THE STUDY OF SORPTION CAPACITY AND CHARACTERIZATION ON CO_2 CAPTURE USING ZEOLITE AND ACTIVATED CARBON FROM SUGARCANE BAGASSE

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ABSTRACT

We evaluated the capture of CO2 using the combination of adsorbents: natural zeolite-(Z-Z), and activated carbon from sugarcane bagasse. The result suggested that CO2 adsorption using natural zeolite and activated carbon from sugarcane bagasse are good. Characterization of the activated carbon and the zeolite was carried out by the following analysis: The Fourier Transform Infrared Spectroscopy (FTIR), The Scanning Electron Microscope (SEM), The X-ray Diffraction (XRD). The TGA, while the activated carbon shows a better sorption capacity than the zeolite. The adsorption capacity of each of the masses are; 0.057, 0.060, and 0.065 mg/g with flow rate of 1l/min; 0.058, 0.061 and 0.068 mg/g with flow rate of 2l/min, and 0.055, 0.063 and 0.070 mg/g with flow rate of 3l/min at 50 minutes and 298 K for the activated carbon. And 0.048, 0.049 and 0.050 mg/g with flow rate of 1l/min; 0.048, 0.053 and 0.055 mg/g with flow rate of 2l/min and 0.048, 0.051 and 0.054 mg/g with flow rate of 3l/min at 50 minutes and 298 K for the zeolite. A very good and porous activated carbon with a high adsorption capacity produced from sugarcane bagasse and used in this work had a better CO2 adsorption capacity than zeolite, it can be suggested that activated carbon in CO2 adsorption is a better performer than zeolite for both commercial and laboratory use because of the larger pore size which enable it to be most effective in CO2 adsrption compare to zeolite while there are all sustainable and inexpensive.
Keywords: *Activated Carbon, CO2 Adsorption, Adsorbents, and Zeolite.*

INTRODUCTION

Globally, there is increase in dependence on petroleum based fossil fuel and other petroleum products as source of energy for the day to day activity of man. One of the most acknowledged gas generated from our day to day activity is carbon dioxide and the release of this gas into the atmosphere has contributed 60% to global warming and serious climatic change. CO2 generated naturally is never a threat to earth on its own but the anthropogenically generated CO2 which are nearly wholly produced by the usage of this fossil fuel has made it a threat. Fossil fuel will continue to be in use because it is mainly used in the generation of energy through power plants and energy will always be generated due to its usefulness. The increasing rate of CO2 in the atmosphere is a global concern which has lead into quite a number of studies into CO2 capture. Adsorption has been seen to be most effective technology to be used due factors like surface area, regeneration etc. Activated carbons are processed carbon materials that are capable of adsorbing various substances from gas and liquid streams, because of their highly developed pore structure and large internal specific surface areas (Aji *et al.*, 2017; Sugumaran *et al.*, 2012). It has been regarded as a unique and versatile adsorbent because of its extended surface area (Gumus and Okpeku, 2015), microporous structure, high adsorption capacity, and high degree of surface reactivity (Williams and Reed, 2006).

Activated Carbon finds application in areas such as wastewater treatment, water purification, discoloration, and removal of toxic organics, heavy metals ions (Rahmani *et al.*, 2009). It have wide applications in domestic, commercial and industrial settings (Mendez *et al.*, 2006), such as air filters at industrial level as well as in general air conditioning application (Oyo and Igbokwe, 2001).

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It is thought to bind to poison and prevent its adsorption by the gastrointestinal tract (Yusufu *et al.*, 2012). Activated carbon is 50% w/w combination with celite, chromatographic separation of carbohydrates (mono, di-trisacchardes) using ethanol solution (5 % - 50 %) as mobile phase (Gumus and Okpeku, 2015). Activated carbon can be prepared from many carbonaceous materials including municipal and industrial wastes and forest and agricultural by-products (Hu *et al.*, 2003; Hu and Srinivasan, 2001; Wu and Tseng, 2006). AC obtained from agricultural by-products has the advantage of offering an effective, low cost replacement for non-renewable coal-based granular activated carbons (GACs) provided that they have similar or better adsorption efficiency (Martin *et al.*, 2003). The abundance and availability of agricultural by-products makes them good sources of raw materials for activated carbon production (Malik *et al.*, 2007).

