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Full Length Article

Comparison of adsorption capacity of mono-ethanolamine and di-ethanolamine impregnated activated carbon in a multi-staged fluidized bed reactor for carbon-dioxide capture

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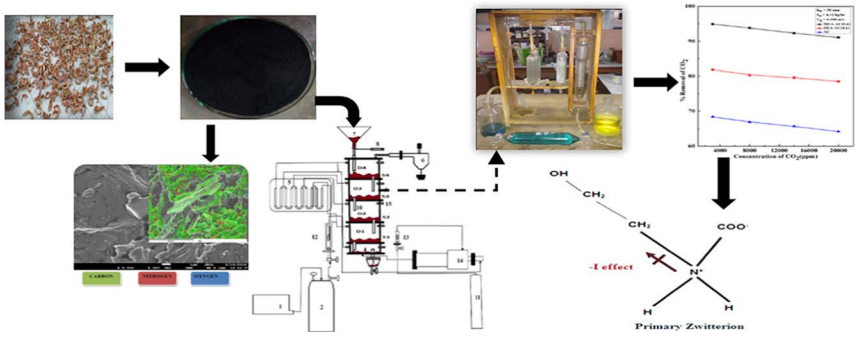
GRAPHICAL ABSTRACT



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ABSTRACT

The increase of carbon dioxide (CO_2) concentration in the atmosphere leads to global warming and climate change. In our present study, a four stage fluidized bed reactor has been designed and developed for removal of CO_2.Two different amine impregnated activated carbons have been prepared and used as adsorbents for capture of CO_2. By changing the three hydrodynamics factors like gas velocity, solid flow rate and weir height, the highest percentage (%) removal of CO_2 has been found out. Sampling and analysis has been performed by using Orsat apparatus. Among the two adsorbents i.e. Monoethanolamine impregnated activated carbon (MEA-AC) and Diethanolamine impregnated activated carbon (DEA-AC), the % removal of CO_2 by Monoethanolamine impregnated activated carbon of impregnation ratio 0.6 (MEA-AC(0.6)) shows the highest, due to high degree stability of primary zwitterions formed than secondary zwitterions.Monoethanolamine impregnated activated carbon (MEA-AC) shows the highest % removal of CO_2 (95%), at minimum gas velocity (0.188 m/s), maximum solid flow rate (4.12 kg/h) and at maximum weir height (50 mm) at initial concentration of CO_2, 3000 ppm. MEA impregnated activated carbon was found to be suitable adsorbent for removal of CO_2 from the flue gas in a multistage fluidized bed reactor.

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1. Introduction

In the recent past the concentration carbon dioxide (CO_2) in the atmosphere increases time to time due to various industrial activities. Fossil fuel combustion leads to emissions of large amount CO_2 which causes a serious effect in relation to global warming and climate change [1]. Different separation technology like absorption, adsorption, cryogenic distillation, and membrane separation have been studied in the literature [2–4], which are used for removal of CO_2 from gas streams. To regenerate the solvent by absorption method, it requires high temperature [5–10]. The disadvantages associated with this process leads to corrosion because of degradation of the solvent by the process of oxidation. In the case of adsorption, by the use of solid sorbents, it leads to greater adsorption capability and breakthrough time which avoids corrosion and evaporation problems. At low temperature, the adsorbents can be regenerated [11]. From the literature, it has been studied that due to its large surface area and porosity, activated carbons (ACs) are very good adsorbents for gas adsorption [12–14]. The simple ACs has some draw backs i.e., the capacity of ACs decreases at high temperatures, and in the presence of water and other gases, the selectivity for CO_2 is poor. To overcome the negative phenomena, amine modified adsorbents are developed, that enhances the removal of CO_2 [9,15–19]. From the literatures, it has been studied that the fluidized bed reactor operating at different regimes can be used as suitable equipment for removal of flue gas at high temperature [20,21], but, at low temperature the efficiency of the reactor decreases. So to avoid the disadvantage of a single stage continuous fluidized bed reactor, multistage continuous fluidized bed reactor having staging effects has been used which enhances separation efficiency [22]. The counter current multistage system is an improvement over the co-current flow system. Here the solids enter at the top and move down from section to section through the down comers and finally leave from the bottom. The gas enters at the bottom and moves upward contacting the solids in each stage and finally leaves at the top. Due to the multiple contacting the solid product is more uniform. The residence time distribution has a definite improvement in counter current flow than co-current flow. In addition net driving force is better for counter-current flow than that of co-current flow. It has been studied from the literature [22,23–27] that the multistage fluidized bed reactor with down comer and counter current flow of fluid and solid has been used, for recovery of gaseous pollutants from industry.

