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REVIEW

A Study of the Fabrication of Different-Dimensional Metal–Organic Frameworks and Their Hybrid Composites for Novel Applications

Asima Imtiyaz[1] · **Ajay Singh**[1]

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Abstract

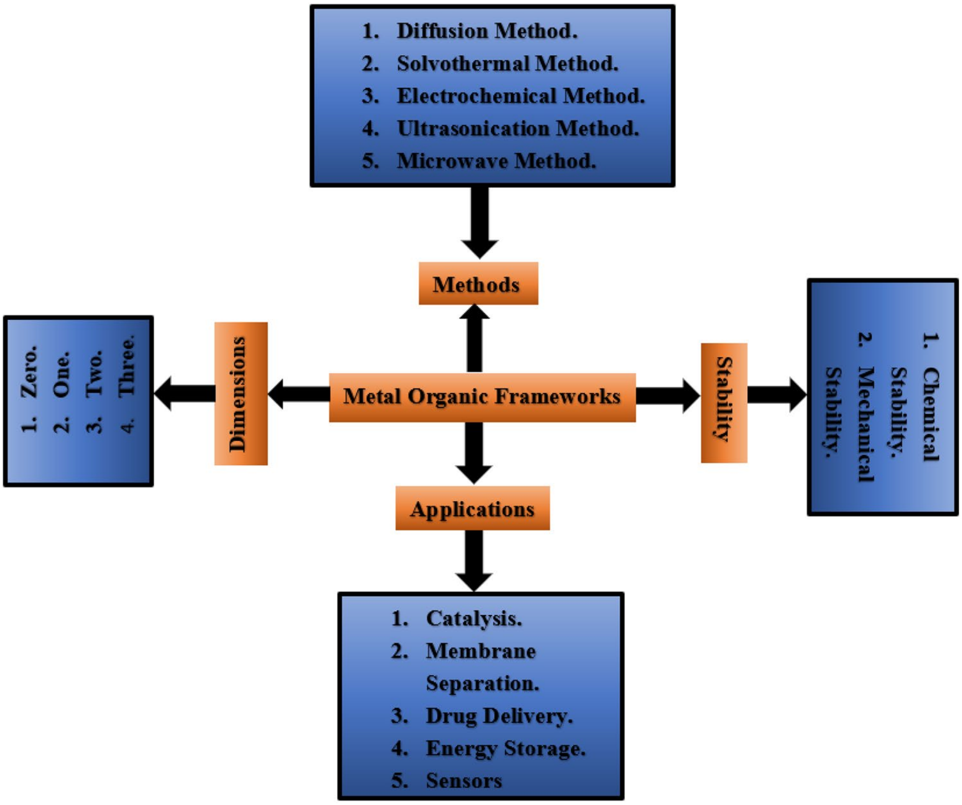
The term "organic and inorganic composite porous materials" refers to metal–organic frameworks. Due to their low density and high porosity, MOFs have an enormous surface area that can be used to store and aggregate many molecules. The pore size may work as a grid to segregate molecules. Changing the materials' inherent characteristics is advantageous because MOFs are porous. Over the past 10 years, several hybrid MOFs containing polymer compounds, carbon-based substances, metal nanoparticles, metal oxides of metal, & biomolecules have been reported for use in various applications. Electronic components, detectors, storage of energy, separation of gases, capacitors, medication delivery, and environmental remediation have all been made using MOFs. The initial part of this review has been devoted to discussing the extraordinary qualities, distinctive architectural orientation, & contemporary uses of MOFs as well as their permeability, equilibrium, and additional determining elements. Additionally, several methods & processes used in the creation & development of MOFs are discussed, including solvothermal, electrochemical, mechanochemical, ultrasonication, & microwave approaches. Various approaches have been used to generate various dimensional MOFs like OD, 1D, etc. & their combined substances were additionally provided, in demand to comprehend the methodical viability of MOFs in generating novel goods. The opportunities for MOFs in the future, as well as the problems still to be solved, research gaps, and potential solutions, have all been discussed. These include the improved design of experiments, mathematical models, simulated approaches, and conceptual notions.