There has been an increasing interest in the production of activated carbon from agricultural byproducts and industrial waste (Rahman *et al.*, 2006), such as cocoa pod husk (Sricharoenchaikal *et al.*, 2007), rice husk (Fierro *et al.*, 2010; Guo and Rockstraw, 2007) periwinkle shell (Atuyor and Badmus, 2008), coconut shells (Azevedo *et al.*, 2007; Hu and Srinivasan, 2001), palm kernel shells, peach stone, physic nut waste, and bamboo stem wastes (El-Sheik *et al.*, 2003; Razada *et al.*, 2005). Others include: olive stone and walnut shell (Martinez *et al.*, 2006), pecan shells, palm seed, apple pulp (Kenneth *et al.*, 2002; Suzuti *et al.*, 2006; Ademituyi *et al.*, 2009), cotton stalk (Deng *et al.*, 2009), date pits (Girgis and EI- Hendawy, 2002), rubber seeds (Hameed and Daud, 2008), and molasses, resins, and dried sewage sludge paper mill sludge, old newspapers (Et-Hendway, 2003; Puziy *et al.*, 2002), and wood (Aji *et al.*, 2017).

METHODS

A. Materials: Activated carbon produced from sugarcane bagasse was used in this experiment. Gaseous CO_2 was purchased from gas deport in Minna Niger state. The adsorption column used was gotten from chemical engineering laboratory and the zeolite used was also gotten from the department. The zeolite used in this work is Zeolite Ammonium ZSM-5 (Zeolite Socony Mobile-5) powder which was produced by Zeolyst International. It is a white odorless powder, the SiO_2/Al_2O_3 mole ratio is 80, the nominal cation form is Ammonium, the Na_2O weight percent is 0.05, the surface area is $425 m^2/g$ and It has an estimated pore size of 5.4 -5.6 Å.

B. Synthesis of Sugarcane Bagasse Activated Carbon

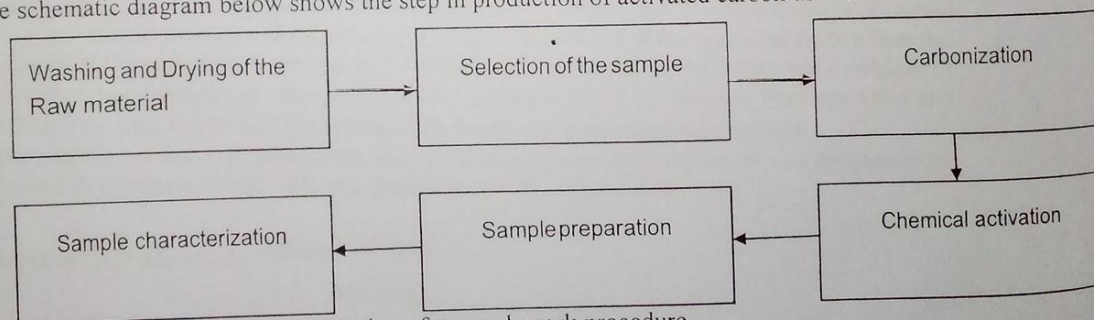The schematic diagram below shows the step in production of activated carbon used in this work.

Figure 3.1 Schematic representation of research work procedure

The Sugarcane bagasse used was collected from Badeji sugar factory Bida. The bagasse was thoroughly washed and further sundried for about five days. The bagasse was grinded using a ball grinder, and oven dried at a temperature of 150^oC to obtain it in its powdered form. The powdered bagasse was sieved to give a particle size of 1 mm which was used. The sample waswashed with distilled water to remove unwanted materials which was separated as filtrate.

The washed bagasse was impregnated with 18.8g of ZnCl for 10hours, after which it was washed with distilled water and dried to remove moisture. The dried weight before carbonization is 1,582.07g, the weight after carbonization is 579g and the weight after activation is 417g. The bagasse was carbonized at a temperature of $450^{O}C$ and the activation was carried out at $105^{O}C$. The surface area of the final Activated carbon is $328m^2/g$ and the pore volume is 0.164cc/g

C. Characterization of the Activated Carbon

Characterization of the produced activated carbon was done using the following analysis: The Fourier Transform Infrared Spectroscopy (FTIR), was done to determine the chemical composition of the activated carbon, and the functional group. The Scanning Electron Microscope (SEM), was done to determine the morphology (structure) and purity of adsorbent. The X-ray Diffraction (XRD) was carried out to determine the crystallinity of the adsorbent. The TGA showed the decomposition of the adsorbent.

D. CO2 Adsorption Experiment (sugarcane bagasse)

This work was done using a glass adsorption column, cylindrical in nature, 14 cm long and an internal diameter of 1.2 cm. The adsorption column was supported by a wooden standing, through which the CO2 was delivered from the gas cylinder was connected to the base end of the column, the other end of the column i.e. the upper part had an open end where an exit hose can be fitted, the open end was well corked and an exit hose was connected through the opening at center of the hose. (Alhassan et al., 2017).

