Development and Characterization of Sr-Dextrin-Based Metal Organic Frameworks for Enhanced Catalytic Applications

[1]Muhammad Junaid[*], [2]Muhammad Amjad Riaz, [3]Abdul Qadir Ahmad, [4]Asif Qayyum
[5]Mahmood Basil A. AL-Rawi, [6]Mohd Arif Dar
[1]Institute of Physics The Islamia University of Bahawalpur 63100 Bahawalpur Pakistan
[2]Department of Chemistry, University of Education Lahore, Vehari Campus 61100 Vehari, Pakistan
[3]Institute of Chemistry, Government College University Lahore, 54000 Lahore Pakistan.
[4] Institute of Botany Bahauddin Zakariya University, Multan 60800 Multan Pakistan
[5]Department of Optometry, College of Applied Medical Sciences,
King Saud University, Riyadh, Saudi Arabia.
[6] Faculty of Allied Health Sciences, Chettinad Hospital, and Research Institute,
Chettinad and Education, Kelambakkam-603103, Tamil Nadu, India.
mjunaid310@yahoo.com*

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Summary: This study presents the synthesis, structural characterization, and application potential of strontium-dextrin metal-organic frameworks (Sr-MOFs) using a single-step crystallization mechanism. In the synthesis process, the Sr atom functions as a pivotal connecting node, directly bonding with both carbon atoms and the organic linker to form the framework. The reaction between the organic linker and the corresponding strontium bromide precursor yields brown crystalline Sr-MOFs. Following synthesis, the crystals were collected, characterized, and evaluated for their thermal stability, solubility, and potential applications. Solubility tests indicated moderate dissolution in common organic solvents, facilitating further processing and application. Thermal analysis revealed that these Sr-MOFs remain stable in air up to 463 K, highlighting their suitability for high-temperature applications. This work underscores the potential of Sr-MOFs as versatile, thermally stable materials, expanding the utility of MOFs in fields that require biocompatible and robust structural frameworks.

Key Words; Thermal Stabilities, MOFs, Organic Linkers.

Introduction

Water purification has been the subject of tremendous endeavors, and several methods have been created. Cleaning up the waste water is now a major challenge for us. Numerous hazardous salts, chemicals, and heavy metals, such as Hg, Ni, Cu, Cr, and Fe, have been dissolved in waste water. Organic metal frames the attention paid to MOFs has increased recently. Metal organic framework is really a network that forms from the combination of metals, most of which are transition elements because they contain vacant d. orbitals with a propensity to take electrons from ligand molecules and other organic compounds. Most metal organic frameworks have porous surfaces that can be adjusted to display catalytic performance and high stability. Heavy metal has a tendency to adsorb on porous surfaces, such as those seen in metal organic frame constructions. Pure and practical chemistry both use metal organic frameworks extensively. MOFs' ability to function as single magnetic molecules is a fantastic phenomenon. A significant global problem nowadays is the removal of heavy contaminants like heavy metals from waste water. Many different technologies have been created to address this problem. Because of the excellent properties coming from the creation of metal organic frameworks with nanoscale effects using MOFS, numerous nanomaterials were created to recover heavy metals from waste water, which has increased the attractiveness of nanotechnology as an emerging technology. Metal organic frameworks (MOFs), an advanced topic in material chemistry, have been developing for about 25 years. They are often created by mixing metals, which may include organic chemistry, d. block, and f. block metals. The amazing phenomena of MOFs acting as single magnetic molecules has been seen. Molecular magnets that exchange four to thirty paramagnetic ions in coupled clusters, typically from the first step of metal complexes, which have large spin ground states, such as S = 10, are a significant part of the study. They do not speak with each other. Some of these molecular magnets can be magnetized at low temperatures, and even after the external field is removed, they will remain magnetized. These systems have been named metal for this function. Linkers which form cage like or interconnected polymeric structures in different dimensions. A characteristic type of binding is developed between metal and linker or ligands which may be ionic covalent and

