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Synthesis, Characterization and CO_2 Adsorption Performance of a Novel POM-132@MOF-5 Composite for Carbon Capture Applications

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Abstract

Developing efficient materials that can absorb carbon dioxide (CO_2) is crucial in the battle against climate change and in reducing greenhouse gas emissions. In this study, a new type of material called POM-132@MOF-5 was made using a simple one-step method. This material combines a polyoxometalate and a metal-organic framework. The composite mixes the large surface area and porous design of MOF-5 with the special redox and oxygen-rich features of POM-132, with the goal of improving CO_2 adsorption performance. The made materials were analyzed using four techniques: Fourier Transform Infrared Spectroscopy (FTIR), X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM), and Energy Dispersive X-ray Spectroscopy (EDS). FTIR and XRD tests showed that POM-132 was successfully added to the MOF-5 structure without damaging either part. SEM images showed a well-organized structure with evenly spread particles. EDS analysis confirmed that the composite contains the elements zinc, molybdenum, carbon, and oxygen. CO_2 adsorption tests were done using a special machine at a temperature of 273 K, and we varied the pressure between 0.5 and 2.5 bar. The POM-132@MOF-5 mix showed that it can hold 25 millimoles of CO_2 for each gram at a pressure of 2.5bar. This means it can absorb CO_2 well and that its ability to do so depends on the pressure. The better performance comes from the combined effect of POM-132 and MOF-5, which adds more active sites and helps with effective gas absorption. The results demonstrate that POM-132@MOF-5 might be an excellent candidate for carbon trapping and contributing positively to ecological health.

Keywords: Metal–Organic Frameworks; Polyoxometalates; POM-132@MOF-5; Hybrid Composite; Carbon Dioxide Capture; CO_2 Adsorption

1. Introduction

Important category of porous materials known as Metal Organic Framework with a variety of applications in fields like gas storage, separation, and catalysis. MOFS possess a highly ordered atomic structure, with atoms arranged in a repetitive pattern, strength and exceptional properties. MOFs are known for their unique combination of high strength and light weight, making them suitable for various applications. They have ultrahigh spaces (up to 90% of the total volume) within a material. The surface area MOFs is more than 6,000 square meters per gram. MOFs, known for their exceptional flexibility in both organic and inorganic aspects, have the potential to play a crucial role in the development of clean energy sources in the future [1]. Traditionally, synthetic chemistry based on discovery has created solids with exceptional characteristics like high porosity[2]. These materials possess various properties, including their high porosity, varying compositions, adjustable pore structure, and diverse range of functions[3]. The use of new MOFs as catalysts is restricted due to their limited effectiveness and instability [4].

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Polyoxometalates (POMs) can be described as clusters consisting of metal oxides. Beginning of the discovery, the first cluster of a compound called (NH4)3[PMo12O40] nH2O was found for the first time by Berzelius[5]. However Due to the difficulty in comprehending the POM structure, significant progress was not achieved until Keggin unraveled the structure of H3PW12O40 in 1934[6]. These structures are changing a lot, not only in how they are made, but also in how they are used in different things like medicine and the environment[7]. These substances have groups of MO6 units (where M can be V, Nb, Mo, W) arranged in a certain way. The metal in the compound usually has an electronic configuration of either d0 or d1, which means it is in its highest oxidation state[8]. The size of the outer layer of MOFs allows for enhancing the qualities of MOFs by mixing them with other types of species[9]. Incorporating a newfound element into the MOF structure enhances its properties, which can be beneficial in a multitude of ways. This partnership can happen between different parts of a material called MOF, such as the node, linker, or spaces, and it involves adding certain elements or compounds[10].

In 2005, Férey and his team were the first to report a POM@MOF hybrid[11]. The POMs are incorporated in MOFs to form composite. In a crucial study, scientists were able to confine a compound called POM within the extensive voids of MIL-101, a remarkably resilient substance. They achieved this by using a method called impregnation. The POM compound has a specific size, measured in Angstroms (Å), which is (13.1 Å). So far, numerous stable MOFs have been utilized as hosts for POMs in catalysis. Examples of these are MIL, UiO, ZIF series, NU-1000, and various others. The structures of Cu-BTC are formed by combining copper (Cu) with a compound called BTC. The foremost inspected POMs that have been typified into MOFs are the well-known Keggin [XM12O40]n− and Dawson [X2M18O62]n−. These compounds are made up of elements like Si, P, V, Bi, and M, which can be V, Mo and W, etc. POMs and their derivatives are compounds or substances that are related to these elements. These POMs are very important because their structure and properties can be changed by taking away one or more MO4+ parts, resulting in POMs like [PW9O34]9−, or by replacing X and M with other metals or a mix of two parts of the Keggin structure, resulting in sandwich-type POMs like [Tb (PW11O39)2]11−.

By altering Polyoxometalates (POMs) into metal-organic frameworks (MOFs), new avenues for research can be pursued, particularly in the catalysis realm, providing a wide range of opportunities. POM/MOF composites possess high acidity levels. POMOFs possess specific properties that contribute to their effectiveness as catalysts in fundamental organic reactions. They possess proficiency in converting substances and possess the autonomy to choose the specific reactions they are involved in[12].

