigate CO<sub>2</sub> emission could be produced from a cheap raw material like *Jatropha curcas* shell, an agricultural waste which suggests a possible cost-effective sorbent for CO<sub>2</sub> capture.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES

1. Dutcher B, Fan M, Leonard B, Dyar MD, Tang J, Speicher EA, Liu P, Zhang YJ. Journal of Physical Chemistry C. 2011;1-15(31):15532-15544.
2. Zhang Z, Wang K, Atkinson JD, Yan X, Li X, Rood MJ, Yan Z. Sustainable and hierarchical porous *Enteromorpha prolifera* based carbon for CO<sub>2</sub> capture. J. Hazard. Mater. 2012;229-230, 183-191.
3. Steven AG. Carbon dioxide capture by tertiary amidine functional adsorbents. University of Pittsburgh. 2007;1-66.
4. Forster P, Ramaswamy V, Artaxo P, Bernsten T, Betts R, Fehey DW. Climate change. The physical science basis, Intergovernmental Panel on Climate Change, Cambridge University Press Cambridge; 2007.
5. Global Monitoring Division. Trends in atmospheric carbon dioxide. Earth System Research Laboratory Retrieved 26/1/2015  
Available: <http://www.esrl.noaa.gov/gmd/ccgg/trends/#mlo>
6. Azar C, Lindgren K, Larson E, Mollersten K. Carbon capture and storage from fossil fuels and biomass – Cost and potential role in stabilizing the atmosphere. Climate Change. 2006;74:47-79.
7. Rochelle GT. Amine scrubbing for CO capture. Science. 2009;325(5948):1652-1654.
8. Shena CZ, Grande CA, Li P, Yu JG, Rodrigues AE. Adsorption equilibria and kinetics of CO<sub>2</sub> and N<sub>2</sub> on activated carbon beads. Chemical Engineering Journal. 2010;160(2):398-407.
9. Dantas TLP, Amorim SM, Luna FMT, Silver Jr IJ, Azevedo DCS, Rodrigues AE. Adsorption of carbon dioxide onto activated carbon and nitrogen-enriched activated carbon: Surface changes, equilibrium and modeling of fixed-bed adsorption. Sep. Sci. Technol. 2010;45:73-84.
10. Aaron D, Tsouris C. Separation of CO<sub>2</sub> from flue gas: A review. Sep. Sci. Technol. 2005;40(13):321-348.
11. Haszeldine RS. Carbon capture and storage: How green can black be? Science. 2009;325:1647-1652.
12. Seader JD, Henley EJ. Separation process principles. New York: John Wiley & Sons; 1998.
13. Zhang B, Fan M, Bland A. CO<sub>2</sub> separation by a new solid K-Fe sorbent. Energy Fuels. 2011;25(4):1919-1925.  
DOI: 10.1021/ef200005x
14. Bollini P, Didas SA, Jones CW. Amine-oxide hybrid materials for acid gas separations. Journal of Materials Chemistry. 2011;21:15100-15120.
15. Jones CW. CO<sub>2</sub> capture from dilute gases as a component of modern global carbon management. Annual Review Chemical Biomolecular Engineering. 2011;2:31-52.
16. Hedin N, Chen L, Laaksonen A. Sorbents for CO<sub>2</sub> capture from flue gas-aspects from materials and theoretical chemistry, Nanoscale. 2010;2:1819.
17. Choi S. Dr, Drese JH, Jones CW. Adsorbent materials for carbon dioxide capture from large anthropogenic point sources. Chem Sus Chem. 2009;2:796-854.
18. Hu X, Radosz M, Cychosz KA, Thommes M. CO<sub>2</sub>-filling capacity and selectivity of carbon nanopores: Synthesis, texture and pore size distribution from quenched-solid density functional theory (QSDFT). Environmental Science & Technology. 2011;45(16):7068-7074.
19. Drage TC, Blackman JM, Pevida C, Snape CE. Energy Fuels. 2009;23(5):2790-2796.
20. Belmabkhout Y, Serna-Guerrero R, Sayari A. Chemical engineering science. 2009;64(17):3721-3728.
21. Siriwardane RV, Shen MS, Fisher EP, Poston JA. Adsorption of CO<sub>2</sub> on molecular sieves and activated carbon. Energy Fuels. 2001;15(2):279-284.
22. Cavenati S, Grande CA, Rodrigues AE. Journal Chemical Engineering Data. 2004;49(4):1095-1101.
23. Millward AR, Yaghi OM. Journal of American Chemical Society. 2005;127(51):17998-17999.
24. Sumida K, Rogow DL, Mason JA, McDonald TM, Bloch ED, Herm ZR, Bae TH, Long JR. Chem. Rev. 2012;112(2):724-781.
25. Furukawa H, Ko N, Go YB, Aratani N, Choi SB, Choi E, Yazaydin AO, Snurr RQ, O'Keeffe M, Kim J, Yaghi OM. Science. 2010;329(5990):424-428.