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[*]**To whom all correspondence should be addressed.**

coordinate covalent. In 1916 complex or coordination polymer terminology was sort out. In 1990s Robson and his coworkers' starts to grow given inspirational papers, [1]. Currently more recent researches clear up the concept, that metal organic frame works and coordination framework structures could be earlier synthesized and refashion in a well-organized appearance which permits the deep understanding of the effects of arrangement of particles [2]. The extraordinary high multi-functionality porosities of MOFs-based materials are what spark the intense interest in them as contrasted to older sponge-like compounds. These distinct qualities make them particularly compelling for a wide range of potential applications, including the storage and separation of gases, medication administration, and catalysis [3].

Comparative analysis stated that the element with the highest electro negativity such as fluorine with low electrical polarizability, a variety of features, including unique adsorption sites for molecules and versatility for the host materials, can be generated. Systematic study reveals Schematic description of the Cu-MOFS/Fe_3O_4 composite synthesis for the removal of MG malachite green in waste water. The copper MOFS can be easily prepared with doping Fe_3O_4 nanoparticles by in situ copper MOFS growth. These particles can be easily characterized by IR, SEM, XRD and Raman spectra. Chemistry of MOFs can be described as the metal organic frame works termed as subgroup of the class of inorganic and organic complexes [4].

The Yang Jinyue et al [5] in 2019 noted that removing heavy compounds from waste water, such heavy metals, has become a serious worry for the globe. Due to their remarkable properties resulting from MOFS manufactured nanoscale outcomes of organic metal frame works, various nano materials have been designed to remove heavy metals from waste water and have grown in favor as a new technology. Several technologies have been created to address this issue [5].

The MOFs are a fantastic and innovative family of chemicals with incredible and consistent pore diameters and higher surface area. Many scientists have worked on the synthesis of MOFs, and information regarding the synthesis and other features of MOFs is gleaned from literature reviews. Rarely studied as bio analytical platforms of the contemporary 2D material kind are metal-organic structure (MOF) nanoscale sheets. As a dye-labeled Platform Aptamer, a series of MOF (MOF-Ln) nanosheets built on ultrathin lanthanide is created.

Yatoo MA et al [6] in 2023 metal-organic frameworks (MOFs) are emerging as highly promising materials in the realm of energy storage, particularly for advanced applications in supercapacitors. Their structural diversity, tunable porosity, and customizable properties offer significant advantages, enabling enhanced electrochemical performance, faster charge/discharge rates, and extended cycling stability. Recent advancements highlight the versatility of MOFs as electrode materials, separators, and catalysts, with their tailored design providing high specific capacity, excellent conductivity, and impressive cycling stability. These qualities position MOFs as strong candidates for future energy storage technologies, supported by their scalable and relatively straightforward synthesis. Despite these benefits, challenges remain in achieving practical implementation, and ongoing research must address these to fully realize the potential of MOFs in energy applications. Looking ahead, continued exploration and innovation in MOF design and application will be vital for progress in this field, with particular opportunities for young researchers to drive the next wave of discoveries and technological advancements in MOF-based energy storage systems

Junaid Khan et al [7] in 2024 highlights the significant potential of Ni-Co-MOF nanospheres, synthesized via a hydrothermal approach with EDTA, for enhancing energy storage capabilities in a battery-supercapacitor hybrid system. The bimetallic Ni-Co-MOF demonstrates unique redox activity and a high specific capacity of 474.56 C/g at 1 A/g, confirming its battery-like behavior with a 94.68% diffusion-dominated response at a scan rate of 3 mV/s. Integrated into an asymmetric hybrid device as a positive electrode, the Ni-Co-MOF exhibits impressive specific energy and power outputs of 72.58 Wh/kg and 8500 W/kg, respectively, alongside excellent cycle stability, retaining 93.2% capacity over 10,000 charge-discharge cycles. The device's reproducibility, with specific energy outputs remaining above 70 Wh/kg over extended testing periods, further supports its practicality for real-world applications. Simulation results reinforce the hybrid's performance with diffusion dominance and capacitive contributions at varying scan rates, affirming the Ni-Co-MOF-based configuration as a highly promising candidate for efficient and reliable energy storage solutions.

