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CO_2 Capture on Lanthanum Oxide–Modified activated Carbon

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Abstract

A series of La_2O_3 catalysts supported on activated carbon, with varying loadings of 2, 4, 6, 8, and 10 wt%, was synthesized via the impregnation method. The characterization of these samples was performed using powder X-ray diffraction (PXRD) and N_2 adsorption-desorption isotherms. Carbon dioxide capture experiments were conducted using the fixed-bed method under room temperature and atmospheric pressure conditions. Notably, the catalyst with 10 wt% La_2O_3 incorporated activated carbon exhibited a high adsorption capacity of 119 µ.mol/g at 30^{0}C

Keywords: La_2O_3, activated carbon, CO_2 capture, fixed bed adsorption

1. Introduction:

The urgent development of carbon capture and storage (CCS) technologies has been driven by anthropogenic CO_2 emissions, with adsorption on solid materials emerging as a cost-effective, low-energy alternative to conventional amine scrubbing [1-3]. Among the solid sorbents, activated and porous carbons prepared from biomass materials are attractive because of their high surface area, tunable porosity, hydrophobicity, and low regeneration energy [4-5]. Surface modification with metal oxides, amines, and heteroatom dopants further enhances CO_2 uptake and selectivity [6-7]. Metal oxide impregnation enhances CO_2 capture through physisorption and chemisorption [8-10]. Incorporating basic inorganic metal oxides into porous carbon enhances chemisorption efficiency via acid–base interactions with CO_2 [7].

Among the single and binary metal oxides, CuO-modified biomass-derived activated carbon achieved 6.78 mmol g^{-1} at 1 bar and 30 °C, a 124.5% enhancement over unmodified carbon, demonstrating the synergistic potential of the combined physisorption–chemisorption mechanisms [8]. The incorporation of MgO into activated carbon nanofibers yielded the highest surface area (413 $m^2\ g^{-1}$) and micropore volume (0.1777 $cm^3\ g^{-1}$) among the MgO, MnO_2, ZnO, and CaO variants, translating to the highest CO_2 uptake of 60 $cm^3\ g^{-1}$ at 298 K [11]. Alkali and alkaline-earth metal oxides (MgO and CaO) form thermodynamically stable carbonates with CO_2, enabling chemisorptive capture [12]. At elevated pressures, Fe_3O_4-modified pyrolytic coke composites reached 71.96 mmol g^{-1} at 5 bar and 298 K, with the Langmuir model confirming strong monolayer chemisorption [13]. In the present study, La_2O_3-incorporated activated carbon was used for CO_2 adsorption.

2. Materials and methods:

Lanthanum nitrate hexahydrate [La $(NO_3)_3 \cdot 6H_2O$, 99.9%] and activated carbon were procured from Sigma-Aldrich, India, and utilized without additional purification. Distilled water served as the medium for synthesizing the adsorbents. High-purity gases, including carbon dioxide, nitrogen, and helium, were obtained from BOC, India.

2.1 Synthesis of La_2O_3 incorporated activated carbon adsorbents:

The specified quantities of lanthanum nitrate hexahydrate and activated carbon were introduced into distilled water and subsequently heated to 100°C to produce the dried material. This material was then calcined at 600°C for duration of 3 hours under a nitrogen gas flow. The resulting product was designated as X wt% La_2O_3/AC, where X represents 2, 4, 6, 8, and 10 wt%.

2.2 Characterization:

X-ray diffraction patterns were taken using a Rigaku Ultima-IV X-ray diffractometer with Ni filtered Cu Kα radiation at 40 kV and 30 mA. The scan range was 2θ = 10 - 80° with a step size of 0.02°/sec. A Micrometrics ASAP 2020 porosity analyzer measured N2 adsorption-desorption isotherms at 77 K. Before measuring the N_2 isotherms, about 0.1 g of the sample was degassed at 200 °C for 6 hours under vacuum. The specific surface area was calculated using the BET method, total pore volume at a relative pressure of 0.95, micropore volume by the t-plot method, and mesopore size by the BJH method.

2.3 CO_2 adsorption study:

About 0.2 g of the sample was placed in a microreactor with a 3 mm inner diameter and a 250 mm quartz reactor. It was heated to 500 °C for 2 hours in a helium flow to remove any gas and moisture that were physically adsorbed. The mixture was then cooled to room temperature for CO2 adsorption. The reactor's outlet was connected to a gas chromatography system (GC 7820 A, Agilent Technologies, Switzerland) with a thermal conductivity detector and a Porapak Q column (3 m long and 3 mm ID). After pre-treatment, 10% CO_2 in helium was injected in pulses using a six-port valve with a 250 µl loop until the sample was saturated at room temperature. The sample was then flushed with helium at the same temperature for 1 hour to remove any physically adsorbed CO_2 gas. Next, the temperature was increased to 800 °C at a rate of 10 °C/min in a helium flow. The desorbed CO_2 gas was monitored using a thermal conductivity detector and GC software.