With the aid of an analytical weighing balance 0.5 g of activated carbon was measured and placed in the column (with a foam support) and the gas cylinder's tap was opened at 1 L/min, and the time of adsorption was varied (10,20,30…) min until an equilibrium was achieved. This operation was carried out at atmospheric pressure and at room temperature $25^{O}C$. The same operation was repeated for 1 g and 1.5 g of activated carbon. All values gotten was recorded and the experiment was carried out again at a different flow rate of 2 L/min and 3 L/min. The weight of the activated carbon samples was measured at the end of each run (i.e. at 10 min interval) to ascertain the difference in weight of the activated carbon (sample) in other to determine the amount of CO2 that has been adsorbed and to determine how long it will take the activated carbon to reach its maximum capacity. This same experiment was repeated for zeolite, and this was done for comparison. All the procedure was followed to the tiniest detail, only the change in the adsorbent used.

$$\text{Amount of CO2 adsorbed} = \frac{Mt(mg) - Mo(mg)}{Mo\ (mg)}$$

Where:

Mo = initial mass before adsorption Mt = final mass after adsorption

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RESULTS AND DISCUSSION
Characterization of Adsorbents
Fourier transform infrared spectroscopy (FT-IR)

The FT-IR analysis is carried out to investigate the functional groups of the adsorbents used in the experiment. Functional groups not only affect the adsorption behavior, but also dominate the adsorption mechanism.
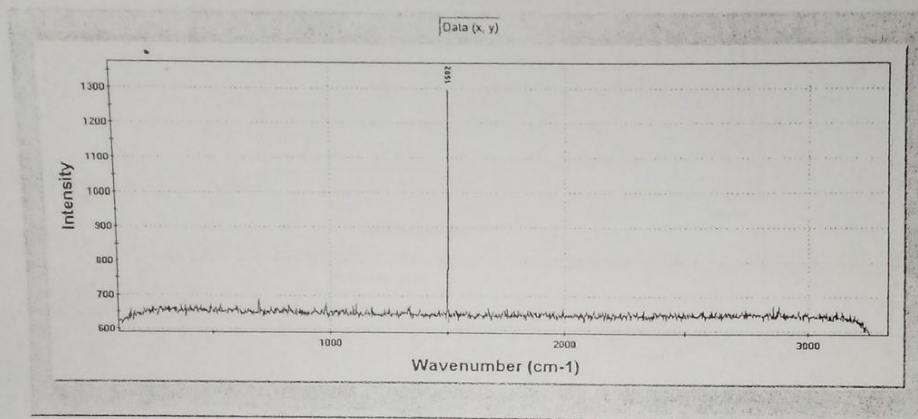
Fig 1: FT-IR before adsorption (Activated carbon)
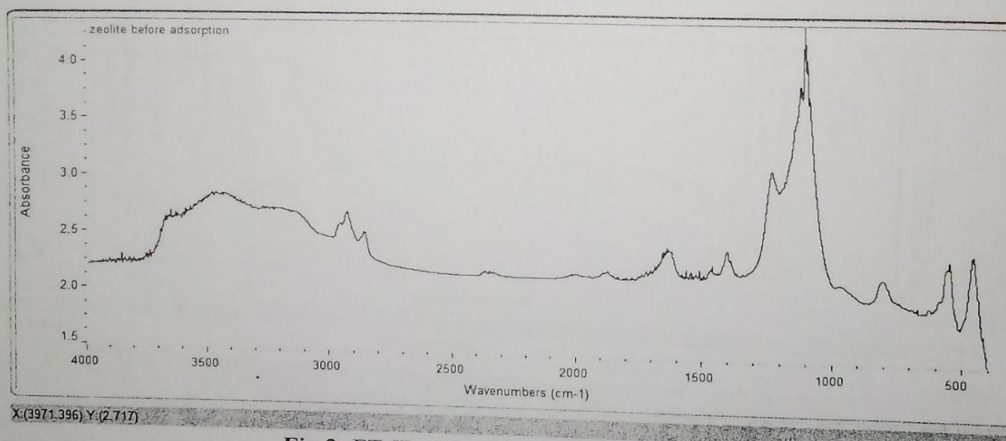
Fig 2: FT-IR After adsorption (Activated carbon)
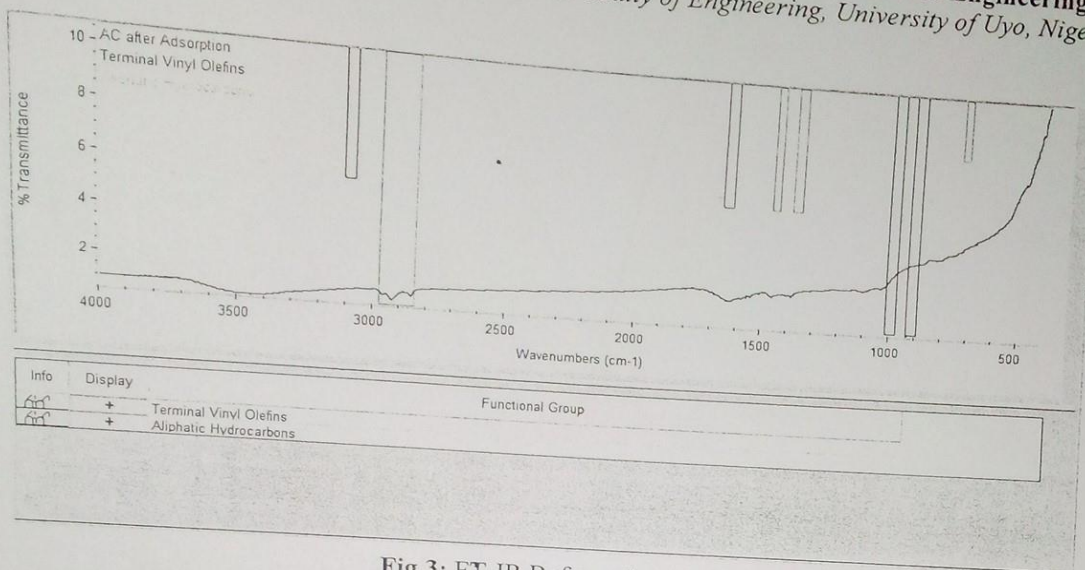
Fig 3: FT-IR Before adsorption (Zeolite)
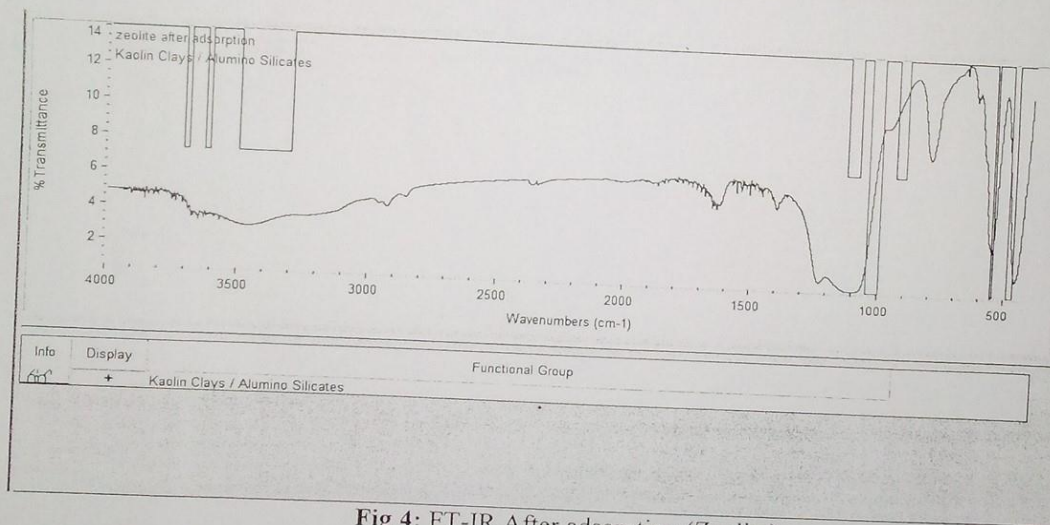
Fig 4: FT-IR After adsorption (Zeolite)