Shahid Alam et al [8] in 2024 the development of MOF-based electrocatalysts presents a promising path forward in the pursuit of sustainable hydrogen production through water splitting. By leveraging the unique features of MOFs including their customizable metal centers, ligand architectures, and high porosity researchers have opened new avenues for optimizing catalytic efficiency in hydrogen evolution reactions. This review categorizes the recent advancements in MOF electrocatalysts into monometallic, multimetallic, composite, and derivative frameworks, offering insight into each class's role in enhancing water splitting performance. The exceptional catalytic properties of these MOFs underscore their potential as valuable materials in advancing water splitting processes, providing a cleaner, renewable energy alternative. Harnessing these innovations is essential to drive progress toward an energy landscape increasingly dependent on sustainable sources.

Preparation of Sample

The synthesis of strontium-dextrin metal-organic frameworks (Sr-MOFs) was carefully controlled to achieve high-purity crystals with desired structural characteristics. The process began by preparing a 0.1M solution of strontium bromide ($SrBr_2$), created by dissolving a calculated quantity of $SrBr_2$ in 30 mL of methanol, chosen for its effectiveness as a solvent for this compound. Separately, a 30 mL solution of dextrin was prepared and placed in a burette for controlled addition during the reaction. The $SrBr_2$ solution was transferred into a conical flask equipped with a magnetic stirrer and positioned on a hot plate, where it was gently heated. The burette containing the dextrin solution was mounted above this setup, allowing the solution to be added dropwise into the $SrBr_2$ solution with continuous stirring. This gradual addition ensured uniform mixing between the metal source and organic linker under controlled conditions.

After the dextrin solution was fully added, continuous stirring was maintained until a clear solution formed. This reaction mixture was then left undisturbed at room temperature for 24 hours, enabling fine needle-like crystals of Sr-MOFs to grow. Following this, any remaining solvent was gently evaporated through controlled heating to further concentrate the solution and promote additional crystal formation, ensuring that the final product was free from residual solvent. To remove impurities, the resulting crystals were washed with cold methanol, taking care to preserve the delicate crystal structure. After washing, the crystals underwent recrystallization to achieve enhanced purity and uniformity, involving further evaporation of methanol through gentle heating.

The dried and purified Sr-MOF crystals, now in a brown crystalline form, were carefully collected and prepared for characterization to assess their structural, physical, and chemical properties. This careful synthesis process enabled the production of high-quality Sr-MOF crystals suitable for further analytical studies and applications.

Results and Discussion

The synthesis of Sr-based metal-organic frameworks (Sr-MOFs) involves several stages: crystallization, collection, characterization, and potential applications of the resulting MOFs. In this process, the Sr atom serves as the connecting point between the metal and the organic linker molecule, bonding directly with carbon and other elements in the linker. The reaction occurs between the organic linker and strontium bromide, enabling the Sr-MOFs to be synthesized in a single step. The final product appears as brown crystals, which can dissolve in various common solvents. These compounds have shown thermal stability in air up to 463 K, indicating their robustness under moderate heating conditions.

XRD Analysis

The D-8 Bruker X-rays diffractometer is used to performed XRD pattern of Sr-MOFS which showed no absorption peak, it gives us information about the amorphous structures. The XRD of Sr-MOFs have high crystallized reflections and also confirmed that these changes cannot be obtained at 19^o. The XRD gives only one diffractions distribution that has a weak value and pointed out at 27^o to 29^o, which shows the characterized amorphous nature of MOFs. This pattern gives a needle like symmetry [9-11].