Using MOFs as a containment method for POMs offers numerous advantages. The surface area of the MOF host is exceptionally large while its spaces are relatively small, facilitating the even dispersion of POM throughout. By preventing the POMs from sticking together, this also improves their stability and facilitates their recyclability. It also helps substances move in and out quickly. MOFs possess cages and windows that maintain a high level of consistency, thereby regulating the entrance of particular substances to the active POM sites. Thirdly, when the MOF and POM work together, they interact and transfer electrons well, resulting in a higher level of successful collaboration and improved catalytic performance. The chemical environment of POMs can be readily modified or enhanced by adjusting or appending functions to MOFs. The integration of POMs and MOFs in POM@MOF hybrids serves to improve catalysis by incorporating the advantages of each material while addressing the limitations of POMs. Alongside the POM@MOF systems discussed here, where the POMs are encapsulated inside a MOF host, POM-based MOFs have also been investigated. The metal nodes in these MOFs are formed by the POMs and are then linked together by organic linkers[13]. By combining Polyoxometalates with metal-organic frameworks, a distinct composition of materials with specific qualities is formed. POMs combine their potent acidity, oxygen-enriched surface, and propensity for chemical reactions as they address issues such as difficult handling, limited surface area, and susceptibility to water dissolution [14].

To the best of our knowledge, the synthesis and CO_2 adsorption performance of a POM-132@MOF-5 composite have not been previously reported. Therefore, this work focuses on the preparation, characterization, and evaluation of a novel POM-132@MOF-5 hybrid material for carbon capture applications. First, the MOF host has very large surface areas and restrictive spaces that allow for an even spread of POM within it. POM@MOF composites combine the features of Polyoxometalates and Metallic Organic Framework, and they solve the issues of Polyoxometalates to provide better catalysis. This research is about POM@MOF hybrids and how they are made. Additionally, it examines the potential applications of these hybrids in various forms of catalysis, including organ catalysis, electrocatalysis, and photocatalysis. Along with discussed POM@MOF composites involving insertion of Polyoxometalates within MOF hosts, we have also analyzed MOFs that are built entirely based on POMs. In Metal Organic Framework, Polyoxometalates make real metal unit which are connected by organic linkers[13].

Currently, many strong and stable Metal Organic Framework were employed to trap Polyoxometalates. Some examples include MIL, UiO, and ZIF series, as well as NU-1000 and Cu-BTC frameworks. The most common method to put Polyoxometalates in Metal Organic Framework by impregnation. Impregnation is an easy and uncomplicated process because most Polyoxometalates dissolve easily in solvents that have positive and negative charges. Usually, the actuated Metallic Organic Framework powder is put in the Polyoxometalates solution to make the composite material. We have made different types of POM@MOF hybrids via impregnation method. Some examples are POM@MIL, POM@ZIF, and POM@UN-1000. To use this technique, Polyoxometalates should smaller than Metallic Organic Framework windows. Furthermore, it was observed that increasing the POM concentration in a water solution did not lead to additional improvement in POM loading for some POMs and MOFs once a particular threshold was reached. For instance, if the POMs are larger than the pentagonal windows of MIL-101(Cr), they will fit inside the big hole. The other cages, which make up 2/3 of all the cages in MIL-101(Cr), will be left empty. Naseri and his colleagues proposed that adding more sandwich-type POM [(HOSnOH)3(PW9O34)2]12− (15.2 Å × 10.4 Å) to water would not enhance the POM loading[15].

The impregnation method is not suitable for MOFs such as Cu-BTC, UiO, and ZIF, which have smaller pores than POMs. So, to make the POM@MOF composite, a method called "One pot synthesis" is used for these MOFs. This method is also known as "bottle-around-the-ship" synthesis. One pot synthesis is a common way to make Polyoxometalates-encapsulated Metallic Organic Framework. In this method, POM helps remove hydrogen from the organic carboxylate ligand. To make POM@MOF composite, we typically use the same conditions as when we make the regular MOF, but with the addition of POM. One pot synthesis is a way to make POM@MOFs composite that cannot be made through impregnation method. This method can also put POMs inside the MOF cages to stop them from leaking if Polyoxometalates are larger than the openings in the Metal Organic Framework.

Encapsulating POMs inside MOFs has been the topic of a number of good studies. The generated composites have been employed as electro catalyst, photo catalyst, oxidative desulfurization catalysts, lithium storage catalysts, adsorption catalysts, and other processes[16].

The world's most critical concern now are environmental sustainability and global climate preservation. The topic of global warming caused by CO_2 emissions has now become a primary concern. To solve this issue, numerous CO_2 capture and sequestration (CCS) systems have been produced. Metal Organic Frameworks (MOFs) have been discovered as the most current and promising material for CO_2 adsorption and separation. Because of their exceptional qualities, this novel class of porous materials has demonstrated a clear potential for gas separation technologies, particularly CO_2 storage and separation[17]. CO_2 chemistry has received a great deal of interest in recent decades as a plentiful, low-cost, and renewable carbon source. Under mild temperatures, CO_2 natural stability made its utilization a daunting issue. CO_2 fixation has recently made tremendous progress thanks to the use of cheap and abundant functionalized Polyoxometalates (POM) catalysts. The future of POM catalysis for sustainable chemistry lies in the synthesis of highly functionalized task-specific POM catalysts, as well as the logical design of innovative reactions, which would pave the way for the construction of green, effective, low-cost, and long-lasting technologies[18].

Although numerous POM@MOF hybrid materials have been reported for catalysis and adsorption applications, the utilization of POM-132 incorporated into MOF-5 for CO_2 capture remains largely unexplored. Therefore, the present work aims to synthesize a novel POM-132@MOF-5 composite and investigate its structural characteristics and CO_2 adsorption performance.

