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Synthesis and Evaluation of MgO-Supported Activated Carbon for Carbon dioxide Capture

J. Madhavi *

Department of Chemistry, Government Degree College (Autonomous) Paloncha, Bhadradri

Kothagudem, Telangana.

Corresponding author: E-mail: madhavi0521@gmail.com

Abstract

Carbon dioxide (CO_2) capture has emerged as a critical strategy for mitigating greenhouse gas emissions and addressing global climate change. In this study, a series of MgO-supported activated carbon adsorbents containing 2, 4, 6, 8, and 10 wt% MgO were successfully synthesized using the impregnation method to evaluate their CO_2 adsorption performance. The structural, chemical, and surface properties of the prepared materials were characterized using powder X-ray diffraction (PXRD), Fourier-transform infrared (FT-IR) spectroscopy, nitrogen (N_2) adsorption–desorption isotherms, and elemental analysis. CO_2 adsorption experiments were conducted in a fixed-bed reactor under ambient conditions at atmospheric pressure and 30 °C to assess the adsorption capacities of the synthesized adsorbents. Among the prepared samples, the adsorbent containing 8 wt% MgO exhibited the highest CO_2 adsorption capacity of **125 µmol/g**, outperforming the other MgO loadings due to its optimal dispersion of active MgO sites and favorable pore structure. In addition to its high adsorption efficiency, the 8 wt% MgO-supported activated carbon demonstrated excellent cyclic stability, maintaining its adsorption capacity over 10 consecutive adsorption–desorption cycles without any noticeable loss in performance. These results indicate that an appropriate MgO loading significantly enhances the CO_2 capture ability of activated carbon while preserving its structural integrity and reusability. The findings highlight the potential of 8 wt% MgO-supported activated carbon as a cost-effective, efficient, and durable adsorbent for practical carbon capture applications in industrial gas purification and environmental protection.

Keywords: MgO, Activated carbon, CO_2 capture, fixed bed adsorption, Recyclability

1. Introduction

The emission of CO_2 into the atmosphere increases with the consumption of fossil fuels, automobiles, petrochemical industries, and power plants, causing global warming [1]. The concentration of CO_2 is reached to 460 ppm, which is higher than the pre-industrial level of 300 ppm. Stabilizing atmospheric CO_2 will require drastic emission reductions. Nearly half of the emitted CO_2 will remain in the atmosphere for centuries. Therefore, it is essential to develop

capture technologies to reduce CO_2 concentrations. Capture technologies are broadly classified into chemical/physical solvent scrubbing, adsorption, cryogenic, and membrane techniques [2-4]. CO_2 capture by solvent scrubbing causes equipment corrosion and high energy consumption for regeneration, whereas cryogenic and membrane technologies are expensive to design. Among these techniques, adsorption is the most widely adopted one for the capture of CO_2 [5-6].

Porous materials such as carbon, zeolites, and silica are useful for gas adsorption and separation. Activated carbon is a porous carbon used for gas adsorption, separation, and energy storage because of its high surface area [7-8]. Carbon dioxide has a Lewis acidic nature and accepts electrons from Lewis bases [9-11]. The presence of basic functional groups and metal oxides can enhance the adsorption of CO_2. However, amine functional groups on activated carbon block the pores [12-13]. To improve the adsorption of CO_2, basic metal oxides such as nickel oxide, copper oxide, magnesium oxide, and calcium oxide have been used [14-17].

In this study, we synthesized MgO supported on activated carbon using the impregnation method and characterized it using X-ray diffraction (XRD), N_2 adsorption-desorption isotherms, Fourier-transform infrared (FT-IR) spectroscopy, and elemental analysis. We also studied its CO_2 adsorption at atmospheric pressure at 30 °C and recyclability for up to 10 cycles.

2. Experimental

2.1 Materials

Magnesium nitrate hexahydrate ($Mg(NO_3)_2.6H_2O$, 99%) and activated carbon were purchased from Sigma-Aldrich. Nitric acid (HNO_3, 69-72 %) and ammonia (NH_3, 25%) were purchased from S.D. Fine Chemicals Pvt. Ltd. India. Laboratory-prepared double-distilled water was used for the synthesis of the adsorbent. N_2 gas (UHP, 99.999%) and 10% CO_2 balanced helium were purchased from BOC, India.