✉ Asima Imtiyaz
asimaimtiyaz78@gmail.com

Ajay Singh
ajay21singh@yahoo.com

[1] Department of Chemistry, School of Applied and Life Sciences, Uttaranchal University, Dehradun, Uttarakhand 248007, India

Graphical Abstract



Keywords Polymer · Detectors · Capacitors · Biomolecules · Equilibrium · Microwave · Metal–organic framework

1 Introduction

The development of many coordination bonds involving inorganic metallic terminals & multidentate living ligands results in the formation of metal–organic frameworks which are crystal-like structure subsections of microporous constituents. Infinite arrays of divergent atoms connected by covalent or coordinate contacts make up the harmonization polymers identified as metal–organic outlines, which comprise metal centers & multitopic living units [1–3]· Metal bulges, which may be metallic particles or metallic oxide collections, living ligands, & nanoscale inner open places, are among constituent elements of MOFs [4]. The base particles incline to ligate via open coordination sites at metal nodes, which are one of these components that are thought to make up a large portion of MOFs [5]. Geometry & interconnectivity of metallic-containing auxiliary structure units with flexible or quasi-multitopic living ligands accounts for the permeability & annulled volume in the outline of MOFs [6]. Its applications in living parting, heterogeneous catalysis, storage of energy, luminescence, detection, ionic & other fields have resulted from the advance of fascinating constructions & distinctive features of MOFs [7–9]. The synthesis of MOFs involves both conventional & novel methods for creating coordination networks, including complicated chemistry, ligand insertion or exchange, & post-synthesis change [10]. Certain essential steps in the development of MOFs include, for example, the use of geometric principles to link SBUs, the combination of living units & related compounds by responding with linkers, & the design of complications inside MOFs' apertures [11]. Prior investigations have revealed that altering the structure & functioning of MOFs may produce materials that are appropriate for the application. This identifies MOFs as one of the greatest intriguing resources amongst researchers & technologists due to their wide range of uses [12, 13]. As these substances remain created by the fusion of metallic particles with living ligands, MOFs have long remained familiar as a management & solid-zeolite interaction component. In addition, lengthy organic linkers encompassing blank spaces are used to create MOFs, like zeolites, to create potential permanent pores. Divalent metallic particles like Zn^{2+} & Cu^{2+} demonstrated high permeability in early investigations of MOFs, which have applications in many different fields [14]. These

MOFs remained shown to be unbalanced in hostile environments with dampness, though, and durability with bases coordinated negative ion, water, & other living mixtures is necessary for industrial processes. Researchers have studied the permeability & steadiness of MOFs in various ecological circumstances over the past few decades to overwhelm these variabilities & obtain ultrafine absorbent steady MOFs [15, 16]. The development of stable-porous true & mixed MOFs with a range of dimensions, as well as their applications, are the main topics of this review. First, a detailed discussion of the skeleton elements of MOFs, aspects influencing the stabilization of MOFs with modulators, & help in making sure enabling stable forms of MOFs is presented. This is further expanded by the researchers' general methods for synthesizing MOFs, their approaches to the synthesis mechanism, & potential applications including large-scale manufacturing. The development of mixed composite MOF structures, different MOF dimensions, functionalization, & decorating with nanoparticles is highlighted to comprehend the relevance of MOF structures. Additionally, it has been elaborated on how MOFs can be used in a variety of disciplines, as well as their sensitivity, catalytic mechanism, & involvement in the production of carbon materials & MOF dopant atoms that outperform other nanocomposite materials. Lastly, the potential research gaps & ongoing problems in the continued progress of MOFs are opposed to the prospects for the future of MOFs. Consequently, this study highlights the most recent research findings and advancements made globally about MOFs, which may be the greatest suitable substantial in the approaching manufacturing revolt. Inorganic as well as organic parts can be found in MOFs. Figure 1 illustrates the conjugated base of a carboxylic acid