The increase and decrease in the spectrum peaks as seen in Figure 1 – Figure 4 shows how the experimental conditions affect the structure of the material. The peaks assigned in the FT-IR spectrum were assigned to their respective wavenumbers.

Thermogravimetric analysis (TGA)

Figure 5 and 6 shows the thermogravimetric analysis of the adsorbents. In this analysis, the adsorbents are measured continuously while subjected to heating.

In Figure 5, there was a steady decomposition (loss of mass) of the adsorbent. And a rapid loss at a temperature between 220 to 350 $^{\circ}$C. The loss is attributed to the elimination of water absorbed in the pores of the carbon (Mettler Toledo, 2001).
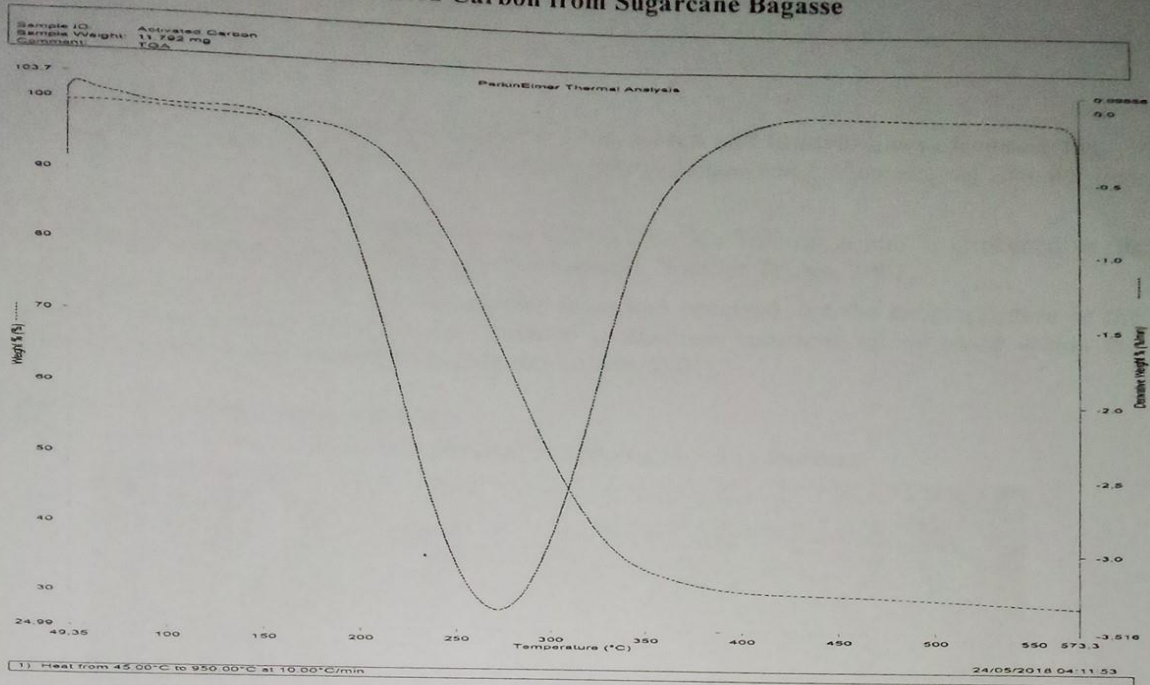
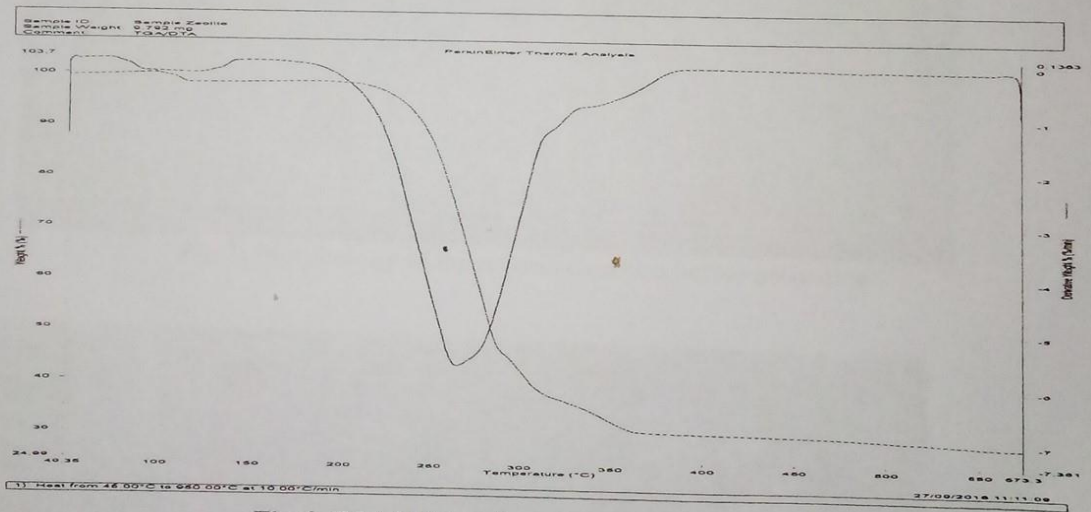**Fig 5:** TGA/DTA before adsorption (Activated carbon)

Fig 6: TGA/DTA before adsorption (Zeolite)

In Figure 6, the mass loss occurred between 300 to 350 °C. This mass loss is attributed to the elimination of water absorbed in the pores of the carbon. (Mettler Teledo, 2001).

In the range of 350 to 550 °C no considerable mass loss occurred, but the decomposition of the material continues. This losses can be attributed to chemical reactions taking place within the adsorbent due to the high temperatures. (Mettler Teledo, 2001).