2.2 Synthesis of MgO supported on activated carbon

Prior to the preparation of MgO supported on activated carbon (AC) using the impregnation method [18]. AC was purified with hot concentrated HNO_3, hot distilled water, hot concentrated NH_3, and hot distilled water up to four cycles to remove impurities, and finally dried at 100 °C overnight [19]. The desired quantity of magnesium nitrate hexahydrate was dissolved in double-distilled water, 1 g of purified activated carbon was added, stirred for 1 h, and then dried at 100 °C for 12 h. The dried material was calcined at 450 °C for 4 h in N_2 flow and labelled as X wt% MgO/AC, where X = 2, 4, 6, 8, and 10 wt percentage.

2.3 Characterizations

X-ray diffraction patterns were recorded on Rigaku X-ray diffractometer Ultima-IV having Ni filtered Cu Kα radiation in the scan range from $2\theta = 10 – 80°$ with scan speed 2°/min, step size 0.01°/sec having tube voltage 40 KV and current 30 mA. N_2 adsorption-desorption isotherms were obtained at 77 K using a Quantachrome Quadrasorb SI surface area analyzer after evacuating the sample at 473 K for 12 h. Multipoint Brunauer-Emmet-Teller (BET) surface area was measured in the relative pressure range 0.05-0.30, total pore volume was determined at a relative pressure of 0.95, micropore volume was determined by t-plot method.

2.4 CO_2 adsorption study

Approximately 0.2 g of the sample was placed in a micro reactor with a 3 mm i.d. and 250 m.m quartz reactor and treated at 500 °C for 2 h in helium flow to remove physisorbed gas and moisture. Finally, the mixture was cooled to room temperature for the adsorption of CO_2. The outlet of the reactor was connected to a gas chromatography GC 7820 A GC system (Agilent Technologies, Switzerland) with a thermal conductivity detector with a Porapak Q column (3 m length and 3 mm ID). After pre-treatment, 10% CO_2 balanced helium was injected by pulses using a six-port valve with a 250 µl loop until the sample was saturated at room temperature. The sample was flushed with helium at the same temperature for 1 h to remove physisorbed CO_2 gas. Subsequently, the temperature was increased to 800 °C at a ramping rate of 10 °C/min in helium flow. The desorbed CO_2 gas was monitored using TCD and GC software. For recyclability, the completely desorbed sample was again treated with 10% CO_2 balanced helium gas to study the stability of the CO_2 adsorption capacity up to 10 cycles.

3. Results and discussions

Fig 1 shows the XRD patterns of MgO supported on activated carbon (AC). The peak at 24.6° corresponds to the activated carbon peak. Loading from 2 to 8 wt% of MgO, no diffraction peaks related to MgO indicates it was well dispersed on activated carbon and which is not detectable limit of XRD range. Similar results were obtained for iron oxide-doped MCM-41 [20]. In 10wt% MgO/AC sample exhibited well-defined diffraction peaks for MgO.