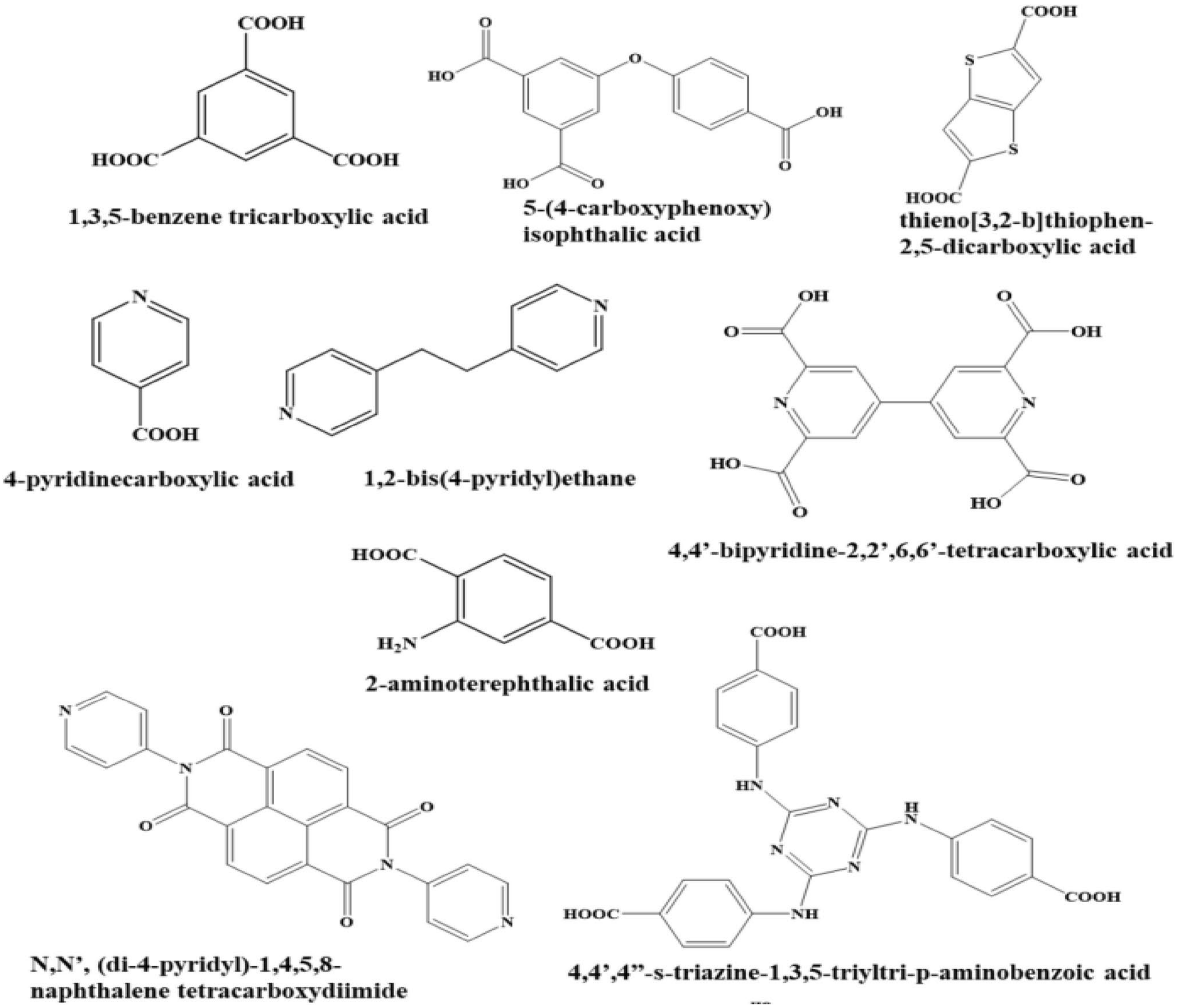


Fig. 1 Organic compounds are employed to produce MOFs as linkers

or anions, such as salts of sulfonic acid, heterocyclic compounds, and organophosphorus compounds, as organic components (bridging ligands/linkers).

2 Elements that Affect the Reliability of MOFs

Synthesis of metallic particles & living ligands, the hydrophobicity displayed by aperture superficial, response or operation conditions, & other parameters all have an impact on the stability of MOF [17, 18]. According to research on MOF stability, coordinate bonds involving metallic particles & living linkers have a key role in determining the material's thermodynamic stability, which is associated with the metal's charge density [19, 20]. Generally, it is assumed that carboxylate-based ligands remain solid bases that produce steady MOFs by greater metallic particles like Zr^{4+}, Ti^{4+}, etc. [21]. The living & mechanical steadiness of MOFs remain explored below about how hard & soft circumstances affect the strength of organization bonds.