In this study, we created a new material called POM-132@MOF-5 using a simple one-step method. We also analyzed it carefully using different techniques like FTIR, XRD, SEM, and EDS. Also, the ability of the created composite to hold CO_2 was tested using a special device that measures gas volume. The better ability to hold onto substances seen in the hybrid material comes from the strong combination of the very porous MOF-5 structure and the oxygen-rich areas offered by POM-132. This study presents a new material made from POM and MOF that can help capture carbon. It shows how this material could be useful for improving the environment and reducing greenhouse gases.

2. Experimental

2.1. Materials

The chemicals involved in this research were top-quality and were used as received, without further purification. Zinc nitrate hexahydrate, terephthalic acid, dimethylformamide, chloroform, hydrazine sulfate, ammonium heptamolybdate tetrahydrate, ammonium acetate, acetic acid, ethanol, and diethyl ether were used to make MOF-5, POM-132, and the POM-132@MOF-5 mixture. We used distilled water for making solutions and for cleaning during the experiments.

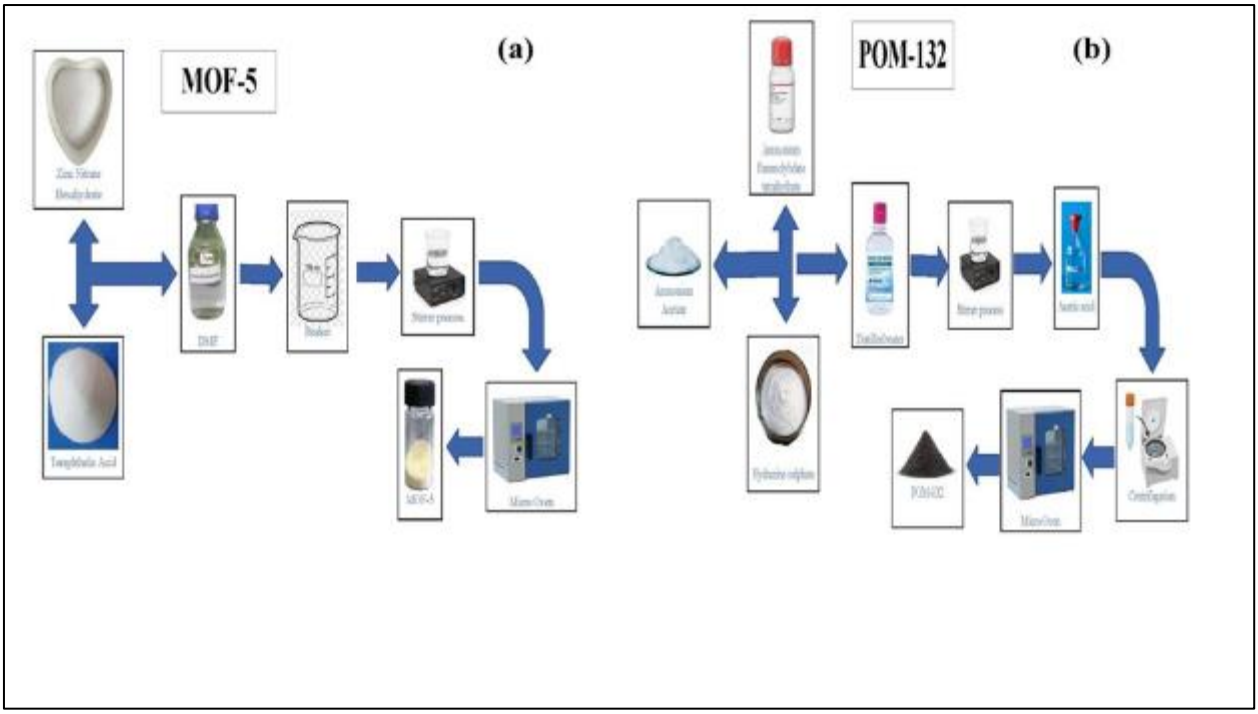

Figure 1 Synthesis of MOF-5 and Synthesis of POM-132

2.2. Synthesis of MOF-5

MOF-5 crystals were prepared by the method reported in the literature[19]. Uniform size of MOF-5 crystal is synthesized by using terephthalic acid (BDC, +99.9 o/o), Zinc nitrate hexahydrate and Dimethylformamide as organic solvent. All chemicals were purchased from commercial suppliers and used without further purification. In synthesis, the solvent DMF was used as a solvent. The solvent DMF was first degassed by argon for 60 min and Zn (NO3)2·6H2O, 2g) and terephthalic acid (H2BDC, 1g) were dissolved in (40ml) DMF solvent. The mixture was quickly transferred to a 100mL glass vial and sealed. The glass vial was then heated to 403K (129.85o F) in oven and held for 4 hours under autogenous pressure by Solvothermal synthesis. After the reaction, the vial was taken out of the oil bath and cooled down to the room temperature naturally. The cubic-like crystals of colorless powder were isolated by filtration and washed thoroughly with DMF in order to remove the unreacted zinc nitrate. After that, the crystals were immersed in chloroform (50 mL), sealed tightly, and put into the oven at 343 K for 3 days. During the heating process, the solvent was decanted and replenished every day. Finally, the sample was dried under vacuum at 363 K overnight and stored in a desiccator until it was used as shown in the figure 1a.