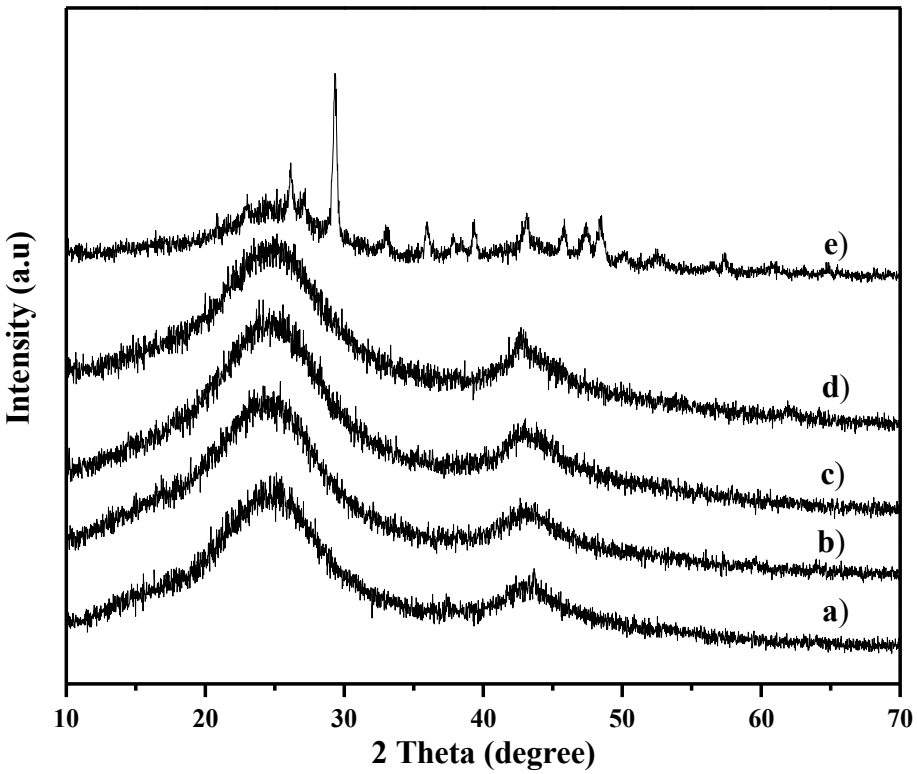

Fig. 1: XRD patterns of a) 2wt% MgO/AC, b) 4wt% MgO/AC, c) 6wt% MgO/AC, d) 8wt% MgO/AC and e) 10wt% MgO/AC

Fig 2 shows the N_2 adsorption–desorption isotherms of MgO supported on AC, and the textural properties are shown in Table 1. 2wt% MgO/AC had a surface area of approximately 624 m^2/gm with a total pore volume of 0.345 cm^3/gm. As the loading increased, the surface area decreased to 345 m^2/gm and the total pore volume decreased to 0.205 cm^3/gm, indicating that some of the pores were blocked by MgO. Similar phenomena have been observed for La_2O_3 supported on Si-MCM-41 [21].