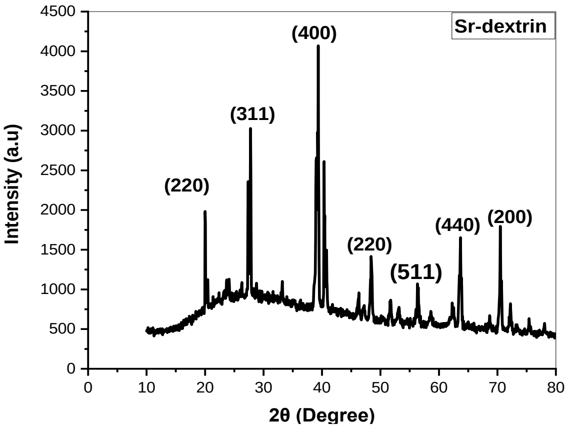
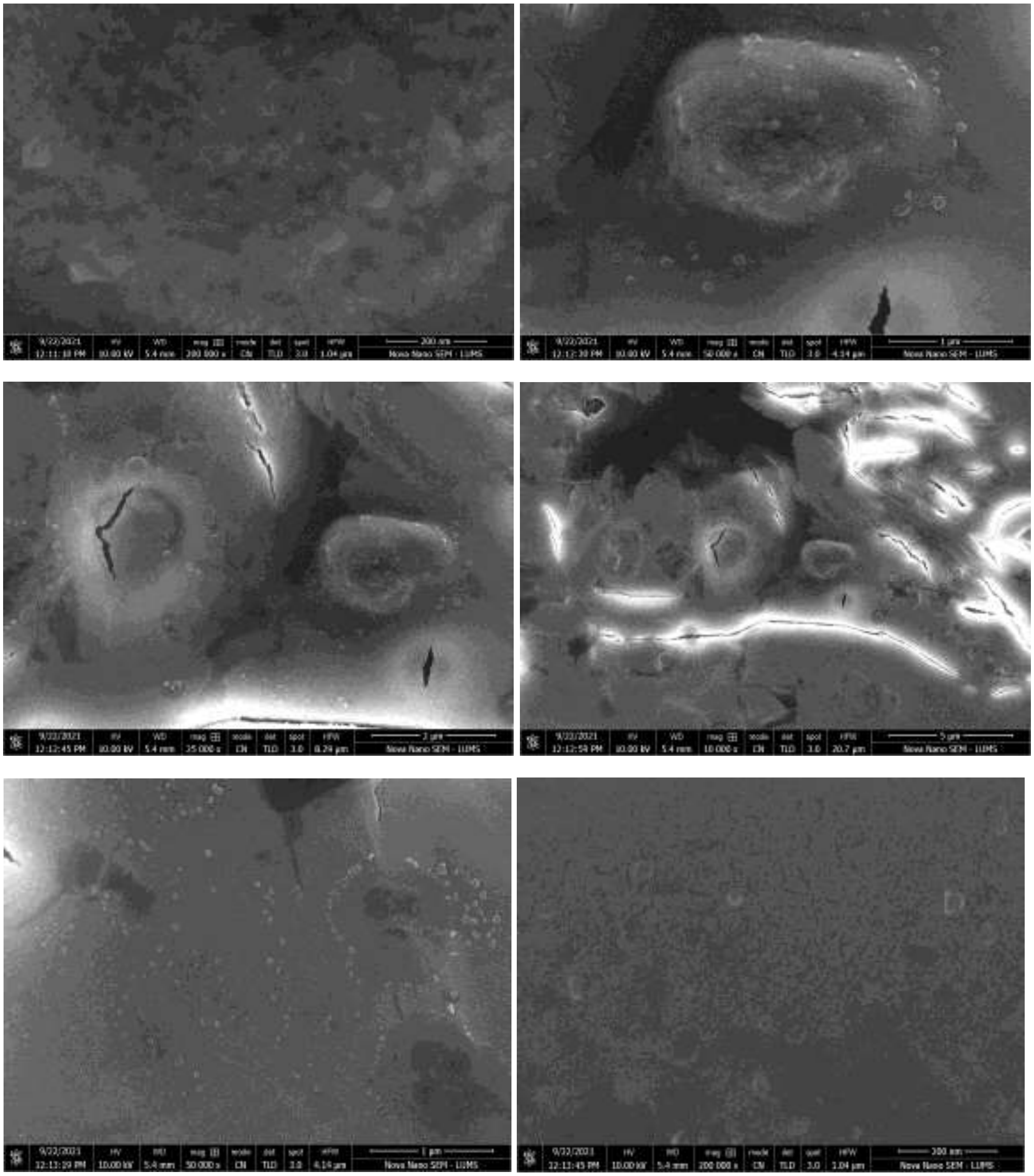