26. Zhenhe C, Shubo D, Haoran W, Bin W, Jun H, Gang Y. Activated carbons and amine-modified materials for carbon dioxide capture. *Frontiers of Environmental Science Engineering*. 2013; 7(3):326-340
27. D'Alessandro DM, Smit B, Long JR. Carbondioxide capture: Prospects for new materials. *Angew Chemica International Edition*. 2010;16 49(35):6058-6082.
28. Masita Mohammad, Zahira Yaakob, Siti Rozaimah Sheikh Abdullah. Carbon derived from jatropha seed hull as a potential green adsorbent for cadmium (II) removal from wastewater. *Materials*. 2013;6:4462-4478.
29. Auta M, Alhassn M, Jossey KS. CO<sub>2</sub> Capture using amine-impregnated activated carbon from *Jatropha curcas* shell. unpublished work; 2017.
30. Lina M, Ruizhu B, Gengshen H, Ru C, Xin H, Wei D, Herbert FMD, Maohong F Capturing CO<sub>2</sub> with amine-impregnated titanium oxides. *American Chemical Society*. 2013;27:5433-5439.
31. Rashidi NA, Yusup S, Lam HL. Kinetic Studies on carbon dioxide capture using activated carbon. *Chemical Engineering Transactions*. 2013;35:361-366.
32. Langmure I. The adsorption of gases on plane surfaces of glass, mica and platinum. *Journal of American Chemistry*. 1918;57:1361-1403.
33. Freudlich H. Adsorption in solution. *Journal of Physical Chemistry*. 1906;57:384-470.
34. Langergrene S. About the theory of so called adsorption of soluble substances, *Kungiga Svenska Vetenskapsakademies handlingar*. 1898;24(4):1-39.
35. Alhassan M, Andrew I, Auta M, Umar M, Garba MU, Isah AG, Alhassan B. Comparative studies of CO<sub>2</sub> Capture using acid and base modified activated carbon from sugarcane bagasse. *Biofuels*, Tylor and Francis Group. 2017;1-10.
36. Alhassan M, Andresen J. Effect of bone during fixed bed pyrolysis of pistachio nut shell. *International Journal of Science and Engineering Investigations*. 2013;2(12):2251-8843.
37. Özcan A, Öncü EM, Özcan AS. Kinetics, isotherm and thermodynamic studies of adsorption of acid blue 193 from aqueous solutions onto natural sepiolite, *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. 2006;277:90-97.
38. Alan LM. Thermodynamics of adsorption, chemical thermodynamics for industry. 2004;Chapter-21:243- 253.
39. Szekely J, Evans JW, Sohn HY. Gas-solid reaction. Academic, New York; 1976.
40. Ebbing DD, Gammon SD. General chemistry. (6<sup>th</sup> ed) Houghton: Boston, MA; 1999.
41. Wang LF, Yang RT. Significantly increased CO<sub>2</sub> adsorption performance of nanostructured templated carbon by tuning surface area and nitrogen doping. *Journal of Physical Chemistry C*. 2012;116(1):1099-1106.
42. Liu Y, Wilcox J. Effects of surface heterogeneity on the adsorption of CO<sub>2</sub> in microporous carbons. *Environ. Sci. Technol*. 2012;46:1940-1947.  
DOI: 10.1021/es204071g
43. Ketcha JM, Dina DJD, Ngomo HM, Ndi NJ. Preparation and characterization of activated carbon obtained from maize cobs by zinc chloride activation. *American Chemical Science Journal*. 2012;2(4):136-160.
44. Sing KSW, Everett DH, Haul RAW, Moscou L, Pierotti RA, Rouquerol J, Siemieniowska T. Reporting physiosorption data for gas/solid systems with special reference to the determination of surface area and porosity. *Pure and Applied Chemistry*. 1985;57:603-619.
45. Khalil HPS, Jawaid M, Firoozian P, Rashid U, Islam A, Akil HM. Activated carbon from various agricultural wastes by chemical activation with KOH: Preparation and characterization. *Journal of Biobased Materials and Bioenergy*. 2013;7:1-7.
46. Auta M, Amat Darbis ND, Mohd Din AT, Hameed BH. Fixed-bed column adsorption of carbon dioxide by sodium hydroxide modified activated alumina. *Chemical Engineering Journal*. 2013; 233:80-87.
47. Maroto-Valer MM, Tang Z, Zhang YZ. CO<sub>2</sub> capture by activated and impregnated anthracites. *Fuel Processing Technology*. 2005;86(14-15):1487-1502.
48. Weiquan C, Lijun T, Jiaquo Y, Mietek J, Xiaoqin L, Bei C, Francis V. Synthesis of amino-functionalized mesoporous alumina with enhanced affinity towards Cr (VI) and CO<sub>2</sub>. *Chemical Engineering Journal*. 2014;239:207-215.
49. Auta M, Hameed BH. Optimized and functionalized paper sludge activated with potassium fluoride for single and binary adsorption of reactive dyes. *Journal of Industrial and Engineering Chemistry*. 2014;20:830-840.



50. Uwadiae SE. Adsorption studies for the removal of Cu (II) and Pb (II) from aqueous solution by local adsorbent using nonlinear regression methods, *Journal of sciences and multidisciplinary research*. 2015;7:6-10.
51. Ho YS, Mikay G. Sorption of dye from aqueous solution by peat. *Chemical Engineering Journal*. 1998;115-124.
52. Fengsheng S, Chungsyng L, Shih-Chun K, Wanting Z. Adsorption of CO<sub>2</sub> on amine-functionalized Y-type zeolites. *American Chemical Society*. 2010;24:1441-1448.

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