2.3. Synthesis of POM-132

In The 100ml flask, the hydrazine sulfate (1gram) was added drop wise to stirrer the mixture of (NH4)6Mo7 O24 0.4H2O (10gram) and ammonium acetate (15 gram) in 100ml distilled water. After 10 mints, to the formed blue-green solution, 80ml of acetic acid was added, and at this point, the mixture color turned green. The rest solution was aged for 4 days at 250C to form a red brown precipitate. The precipitate was collected by centrifugation. Finally washed with ethanol and diethyl ether to obtained POM-132 as shown in the figure 1b [20].

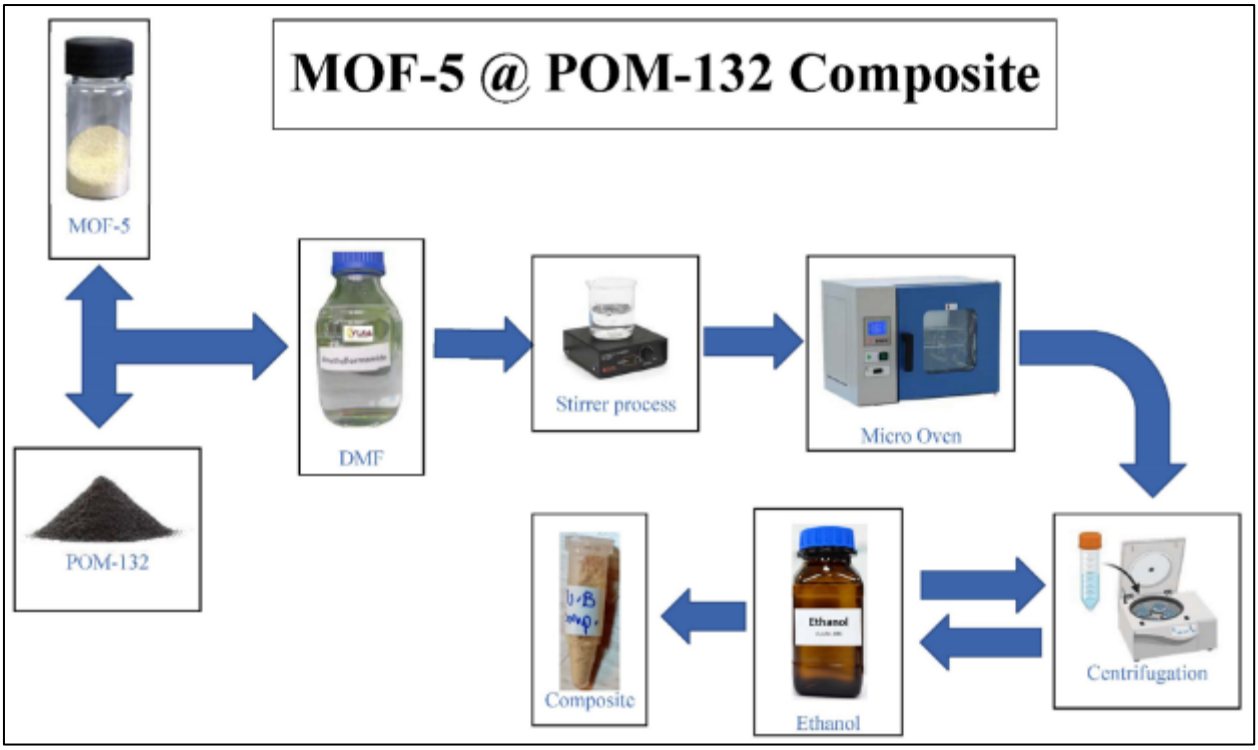

Figure 2 Synthesis of POM-132@MOF-5

2.4. Synthesis of POM-132@MOF-5

This is the newly synthesized composite of MOF-5 and POM-132 in fig 2. The POM-132@MOF-5 composite was synthesized by dispersing 1 g of MOF-5 and 1 g of POM-132 in 10 mL of DMF under continuous stirring. After the mixing, the solution was stirred for 30 minutes with Temperature up to 80oC that the MOF-5 and POM-132 were mixed completely. Finally, the solution was kept in the oven for two hours that the DMF will evaporate completely and the red brown powder was obtained.

2.5. Characterization

The synthesized MOF-5, POM-132, and POM-132@MOF-5 composite were comprehensively characterized using X-ray diffraction (XRD), Fourier-transform infrared (FTIR) spectroscopy, and scanning electron microscopy (SEM) to evaluate their structural integrity, chemical composition, and morphological features. XRD analysis confirmed the successful formation of highly crystalline phases and demonstrated that the characteristic framework of MOF-5 was preserved following the incorporation of POM-132. FTIR spectroscopy further verified the presence of the essential chemical functionalities associated with both components, providing evidence of the successful integration of POM-132 within the porous MOF architecture. In addition, SEM analysis revealed distinct morphological characteristics for the individual materials and demonstrated that the composite retained the fundamental structural features of MOF-5 while exhibiting a homogeneous distribution of POM-132 throughout the framework. The combined results obtained from XRD, FTIR, and SEM analyses provide strong evidence for the successful synthesis of the POM-132@MOF-5 composite and confirm the effective interaction between the polyoxometalate species and the metal–organic framework without compromising their structural stability.