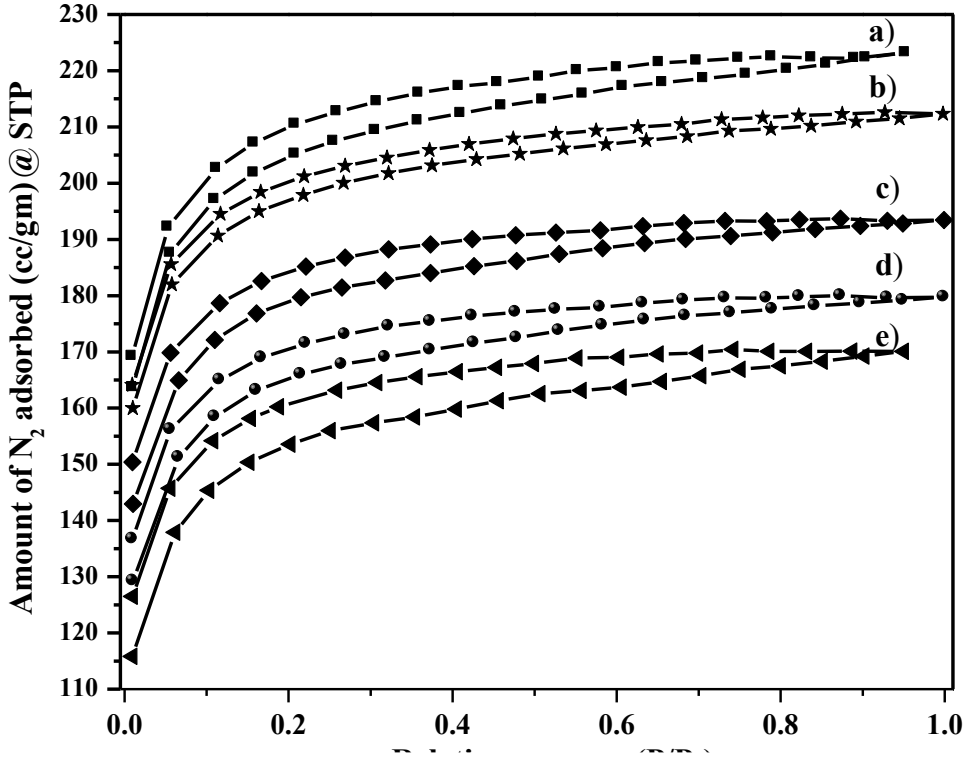

Fig. 2: N_2 adsorption-desorption isotherms of a) 2wt% MgO/AC, b) 4wt% MgO/AC, c) 6wt% MgO/AC, d) 8wt% MgO/AC and e) 10wt% MgO/AC

Table 1: Textural properties of MgO supported on AC

Sample	S_{BET}[a] (m^2/gm)	Pore size [b] (n.m)	V_{total}[c] (cm^3/gm)	V_{micro}[d](cm^3/ gm)	V_{micro}[e] (%)	CO_2 adsorbed (µmol/gm)
2wt% MgO/AC	624	2.21	0.345	0.294	85	34.5
4wt% MgO/AC	587	2.23	0.328	0.290	88	52.5
6wt% MgO/AC	493	2.25	0.278	0.243	87	96.9
8wt% MgO/AC	470	2.24	0.263	0.250	95	125
10wt% MgO/AC	345	2.18	0.205	0.180	87	41

[a]BET surface area

[b] Average pore size by BET method

[c]Total pore volume at relative pressure of P/P0 = 0.95

[d]Micro pore volume by t-plot method

[e] Micro pore volume (%) = V_{micro}/ V_t

3.2 CO_2 adsorption on MgO/AC

Fig 3 shows the temperature-programmed desorption of CO_2 from MgO supported on AC. In all MgO-loaded samples, the desorption peak at 100 – 200 °C indicates low basic sites whereas in 8wt% MgO/AC has a desorption peak at 350-450 °C indicates moderate basic sites. This is attributed to the high adsorption of CO_2 compared to the other samples. In this sample, MgO was well-dispersed on the activated carbon, and the maximum number of basic sites was

responsible for the high CO_2 capture. In 10wt% MgO/AC, the bulk nature of MgO and the fewer number of sites resulted in a lower adsorption capacity.