2.1 Chemical Stability

The kind of metal ion-ligand used in the creation of MOF structures and the reactivity or functioning conditions to which MOFs are uncovered determine the chemical stability of MOFs. The preliminary baseline learning entailed exposing MOFs to liquid & vaporized water when the ligands in the metal ion-ligand framework were changed to water or hydroxides [22, 23]. Strengthening the coordination relationship among inorganic metals clusters & coordination groups is necessary to overcome this vulnerability. The hard/soft acid/base theory states that interactions among strong Lewis bases & acids or soft Lewis bases & acids typically have bigger effects than interactions between acids and bases in the other direction [24]. As stated above, most MOFs are created utilizing low-valence transition metal ions & isolate-based ligands, or high-valence metal ions & carboxylate-based ligands [25]. Protons & hydroxide particles stand shown to be more harmful to MOFs than neutral water molecules. The constancy of MOFs varies with acids & bases as a result of the differences between acidic & basic solutions. High heavy metal ion & carboxylate-based ligands demonstrate great acid resistance in these MOFs' structures, but they appear to be weaker in bases [20]. Protons, hydroxides, & other coordinating anions found in aqueous solutions, such as $CO3^{2-}$, F^{-}, & $PO4^{-3}$, have an essential function in the disintegration of MOF structure. To regulate the pH of the solution, these anions work as buffer pairs with conjugated acids. They are primarily categorized among Lewis bases that operate as substitutes for carboxylate ligands in structures by interacting with high-valency metallic particles like Zr^{4+}, Al^{3+}, etc. Utilizing low-valence metallic ions and ligands, MOFs are created to counteract the effects of coordinating negative ions [26].

2.2 Mechanical Stability

Mechanical steadiness is the capacity of MOFs to endure pressure or vacuum while maintaining their pore size & porosity. The most frequent techniques used throughout the initiation procedure to prevent physical ruin are fluid interchange & solvent removal, where advanced superficial tension solvents are swapped with lesser ones like CH_2Cl_2, and $CHCl_3$ [27–29]. As was already mentioned, operating or reaction criteria, such as acidic or basic or oxidizing or reducing circumstances, might affect the stability of MOFs. Acidic conditions are found to be stable for large metallic ions and carboxyl ligands. However, the MOF construction dissolves in the presence of the coordinating anion, MOF structure dissolves [30]. This highlights the urgent necessity to design MOFs by the normative specifications of a specific response in manufacturing & extra application procedures.

3 Variables Affecting MOFs' Stable Forms

The high connection among metal nodes & ligands, the stiffness of the ligands, & the existence of hydrophobic groups are the three key parameters determining the stability of MOFs. The rate of structural defect healing is accelerated by high metal node and ligand connection; when the ligand detachment degree falls, the suggestion degree rises. This is known as the "3D chelating action of ligands" & is meant to imitate the chelating actions of multi-dentate ligands [20, 31]. The material's inertness is then increased by the ligand terminals' bent transition states; short, rigid ligands suggest a determined at a greater angle, necessitating higher activation energy to dissolve MOFs from their structure [32, 33]. Then, it appears that adding hydrophobic groups to ligands in MOFs causes them to display aquatic confrontation. The maximum prevalent collection that helps block water particles is the methyl collection, which reduces porosity and compresses water vapor at a pressure range [34].

3.1 Modulators

Recently, physical characteristics like crystalline construction, absorbency, measurement, superficial area, & structure have established cumulative attention during the mixture of MOFs. Recently, physical features like crystalline construction, permeability, measurement, & defectivity have conventional increasing consideration during the mixture of MOFs [35]. Hermes et al. opened up new perspectives on MOFs by applying p-perfluoro methyl benzoic acid as a modulator.