2.6. CO_2 Adsorption Test

The CO_2 adsorption performance of MOF-5, POM-132, and the POM-132@MOF-5 composite was investigated using a Sieverts-type volumetric adsorption apparatus to evaluate their gas capture capabilities under controlled experimental conditions. This technique enables precise determination of the amount of CO_2 adsorbed by monitoring pressure changes within a calibrated system at equilibrium. Prior to adsorption measurements, all samples were activated under appropriate conditions to eliminate residual solvents, moisture, and other guest species from the porous network, thereby maximizing the availability of adsorption sites. The resulting adsorption isotherms were employed to assess the CO_2 uptake capacity and adsorption behavior of the synthesized materials. Furthermore, the volumetric measurements provided valuable insight into the influence of POM incorporation on the textural properties and gas

sorption performance of MOF-5, allowing a comprehensive evaluation of the potential applicability of the POM-132@MOF-5 composite for carbon capture and environmental remediation applications.

3. Results and Discussion

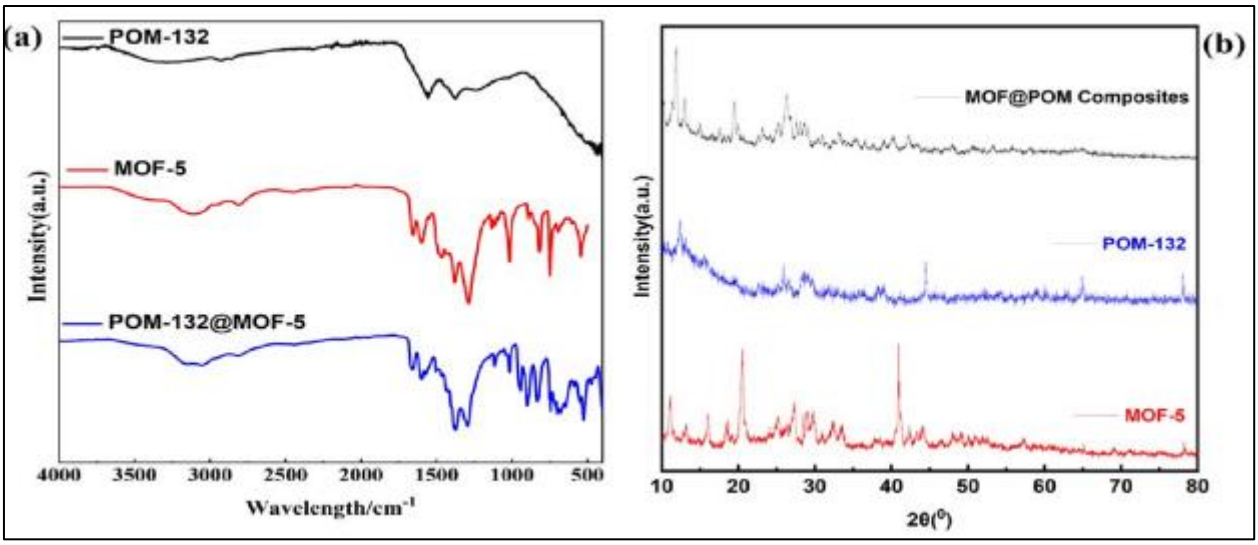

Figure 3 (a) FTIR of MOF-5, POM-132 and MOF-5/POM-132 Composite. (b) XRD of MOF-5, POM-132 and MOF-5/POM-132 Composite

3.1. FTIR

The successful incorporation of POM-132 into the MOF-5 framework was confirmed by FTIR spectroscopy through the coexistence of the characteristic vibrational bands of both constituents in the composite material in fig 3a. The FTIR spectrum of pristine MOF-5 exhibited prominent absorption bands at approximately 1590 and 1385 cm^{-1}, which are attributed to the asymmetric and symmetric stretching vibrations of coordinated carboxylate (COO^{-}) groups originating from the benzene-1,4-dicarboxylate (BDC) linker, thereby confirming the coordination of the organic ligand to Zn^{2+} centers and the formation of the MOF-5 architecture[21, 22]. Moreover, the bands observed within the 750–830 cm^{-1} region are associated with out-of-plane aromatic C–H bending vibrations of the terephthalate linker, which are characteristic of the MOF-5 framework. In contrast, the FTIR spectrum of POM-132 displayed a strong absorption band near 960 cm^{-1} corresponding to terminal metal–oxygen (M=O) stretching vibrations, together with bands centered around 880 and 790 cm^{-1} arising from bridging metal–oxygen–metal (M–O–M) vibrations, which are recognized as the characteristic fingerprint bands of polyoxometalate clusters [23, 24]. Following composite formation, the POM-132@MOF-5 spectrum retained the diagnostic bands of both MOF-5 and POM-132, confirming the successful immobilization of the polyoxometalate species within the porous MOF matrix. Furthermore, slight shifts in band positions accompanied by variations in peak intensity were observed after POM incorporation, suggesting the existence of interfacial interactions between the oxygen-rich polyoxometalate clusters and the coordinatively unsaturated sites of the MOF framework. The simultaneous preservation of the characteristic carboxylate vibrations of MOF-5 and the emergence of the POM fingerprint bands indicate that the structural integrity of the host framework remained largely intact during the encapsulation process while enabling effective incorporation of POM-132 within the MOF pores, thereby leading to the formation of a stable hybrid composite material[2].