Fig. 1: XRD analysis of prepared sample.

The peak of diffractions was broad in width but have low values of intensity which indicates that in the obtained product have a good number of crystallites of nanosized and compare it all peaks with CCDC: 1551141 as shown in Fig 1.

SEM Analysis

The SEM (Cube II Emcraft South Korea) setup is used to analyze the morphology which is relatively arranged, along with a high degree of sample agglomeration. The morphological studies of brown colored MOFs were done by using a characterization technique that name SEM. The micrographs of all the crystals look very close to each other because one crystal shows the properties carried out by all crystals [12]. Those micrographs also give information about the distribution of particle size in the low range of micrometeorites shapes were heterogeneous and was undefined. The SEM image shows that the metal organic frameworks that were synthesized by using metal bromide gives different morphological shapes including strips and strip shaped clusters too [13]. The SEM images of Sr-MOFs at different resolutions are mentioned in Fig. 2.



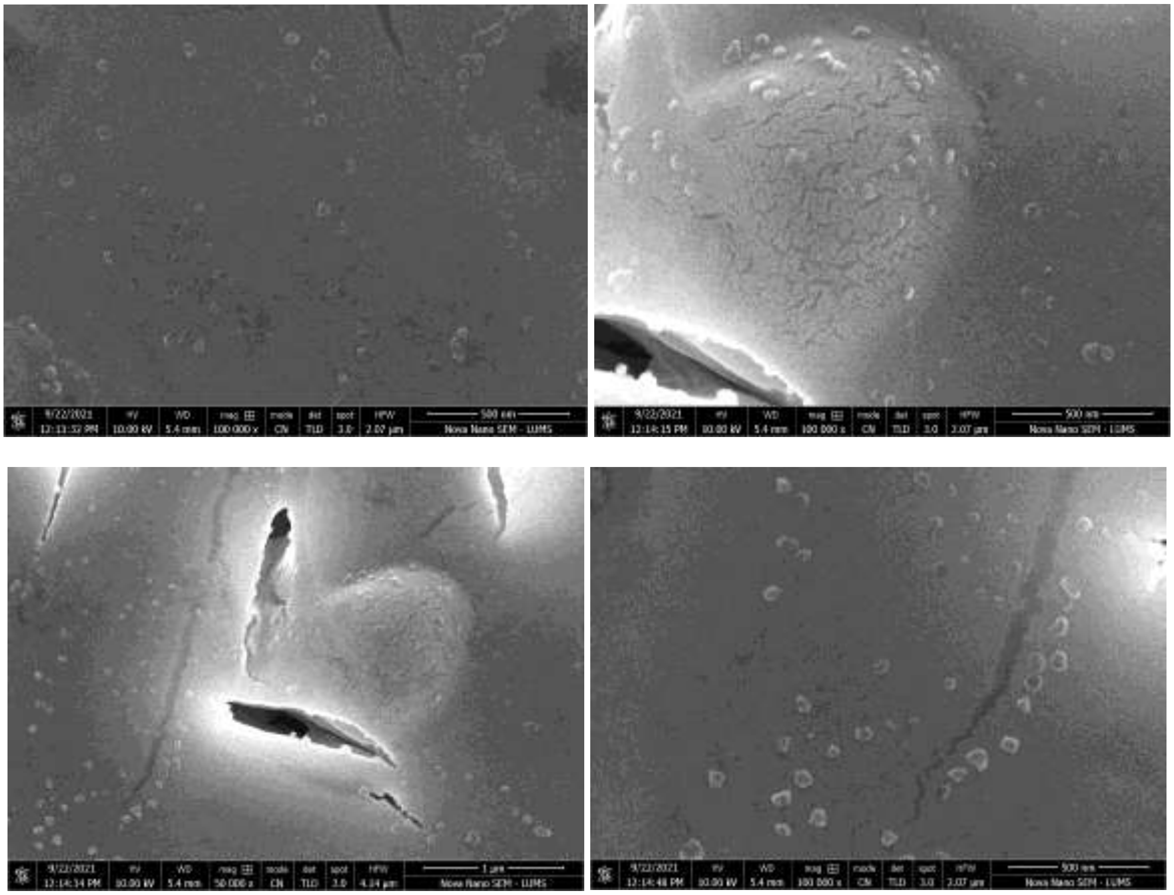


Fig. 2*:* SEM analysis of prepared sample at different Scan rate.

The SEM images of synthesized Sr-based metal-organic frameworks (Sr-MOFs) reveal distinct morphological characteristics that reflect their structural attributes. Typically, these images show well-defined particles, often exhibiting a range of shape spherical clusters. The particle surfaces may appear rough or textured, indicating the inherent porosity of the MOF