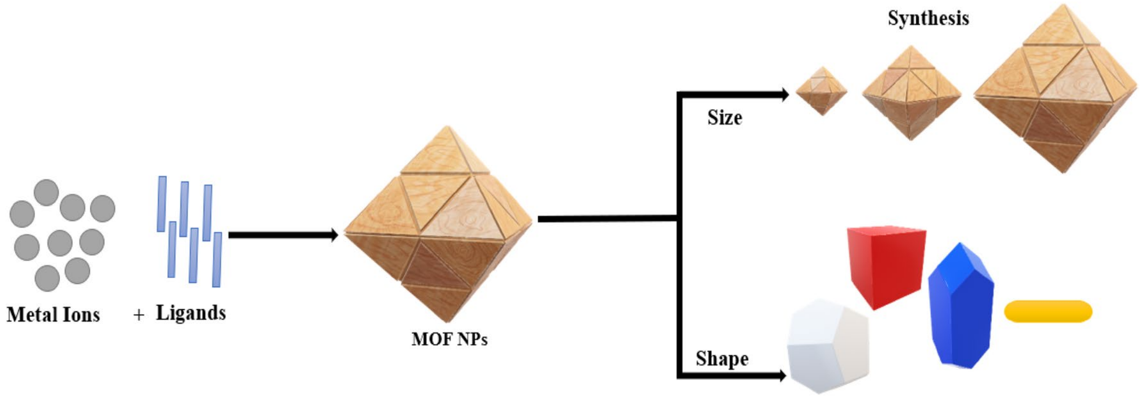


Fig. 2 Formation MOF structure

Findings showed that based on the modulation to MOF precursor ratio, modulator tends to lower crystal size from 350 to 100 nm & also enables a solution's colloidal stability [36]. Then MOF, which was created in 3 different forms of octahedron, cuboid & acquired a mean scope of 2 m by enhancing the attention of the modulator, lauric acid, on the other hand, is an example of selective modulation being stretched to regulate shape & size of MOFs [37]. Changes in the manufacture of MOF crystal structures also resulted in their conversion into amorphous forms, which were then melt-quenched to produce MOF glasses in large quantities [38]. Moreover, it has been observed that ethanol and water work together to modify the structure of Zr-based MOFs in a co-solvent state at room temperature [39].

4 Techniques for Creating MOFs

Typically, organic linkers and metallic centers make up the construction of MOFs, with the living linkers serving as SBUs and the metal centers as joints. Several organic linkers & metal centers are utilized in the synthesis of MOFs to provide a required stretchy molecular structure block susceptible to changes in chemical & physical features as shown in Fig. 2 [40]. There are several ways to make MOFs, however, the following are some of the more widely used ones (Table 1).

4.1 Diffusion Method

Single crystal or nano-sized MOFs are frequently synthesized at room temperature using slow diffusion and quick precipitation procedures [41]. The diffusion approach allows crystal formation and nucleation to gradually occur at the interface by progressively transferring the reactive species using a solvent or gel. There are two diffusion methods used in this procedure. In the first approach, crystal formation takes place at the interface & solvent-liquid dispersal occurs where the densities of two diluters vary. The second method involves gradually allowing reactants to permeate through

Table 1 A summary of studies regarding MOF synthesis

S.no	MOF	Method used	References
01	I. MIL-96(Al) II. UiO-66-NH$_2$	Solvothermal method by using atomic layer deposition	[45]
02	Zn$_3$(BTC)$_2$	Ultrasonication method	[50]
03	Zn$_4$O(BDC)$_3$	Ultrasonication method	[52]
04	Zr-NDC	Microwave method	[58]
05	I. Hf-UiO-66 II. Zr-UiO-66	Microwave method	[59]
06	IRMOF-9 and -10	Sono-chemical method	[134]
07	Zn-imidazolates	Electrochemical method	[135]
08	Cr-MIL-100	Microwave-assisted synthesis	[136]
09	Fe-MIL-10	Microwave method	[137]
10	Cr-MIL-101	Microwave method	[138]
11	MOF-177	Microwave method	[139]
12	HKUST-1	Microwave-assisted synthesis	[140]
13	[Co$_3$Cl$_6$(L0)$_2$]	Mechanochemical synthesis	[141]
14	Fe-MIL-88A	Sono-chemical synthesis	[142]
16	[Ln (BTC) (H$_2$O)]	Mechanochemical synthesis	[143]
17	Fe-MIL-88A	Sono-chemical synthesis	[144]
18	Zn-& Cu-carboxylates	Electrochemical synthesis	[145]
20	[Zn$_2$(FMA)$_2$(BPY)]	Mechanochemical synthesis	[146]
22	HKUST-1	Electrochemical method	[147]
23	Ni-glutarates	Microwave synthesis	[148]
24	Ni-CPO-27	–	[149]
25	[M$_3$(NDC)$_3$(DMF)$_4$]	–	[150]
26	[Mg$_2$(BTEC) (H$_2$O)$_4$]	–	[151]