3.2. X-Ray Diffraction

The XRD patterns of MOF-5, POM-132, and the POM-132@MOF-5 composite are shown in Fig. 3b. The diffraction pattern of MOF-5 exhibited several characteristic sharp reflections at approximately 2θ = 13°, 17°, 19°, and 25–30°, which are attributed to the highly ordered crystalline framework of MOF-5 and are consistent with previously reported diffraction data for MOF-5 [25]. The sharpness and high intensity of these peaks indicate a high degree of crystallinity and successful formation of the Zn-based metal–organic framework. The XRD pattern of POM-132 displayed distinct diffraction peaks at around 12°, 26°, 29°, 44°, 65°, and 78°, which are characteristic of the crystalline polyoxometalate structure and confirm the preservation of the POM phase[23]. After incorporation of POM-132 into the MOF-5 framework, the POM-132@MOF-5 composite retained the major diffraction peaks of both MOF-5 and POM-132, indicating that the crystal structures of both components remained intact during synthesis. In particular, the persistence

of the MOF-5 peaks near 13° and 17° suggests that the framework was not destroyed during POM loading, while the appearance of POM-related reflections around 26–30° and 44° confirms the successful incorporation of POM-132 within the porous matrix. Furthermore, a slight decrease in peak intensity and peak broadening was observed in the composite compared with pristine MOF-5, which may be attributed to the interaction between POM clusters and the MOF framework, as well as the partial occupation of MOF pores by POM species. Similar observations have been reported for POM/MOF hybrid materials, where the encapsulation of polyoxometalates leads to reduced crystallite size and slight lattice distortion without causing structural collapse [24]. The absence of additional impurity peaks further indicates that no undesirable crystalline phases were formed during composite preparation, confirming the successful synthesis of the POM-132@MOF-5 composite.