structure, which is essential for applications that rely on high surface area. In some images, Sr-MOF particles are seen to aggregate, forming larger clusters that highlight the material's tendency toward secondary particle interactions [14-17]. This agglomeration can result from electrostatic or van der Waals forces, which may occur during the drying and sample preparation processes. The particles often display a consistent size distribution, suggesting a controlled and reproducible synthesis process. At higher magnification, the images may reveal finer details such as layered textures or small pores, which contribute to the MOF's high surface area and potential for applications like catalysis or adsorption [18].

Nuclear Magnetic Resonance (NMR) Study

Given graph of C13 NMR shows a chemical shift value of 181.2 ppm in a C13 NMR (Carbon-13 Nuclear Magnetic Resonance) spectrum typically indicates the presence of a carbon atom in a highly deshielded environment. This means that the carbon atom is experiencing a strong magnetic field from nearby electronegative atoms or functional groups, which can pull electron density away from the carbon atom. Chemical shifts in this range are often associated with carbonyl groups (C=O), carboxylic acids (COOH), or other highly electron-withdrawing substituents [19-23]. The MNR of Sr-MOFs is mentioned in Fig 3.

The specific interpretation may depend on the molecular structure and other factors, so it's essential to consider the context of the entire NMR spectrum and the molecule in question for a precise identification as shown in Fig 4.