Scanning electron microscopy (SEM)
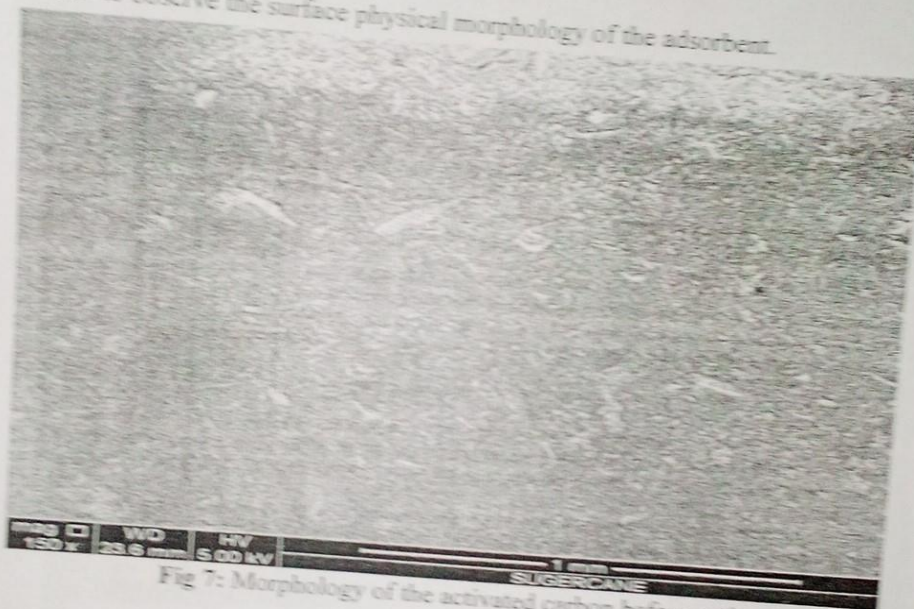SEM was used to observe the surface physical morphology of the adsorbent.

Fig 7: Morphology of the activated carbon before activation

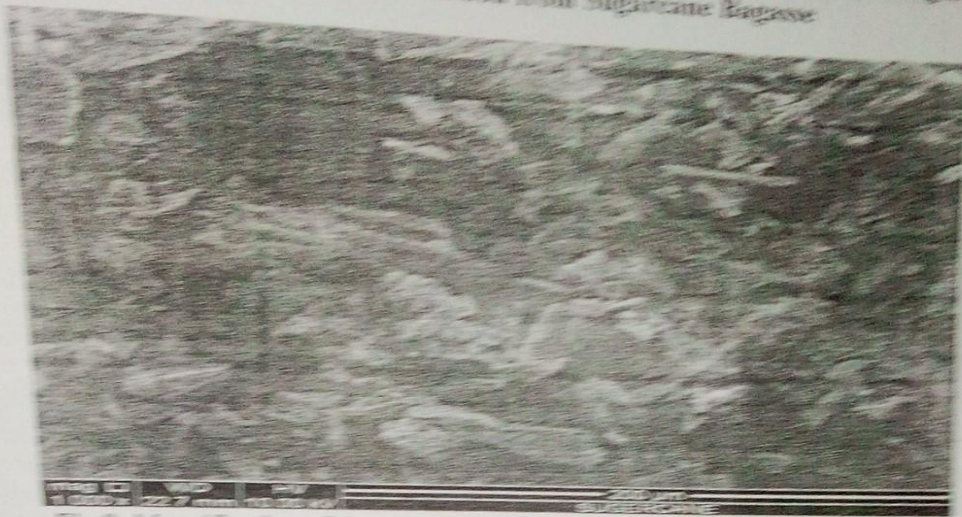Fig 8: Magnification of the activated carbon 500x before adsorption

Fig 9: Magnification of the activated carbon 1000x before adsorption

Fig 10: Magnification of the activated carbon 2000x before adsorption.

SEM analysis is been done to study the physical surface morphology of the activated carbon. Figure 4.26a shows the presence of some flaky structures and pores which are quite poor in porous cavity. Figure 4.26b – Figure 4.26d shows the presence of wide pore from the various variations. The wide pore space is attributed to the activation done on it.
The results obtained from the characterization of the adsorbents before and after the adsorptions using both samples are analyzed and the effect of varying weight and time.

CARBON DIOXIDE SORPTION CAPACITY

As earlier discussed in the methodology; 0.5, 1.0, and 1.5 grams of adsorbents were measured to carry out this experiment. Figure 4.1 - 4.3 shows clearly the relationship between the adsorbent (activated carbon) dosage and the quantity of CO_2 adsorbed at different time interval of 10, 20, 30, 40, 50 and 60 minutes, and Figure 4.4 – 4.6 shows the relationship between the adsorbent (zeolite) dosage and the quantity of CO_2 adsorbed at different time interval of 10, 20, 30, 40, 50, and 60 minutes. From the graphs (Fig 4.1 - 4.6) below, it is noticed that the quantity of CO_2 adsorbed increases as the time of adsorption increases, and the optimum weight in this experiment as seen is 1.5 gram. This is because high weight result in high adsorption. And this will continue as the weight further increases because the more the adsorbent the more the active site for the adsorbent and the more CO_2 adsorbed (Alhassan et al., 2016).
For the activated carbon at the first flow rate of 1L/Min, there was a steady increase of the CO_2 adsorbed as time and weight increases. This is because the CO_2 have enough time to be adsorbed into the surface of the activated carbon. This will continue until all the active sites of the activated carbon is occupied (Alhassan et al., 2016). For the second and third flow rate of 2L/Min and 3L/Min respectively, there was a steady increase of CO_2 adsorbed until the 40th minute where there was a slight drop in the CO_2 adsorbed, which could be attributed to environmental to conditions such as temperature, and this reduces the amount of CO_2 adsorbed. Equilibrium occurred at the 50th minute in the three different flowrates as seen in the graph (Figure 4.1 – 4.3), which is as a result of all the available active sites of the activated carbon been occupied by the CO_2 gas.
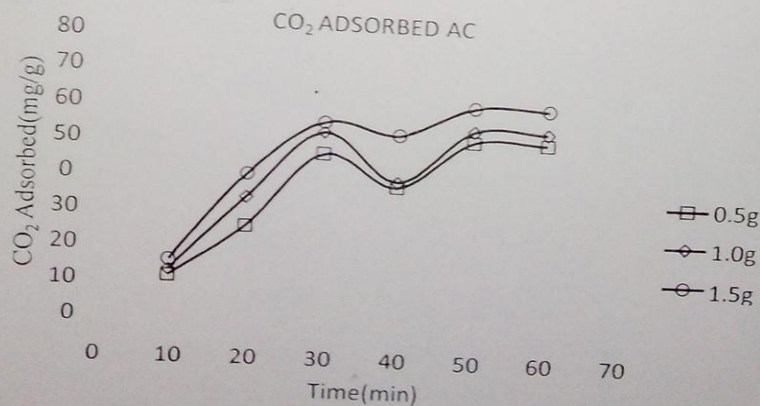