The objective of this research is to study the effect of amine impregnated activated carbon adsorbents for enhancing the adsorption separation of CO_2 from flue gas stream and then to find out the best among them for removal of CO_2 inside the four- staged fluidized bed reactor.

2. Materials and methods

2.1. Preparation of sorbent

Fresh green coconut shells were collected from Technology market of IIT Kharagpur and then cut into small pieces. Those shells were washed with normal water for removal of dirty material adhere to it and then kept in the sunlight for 15–20 days till it becomes completely dry as shown in Fig. 1. Dried coconut shells were placed inside the hot air oven maintained at temperature 105 °C for 48 h for moisture removal & other volatile impurities present in it. The samples were crushed& sieved to a size of 512 μm followed by chemical activation with $ZnCl_2$. The powdered sample materials were mixed properly in the mechanical shaker for 2 h and placed inside the hot air oven at 105 °C for 36 h. The dried chemical impregnated samples were placed inside a galvanized iron container and kept inside the furnace for 1 h. The carbonization temperature that has been maintained inside the muffle furnace was 650 °C under the nitrogen flow rate of 120 $cm^3\,min^{-1}$ STP. After cooling the sample with nitrogen gas, all the material has been taken out from the furnace. It was washed with 0.5 N HCl followed by warm distilled water to remove any kind of residual organic & mineral matter present in it. The final step was washing with cold distilled water till the solution becomes neutral. All the samples were dried for 48 h at 105 °C inside a hot air oven till it was completely dried. Final sample that has been obtained was activated carbon (AC).

Fig. 1. Green coconut shell.

2.2. Preparation of Diethanolamine impregnated activated carbon (DEA-AC) and monoethanol amine impregnated activated carbon (MEA-AC)

The dried AC was impregnated with Diethanolamine solution (HO-CH_2-CH_2-NH-CH_2-CH_2-OH) and Monoethanolamine solution (OH-CH_2-CH_2-NH_2) in different impregnation ratio (0.2–0.6). The amine-impregnated AC was dried in the hot air oven at temperature 105 °C for 48 h till it became dry and kept inside an air tight container for the experimental purpose. Fig. 2 shows the amine impregnated AC.

3. Characterization of adsorbents

The adsorbent used for removal of CO_2 in our experimental set up were AC and amine impregnated AC(MEA-AC and DEA-AC). The adsorbents were characterized by using Proximate and Ultimate Analysis, Accelerated Surface Area and Porosimetry analyzer (ASAP2020), Thermo Gravimetric Analysis (TGA), Scanning Electronic Microscope (SEM) and Fourier Transfer Infrared Spectroscopy (FTIR).

3.1. Proximate and ultimate analysis

From proximate analysis, it has been observed that the fixed carbon content of AC and amine impregnated AC was very high, which results in better adsorbent for adsorption purpose. The proximate and ultimate analysis results were shown in Table 1. From Table 1, it was observed that, the carbon content of AC was 77.91%. The carbon content of MEA-AC (0.4), MEA-AC (0.6), DEA-AC (0.4) and DEA-AC (0.6) were 70.634%, 71.24%, 69.991% and 70.51% respectively.

It has been seen that due to the amine impregnation the wt% nitrogen content of the amine impregnated ACs samples were more as compared to AC and the raw precursor. Among the two activated carbon, the wt% of nitrogen for MEA-AC (0.4) was more i.e. 7.66% while less in case of DEA-AC (0.6) i.e. 4.87%.

3.2. Surface area and pore size distribution

The micropore surface area, total surface area, and micropore volume for amine impregnated AC, AC and raw precursor has been shown in Table 2. The external surface areas consist of the mesopores and