XRD

La_2O_3 supported on activated carbon is shown in Fig. 1. The La_2O_3/AC materials exhibit diffraction peaks characteristic of lanthanum oxide, which are observed even at lower loadings.

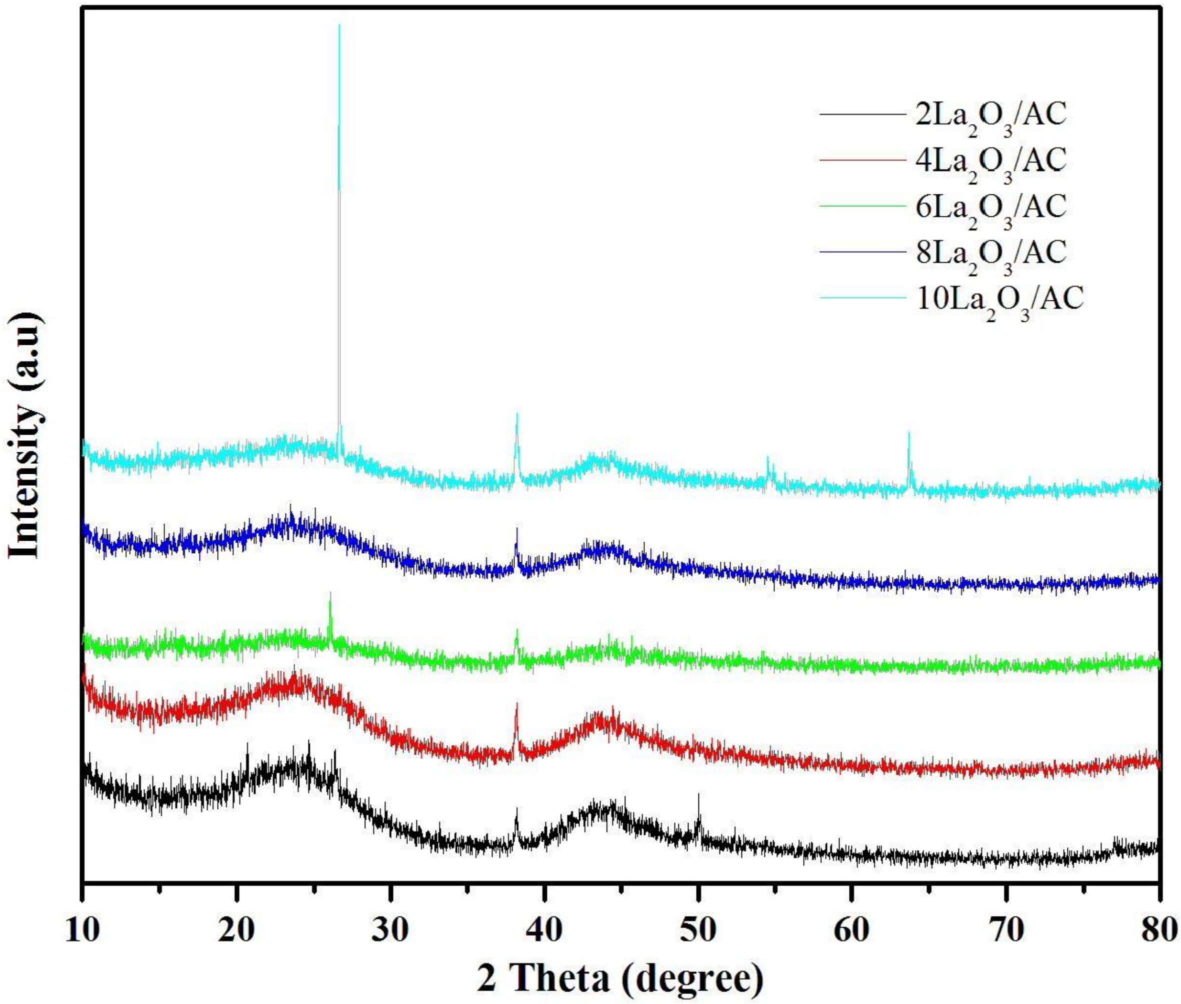

Fig 1: XRD patterns of La_2O_3 incorporated activated cabon catalysts

N_2 adsorption- desorption isotherms:

N_2 adsorption desorption isotherms of La_2O_3 supported on activated carbon and textural properties were shown in table1. 2wt% La_2O_3/AC has shown surface area about 826 m^2/gm with total pore volume of 0.5 cm^3/gm. As the loading of La_2O_3 increases to 10wt%, surface area decreased to 613 m^2 /gm and total pore volume to 0.37 cm^3/gm which indicates some of the pores were blocked by La_2O_3.