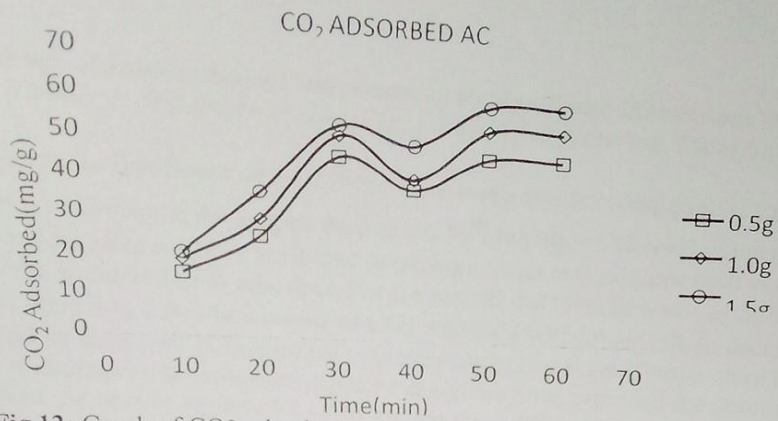Fig 11: Graph of CO2 adsorbed against time at 1L/Min (Activated Carbon)

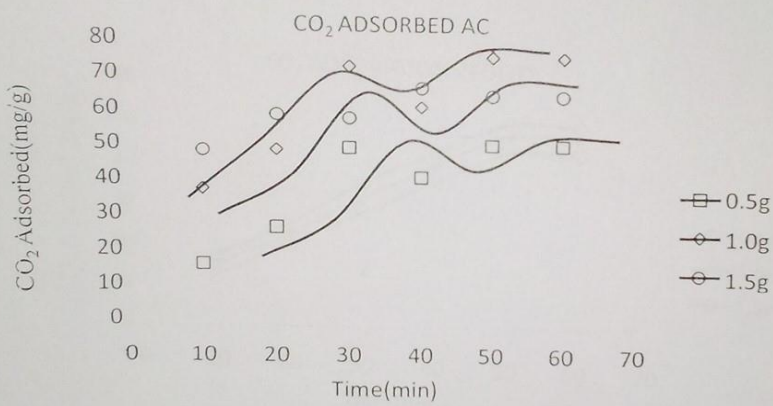**Fig 12**: Graph of CO2 adsorbed against time at 2L/Min (Activated Carbon)

Fig 13: Graph of CO2 adsorbed against time at 3L/Min (Activated Carbon)

For the zeolite at the first flow rate of 1L/Min, there was a steady increase of the CO_2 adsorbed with a little variation resulting in the sudden drop at the 50th minute which marked the equilibrium point as well, the sudden drop could be attributed to environmental to conditions such as temperature, and this reduces the amount of CO_2 adsorbed. For the second and third flow rate of 2L/Min and 3L/Min respectively, there was a steady increase of CO_2 adsorbed without any slight decrease or increase, and this could be attributed to favourable environmental conditions. Temperature has an effect on adsorption; it increases the adsorption capacity at a given time, provided the optimum temperature is not achieved. As seen in Figure (4.4 - 4.6), for the three different flow rates, an equilibrium point was noticed at the 50th minute which is as a result of all the available active sites of the activated carbon been occupied by the CO_2 gas.
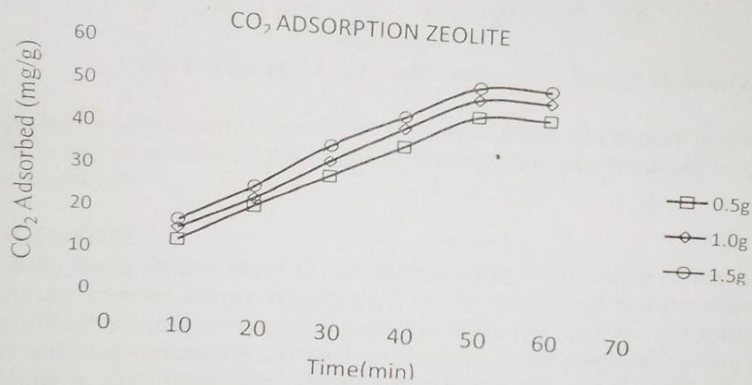