3.3. Scanning Electron Microscopy

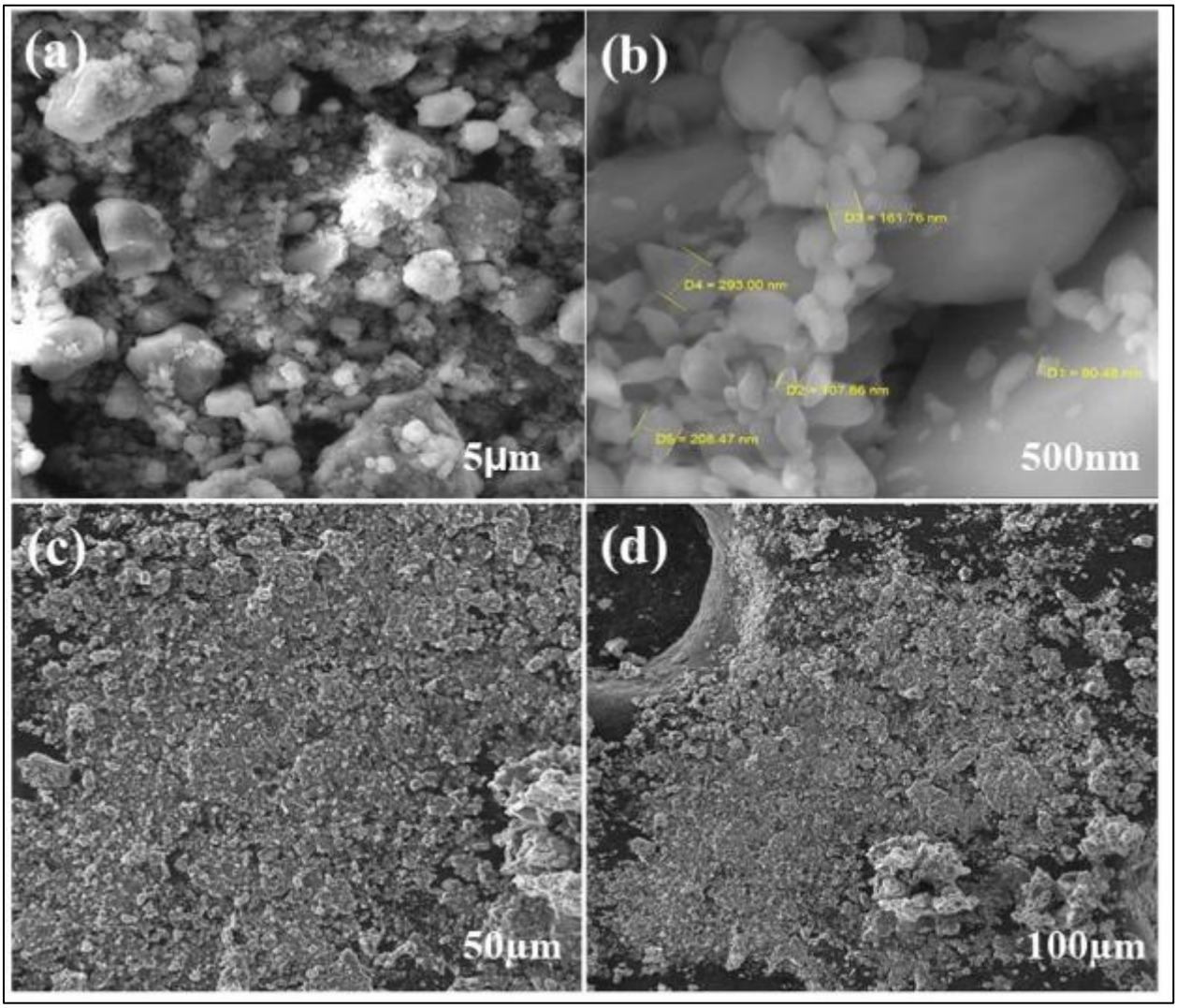

Figure 4 SEM of MOF-5/POM-132 Composite

The morphological characteristics of the POM-132@MOF-5 composite were examined at different magnifications using scanning electron microscopy (SEM), as shown in Fig. 4. At lower magnification, the composite exhibits a relatively uniform distribution of aggregated particles with a well-developed hierarchical architecture, indicating the successful formation of an integrated hybrid material. The preservation of the overall framework morphology suggests that the incorporation of POM-132 did not significantly compromise the structural integrity of the MOF-5 host, which is consistent with previous reports on polyoxometalate-functionalized metal–organic frameworks[25]. At higher magnifications, the surface appears considerably rougher and is composed of densely packed nanoscale domains distributed throughout the framework. The emergence of these fine surface features can be attributed to the successful deposition and dispersion of POM-132 species within the porous MOF matrix, leading to increased surface heterogeneity and a higher density of accessible active sites [26]. Furthermore, the absence of obvious phase separation

or large isolated clusters suggests strong interfacial interactions between the polyoxometalate units and the MOF framework. Such hierarchical micro/nanostructured morphology is advantageous for adsorption applications because it promotes efficient mass transfer, improves the accessibility of adsorption sites, and facilitates stronger interactions with guest molecules[27]. Therefore, the SEM observations provide convincing evidence for the successful fabrication of the POM-132@MOF-5 composite and support its enhanced adsorption performance.

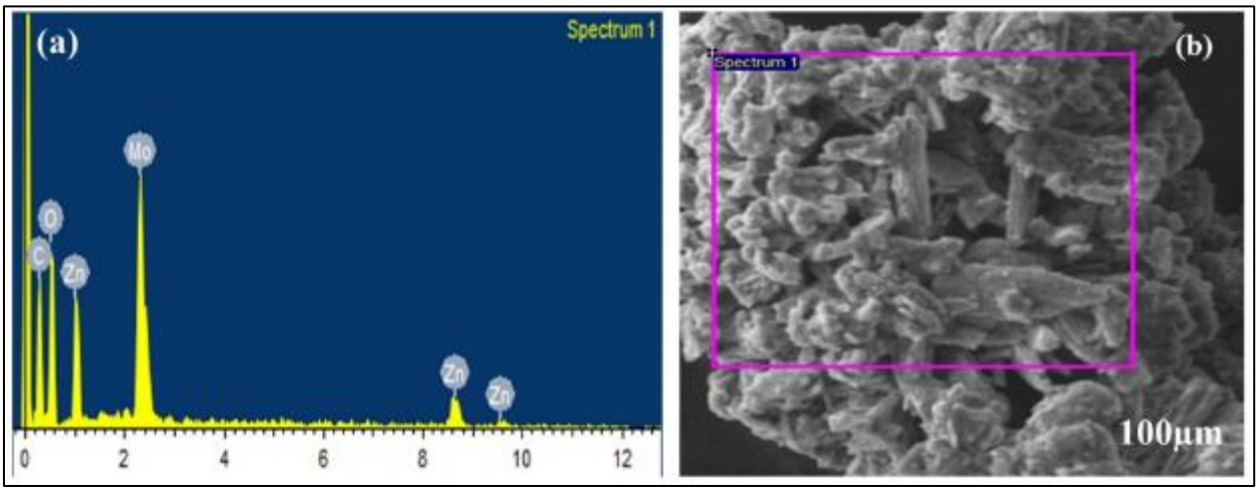

Figure 5 EDS of MOF-5/POM-132 Composite

3.4. Energy Dispersive Spectroscopy of POM-132@MOF-5 Composite

Energy-dispersive X-ray spectroscopy (EDS) analysis was performed to investigate the elemental composition and distribution within the POM-132@MOF-5 composite. The EDS results confirmed the presence of the characteristic elements associated with both MOF-5 and POM-132, demonstrating the successful incorporation of the polyoxometalate species into the metal–organic framework. The detected elemental signals and their homogeneous distribution across the analyzed region indicate effective integration of POM-132 within the MOF-5 matrix without the formation of significant phase segregation. These findings provide additional evidence supporting the successful synthesis of the composite material and complement the structural and morphological analyses obtained from XRD, FTIR, and SEM characterization techniques. The presence of molybdenum confirms successful incorporation of POM-132, while zinc originates from the MOF-5 framework. The coexistence of Mo and Zn signals demonstrates the formation of the hybrid composite structure.

Spectrum processing:

- No peaks omitted
- Processing option: All elements analyzed
- (Normalized)
- Number of iterations = 5

Element	Weight%	Atomic%
C K	37.74	56.63
O K	32.90	37.06
Zn K	8.97	2.47
Mo L	20.40	3.83
Totals	100.00	

"EDS analysis confirmed the presence of C, O, Zn, and Mo, corresponding to the MOF-5 framework and POM-132 clusters, further confirming successful composite formation."