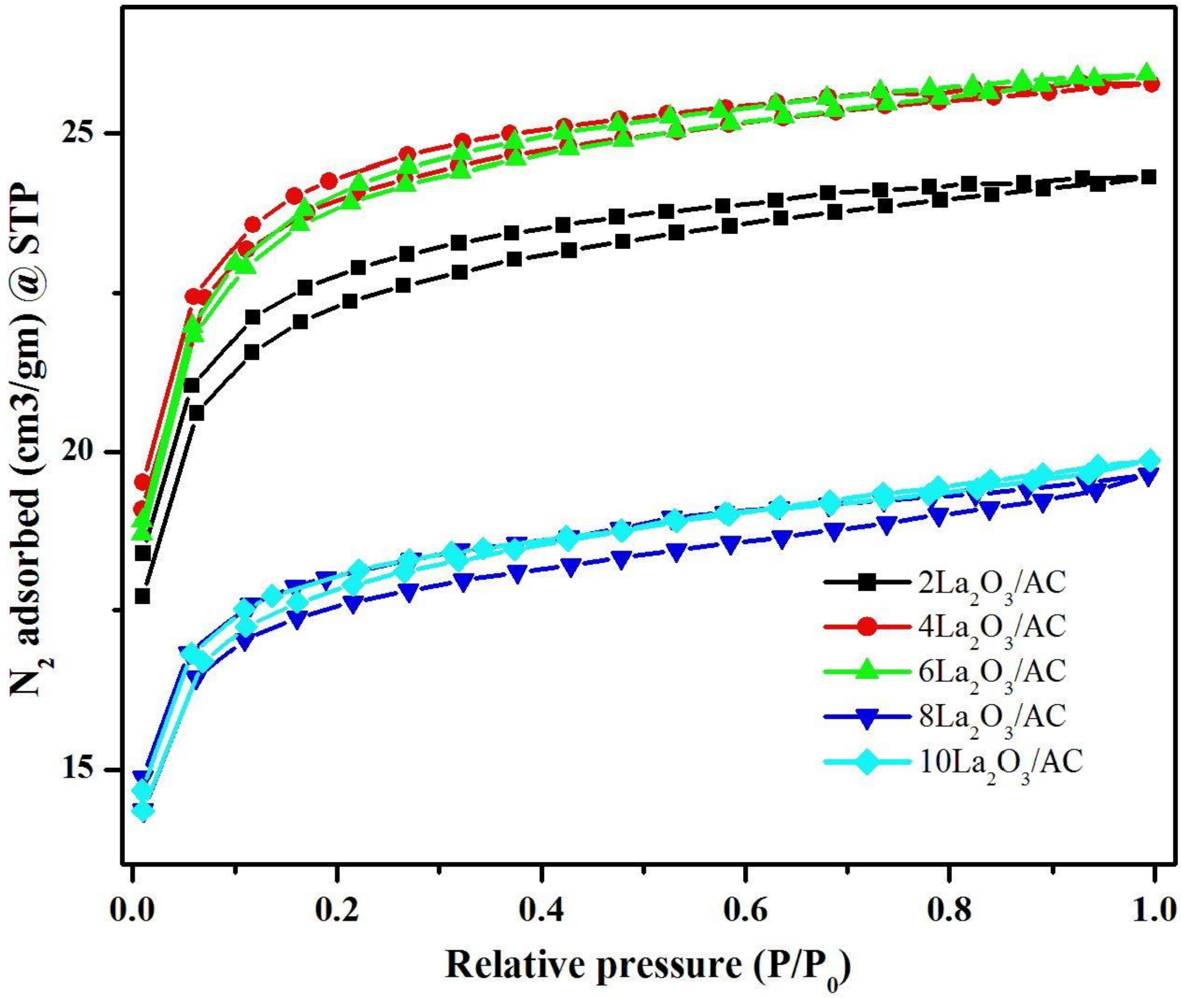

Fig 2: N_2 adsorption isotherms of La_2O_3 incorporated activated carbon catalysts

Table : 1 Textural properties of La_2O_3 supported on AC

Adsorbent	Surface area [a] (m^2/gm)	Total pore volume [b] (cm^3/gm)	Pore size [c] (n.m)
$2La_2O_3$/AC	826	0.50	3.2
$4La_2O_3$/AC	659	0.39	3.2
$6La_2O_3$/AC	793	0.46	3.1
$8La_2O_3$/AC	681	0.41	3.0
$10La_2O_3$/AC	613	0.37	3.2

[a] Multipoint BET surface area
[b] Total pore volume at relative pressure of 0.99
[c] Pore size from BJH adsorption

Figure 3 illustrates the adsorption capacities of activated carbon incorporated with La_2O_3 at various loadings. The adsorption capacities were measured as follows: 12 μmol/g for $2La_2O_3/AC$, 72 μmol/g for $4La_2O_3/AC$, 77 μmol/g for $6La_2O_3/AC$, 109 μmol/g for $8La_2O_3/AC$, and 119 μmol/g for $10La_2O_3/AC$. Notably, the adsorption capacity of $10La_2O_3/AC$ was particularly high.