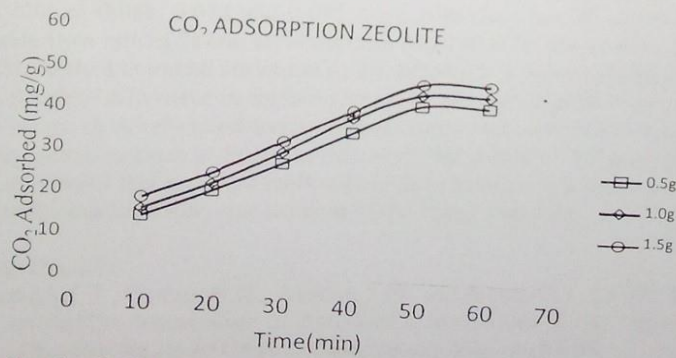Fig 14: Graph of CO2 adsorbed against time at 1L/Min (Zeolite)

Fig 15: Graph of CO2 adsorbed against time at 2L/Min (Zeolite)

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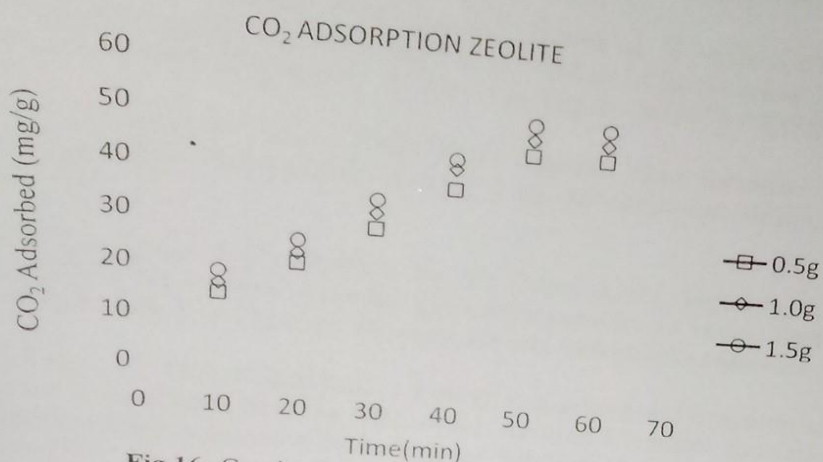

Fig 16: Graph of CO2 adsorbed against time at 3L/Min (Zeolite)

Comparing the adsorption capacity of activated carbon and zeolite in this experiment, activated carbon is said to be have a higher capacity than zeolite, and this could be attribute to the pore size of the adsorbents.

CONCLUSION.

The study demonstrated that CO2 adsorption using combination of natural zeolite and activated carbon can improve energy efficiency. it can be established that the activated carbon is a better adsorbent compared to zeolite when it comes to CO2 capture. From the results of the characterization of the activated carbon, the activated carbon has a better sorption capacity which makes it a better performer in CO2 adsorption. The two adsorbents are good for CO2 adsorption. The adsorption capacity of each of the masses are; 0.057, 0.060, and 0.065 mg/g with flow rate of 1l/min; 0.058, 0.061 and 0.068 mg/g with flow rate of 2l/min, and 0.055, 0.063 and 0.070 mg/g with flow rate of 3l/min at 50 minutes and 298 K for the activated carbon. And 0.048, 0.049 and 0.050 mg/g with flow rate of 1l/min; 0.048, 0.053 and 0.055 mg/g with flow rate of 2l/min and 0.048, 0.051 and 0.054 mg/g with flow rate of 3l/min at 50 minutes and 298 K for the zeolite. The difference in the amount of CO2 adsorbed could be attributed to the difference in pore volume and surface area which could be as a result of difference in surface area.. The adsorption capacities of each mass of the adsorbent loaded are good. A very good and porous activated carbon with a high adsorption capacity produced from sugarcane bagasse and used in this work had a better CO2 adsorption capacity than zeolite, it can be employed that activated carbon in CO2 adsorption is a better performer than zeolite for both commercial and laboratory use because of the larger pore size.

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