3.5. CO_2 Adsorption Test

The CO_2 adsorption tests were performed by SIEVERT apparatus as in fig 6. To properly evaluate the applicability and reusability of our POM@MOF Composite sample in the CO_2 capture, CO_2 adsorption isotherms at constant 273K and pressure were changed at 0.5bar,10mmol/gm CO_2 were absorbed with catalyst concentration is 0.3mg. At pressure 1bar, 14mmol/gm CO_2 absorbed with catalyst concentration is 0.6mg. When pressure change to 1.5bar,19mmol/gm CO_2 absorbed with catalyst concentration 0.9mg and on increasing pressure to 2bar, 21mmol/gm and 2.5bar, 25mmol/gm CO_2 absorbed with catalyst concentration is 1.2mg and 1.5mg respectively) were measured in static adsorption conditions. The reported values do not represent a change in catalyst composition but correspond to the amount of sample used during each adsorption measurement. The pressure was varied to evaluate adsorption behavior under different operating conditions. It is observed that all isotherms are almost coincident, showing that the adsorption capacity of the POM@MOF Composites increase with increase in pressure at constant temperature. The improved CO_2 adsorption performance obtained in this work could probably be related to a better crystallization of the POM@MOF composites obtained according to our described methodology. The CO_2 uptake increased from 10 mmol g^{-1} at 0.5 bar to 25 mmol g^{-1} at 2.5 bar, indicating pressure-dependent adsorption behavior. The rapid increase in adsorption capacity at lower pressures suggests the presence of abundant accessible adsorption sites within the composite structure. The incorporation of POM-132 may enhance the interaction between CO_2 molecules and the adsorbent surface through the oxygen-rich environment provided by the polyoxometalate clusters. Furthermore, the porous framework of MOF-5 facilitates efficient diffusion of gas molecules, contributing to the observed adsorption performance. The primary objective of this study was to demonstrate the successful synthesis and preliminary CO_2 adsorption performance of the newly developed POM-132@MOF-5 composite. The adsorption capacity obtained (25 mmol g^{-1} at 2.5 bar) indicates promising performance. A detailed comparative investigation with pristine MOF-5 and POM-132 is planned as part of future work to further quantify the contribution of each component.

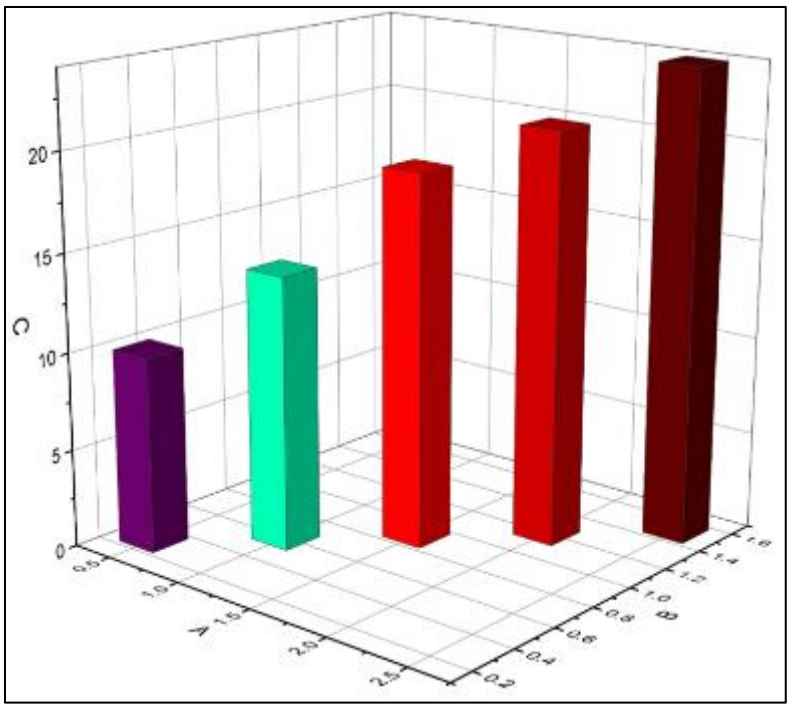

Figure 6 CO_2 Adsorption Graph on POM-132@MOF-5

Temp	Pressure(bar)	CO_2 uptake (mmol/g)	Catalyst Concentration (mg)
273K	0.5	10	0.3
273K	1	14	0.6
273K	1.5	19	0.9
273K	2	21	1.2
273K	2.5	25	1.5

4. Conclusion

A novel POM-132@MOF-5 composite was successfully synthesized and evaluated as an adsorbent material for CO_2 capture. Structural characterization by FTIR, XRD, SEM, and EDS confirmed the successful incorporation of POM-132

within the MOF-5 framework while maintaining the crystallinity and structural stability of the parent materials. Morphological analysis revealed a well-dispersed hybrid architecture with strong interfacial interaction between the polyoxometalate clusters and the metal–organic framework. The CO_2 adsorption performance, investigated using a Sieverts apparatus at 273 K, demonstrated a progressive increase in adsorption capacity with increasing pressure, reaching a maximum uptake of 25 mmol g^{-1} at 2.5 bar. The enhanced adsorption behavior can be attributed to the synergistic combination of the porous MOF-5 structure and the oxygen-rich active sites provided by POM-132. The results indicate that the POM-132@MOF-5 composite is a promising candidate for carbon dioxide capture and separation technologies. Furthermore, this study provides a foundation for the development of advanced POM/MOF hybrid materials with improved adsorption properties for environmental and energy-related applications. Future work will focus on BET surface area analysis, adsorption–desorption cycling studies, and comparison with pristine MOF-5 and POM-132 to further elucidate the adsorption mechanism.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no known competing financial or personal interests that could have appeared to influence the work reported in this paper.

Data availability

The data supporting the findings of this study are available within the article.

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