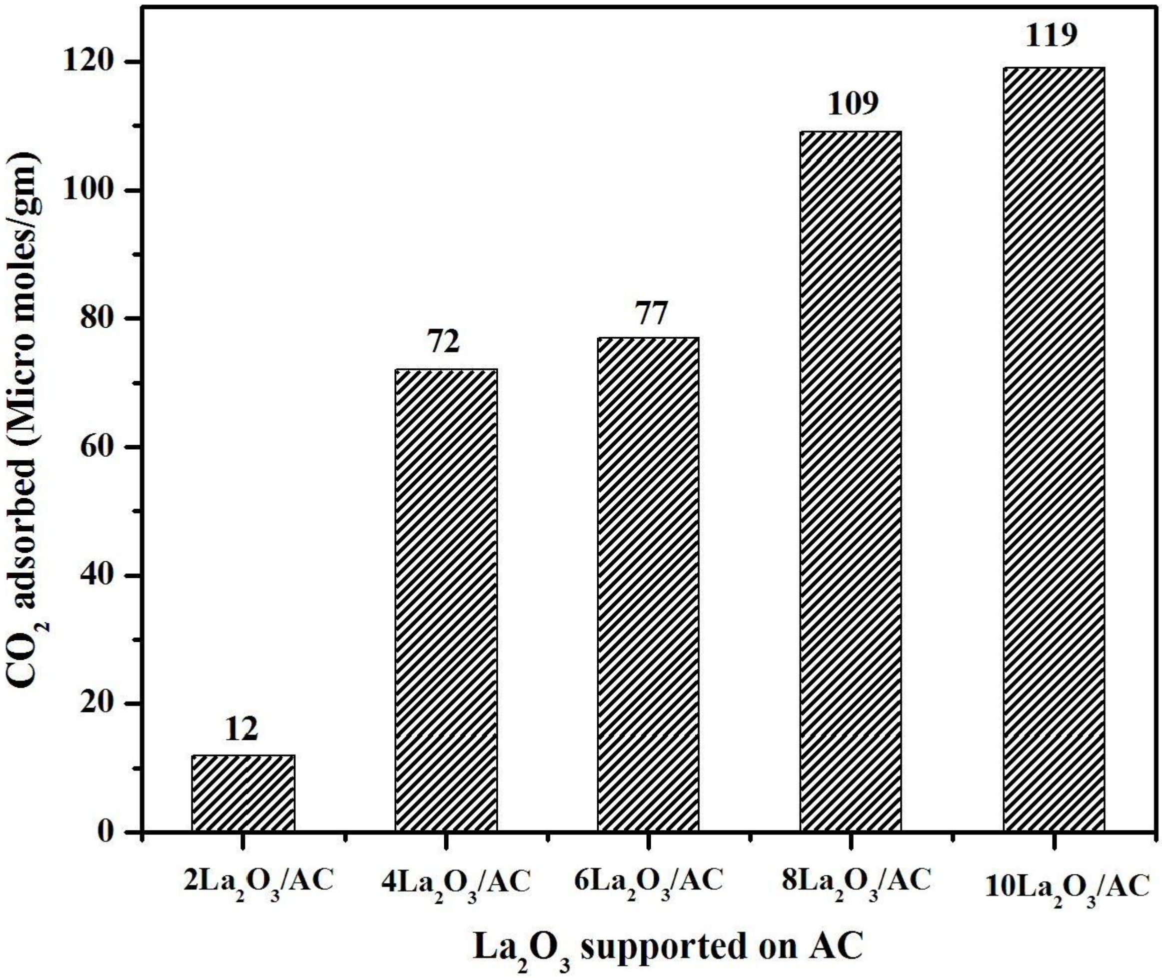

Fig 3: CO_2 adsorption capacity of La_2O_3 incorporated activated carbon catalysts

3. CONCLUSIONS:

The CO2 adsorption of La_2O_3 supported on activated carbon was studied, and the results revealed that 10wt% CaO/AC had a high adsorption capacity of 119 μmol/g at 30 °C compared to the remaining catalysts. High basic strength and a large number of micropores are responsible for the high adsorption

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