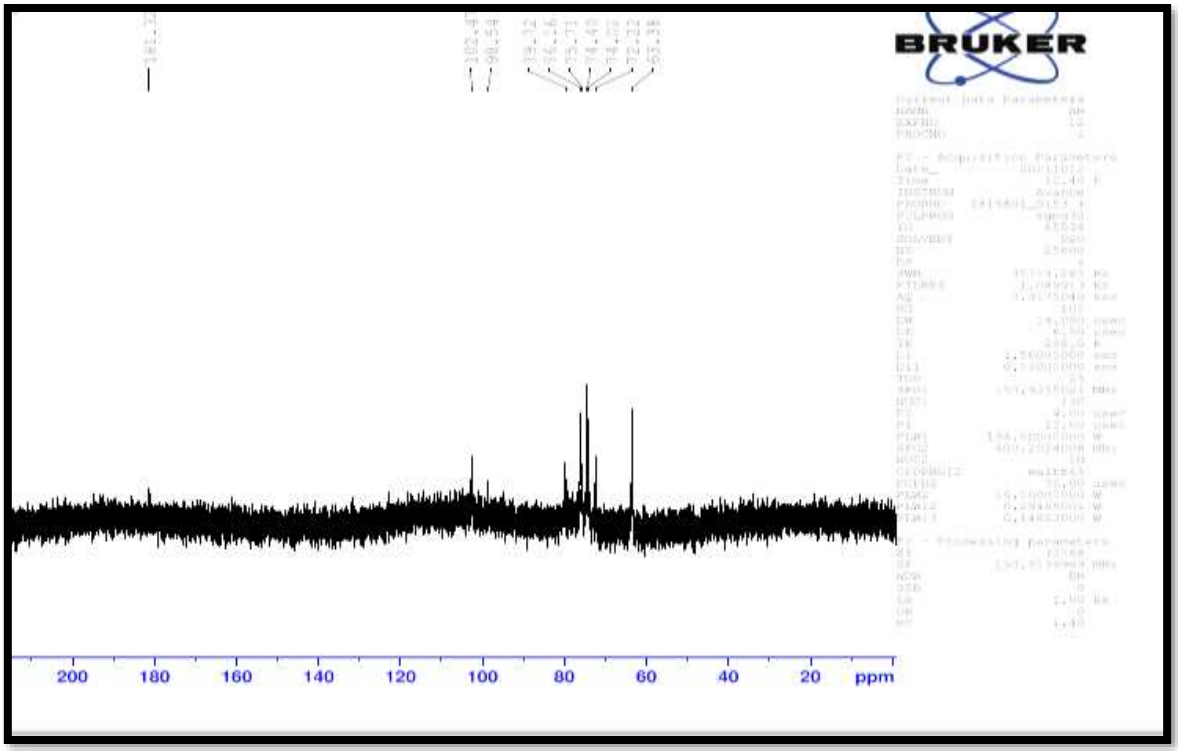


Fig. 3: MNR study of sample

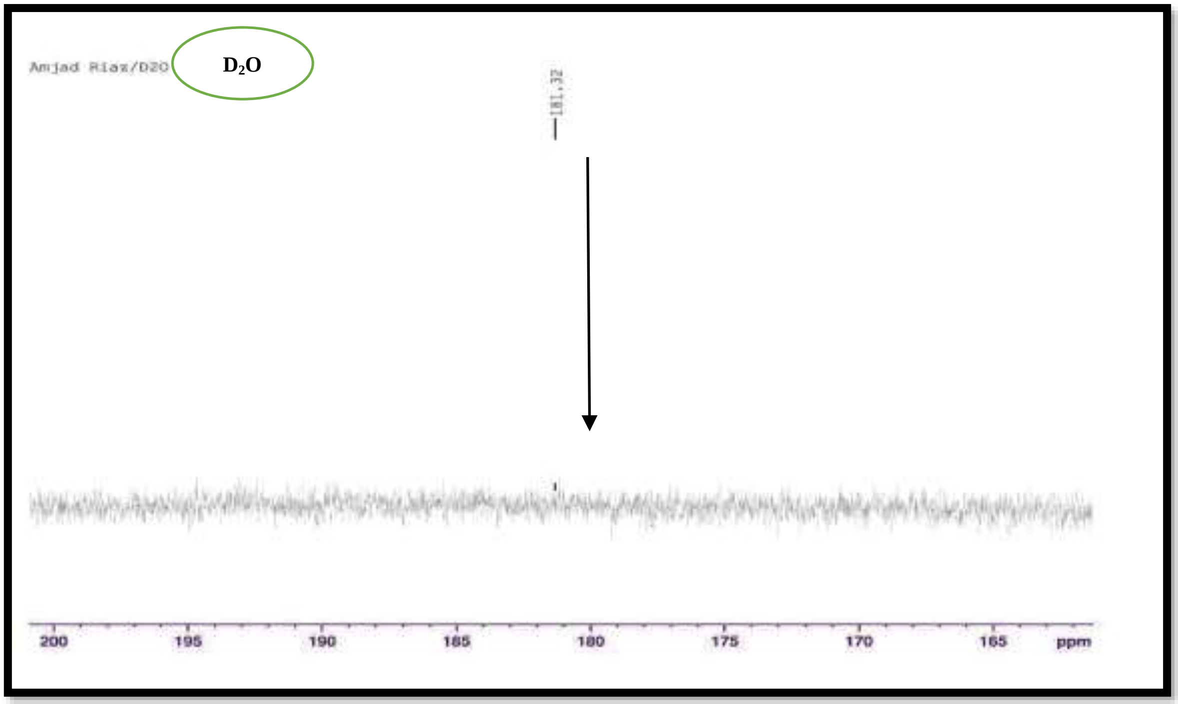


Fig. 4: Magnifying MNR Study.

The 1st peak of the MNR were noted at shows a chemical shift value of 181.2 ppm in a C13 NMR (Carbon-13 Nuclear Magnetic Resonance)

Applications of Sr-MOFS in the Removal of Heavy Metals from Waste Water

The water that is used for drinking purposes usually contaminated by heavy metals. Mixing of lead into water have very dangerous effect and health risk. The water purification method used for now a day not more efficient and reliable. Here is easiest and cheapest way for waste water treatment. It is most stable metal organic framework to purify water. This water stable organic frameworks are of Sr-MOFs [24]. All the MOFs structures have high porosity, which makes a porous extrinsic composite that combine with 390mg of lead ions and removes 99.6% of these lead ions from little ppm number of solutions. This technique increases the quality of drinking water in few seconds. Sr- MOFs were synthesized by using known methods.it contain empty cages of mesomorph sizes that ranges from 25 to 29A° diameter [25].

Conclusion

This study investigated the synthesis, characterization, and potential applications of strontium-dextrin metal-organic frameworks (Sr-MOFs), emphasizing their structural and functional capabilities. Sr-MOFs were synthesized via a single-step crystallization process where strontium atoms act as a connector, binding directly with the organic dextrin linker. The final product resulted in brown crystals that dissolve in certain solvents, making them suitable for further applications. Characterization techniques such as XRD, SEM, and NMR revealed detailed structural features. XRD analysis indicated the amorphous nature of the Sr-MOFs, displaying broad diffraction peaks and