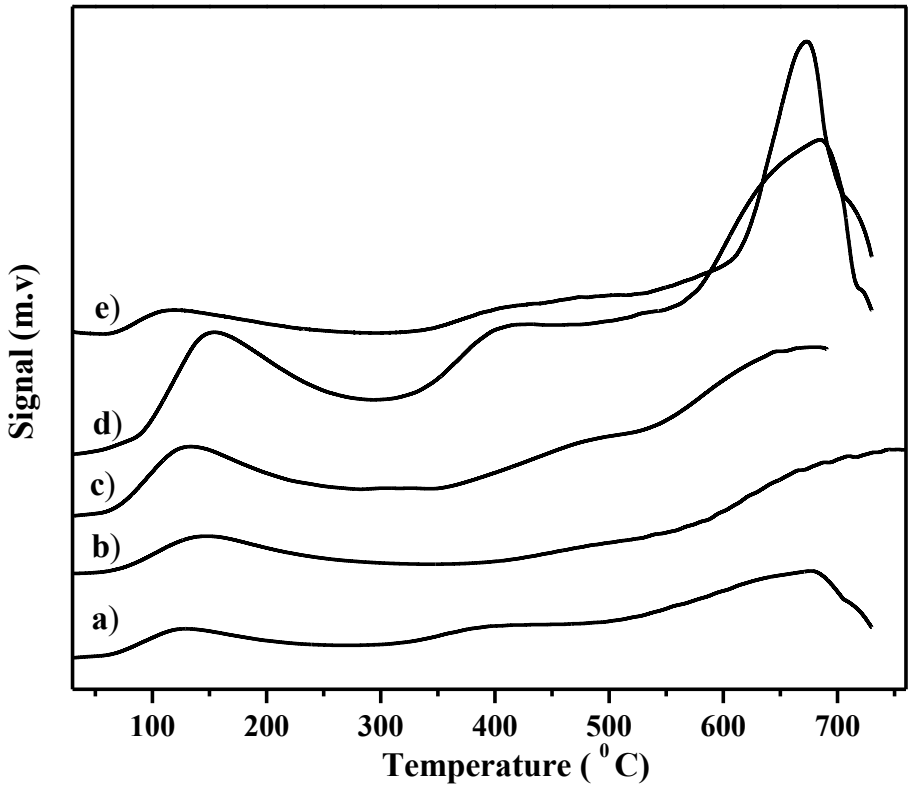

Fig. 3: NH_3- TPD patterns of a) 2wt% MgO/AC, b) 4wt% MgO/AC, c) 6wt% MgO/AC, d) 8wt% MgO/AC and e) 10wt% MgO/AC

The adsorption capacities of MgO supported on AC are shown in Table 1, and the corresponding adsorption capacities are 34.5 µmol/gm, 52.5 µmol/gm, 96.9 µmol/gm, 125 µmol/gm, and 41 µmol/gm, respectively. The recyclability of 8wt% MgO/AC was studied for up to 10 cycles at room temperature, as shown in figure 4. 8wt% MgO/AC exhibited good stability without loss of adsorption capacity.

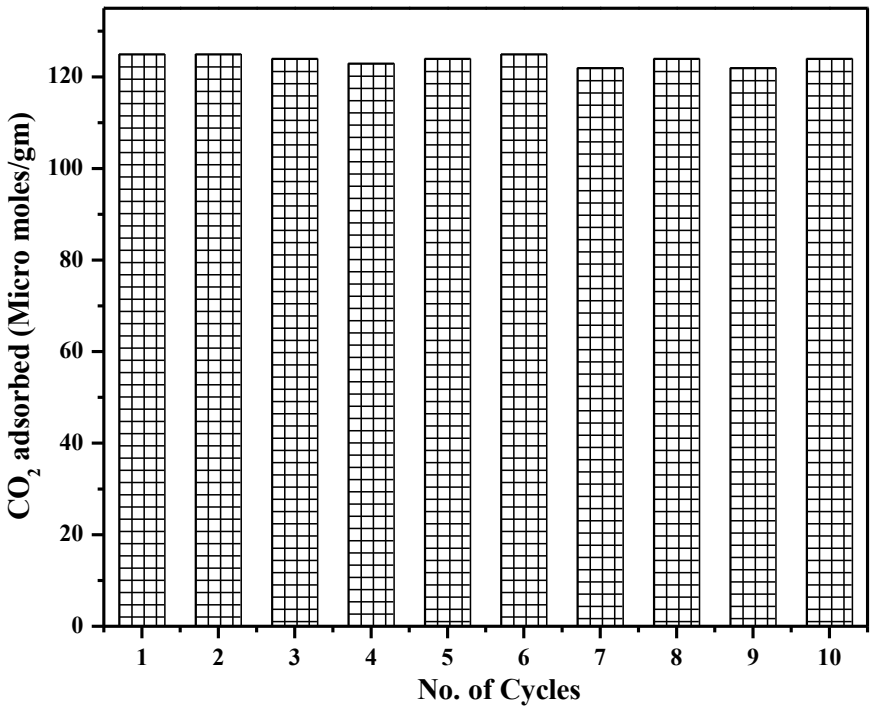

Fig. 4: Recyclability of 8wt% MgO/AC at 30 °C

4. Conclusion

The CO_2 adsorption of MgO supported on activated carbon was studied, and the results revealed that 8wt% MgO/AC had a high adsorption capacity of 125 μmol/g at 30 °C compared to the remaining samples. High basic strength and a large number of micropores are responsible for high adsorption. It exhibited good stability for up to 10 cycles without loss of adsorption capacity. Finally, it is a prominent metal oxide-supported activated carbon adsorbent for CO_2 capture for industrial use.

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