confirming nanoscale crystallinity. SEM imaging showed that the Sr-MOFs formed clustered, textured particles with a porous surface, essential for catalysis and adsorption. SEM study of Sr-Based MOFs shows that particles of Sr-Based are of 200nm.These particles may act as a single magnetic molecule as well as a nanoparticles and very small size till 500nm. NMR shows a chemical shift value of 181.2 ppm in a C13 NMR (Carbon-13 Nuclear Magnetic Resonance) spectrum typically indicates the presence of a carbon atom in a highly deshielded environment. This means that the carbon atom is experiencing a strong magnetic field from nearby electronegative atoms or functional groups, which can pull electron density away from the carbon atom. Chemical shifts in this range are often associated with carbonyl groups (C=O), carboxylic acids (COOH), or other highly electron-withdrawing substituents NMR data supported the presence of specific carbonyl or carboxylic groups in the framework structure, contributing to the compound's stability and binding characteristics. One of the primary applications highlighted was the use of Sr-MOFs in removing heavy metals from contaminated water, a significant environmental benefit. Due to their high porosity and affinity for metal ions, Sr-MOFs demonstrated high efficiency in binding and removing lead from water, improving water quality. The thermal stability of Sr-MOFs up to 463 K makes them resilient for diverse applications, especially in water purification and catalysis.

Sr-MOFs show great potential for environmental applications due to their stability, structural properties, and ability to remove contaminants effectively. This research advances the understanding of Sr-MOFs, with promising implications for future catalytic and environmental technologies.

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