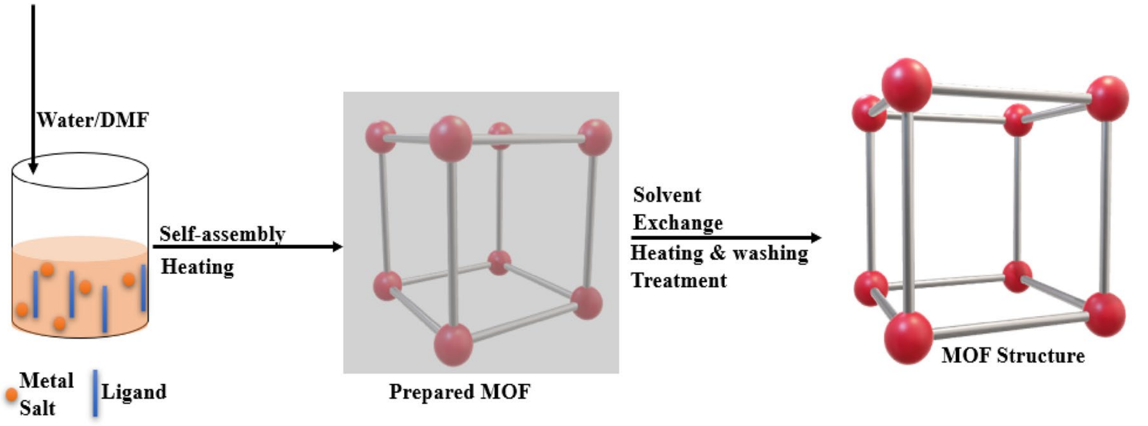


Fig. 3 MOF structure solvothermal synthesis

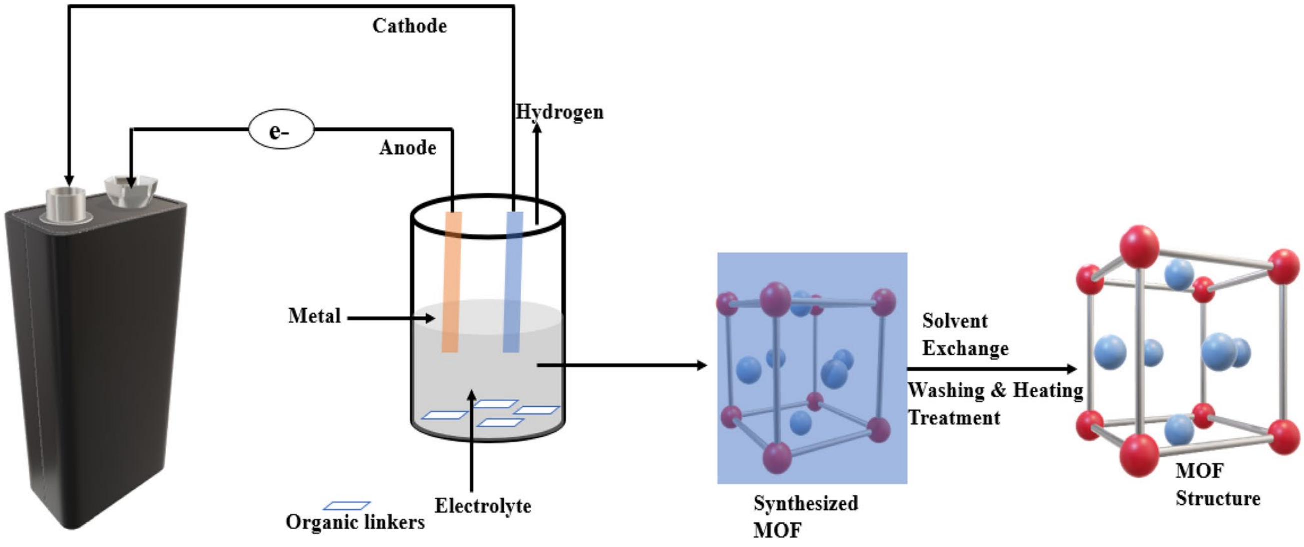


Fig. 4 MOF structure electrochemical synthesis

a physical barrier [42]. Whereas crystal formation takes place where supersaturation is low in the dispersal process, nucleation predominates at surface where supersaturation is maximum. The interface distance varies along with the gradient in crystal size [43].

4.2 Solvothermal Method

Self-assembly of micro-porous crystals is planned in the solvo/hydro-thermal production of MOFs employing solvable linkers, metallic salts, & elective patterns reacting at the temperature fluctuating from 80 to 260 °C for 24–48 h [44]. This is the most widely used synthetic method since it needs no specialized equipment and produces minerals with more levels of absorbency, cleanliness, & superficial area quickly as shown in Fig. 3. Several investigations addressing the solvothermal manufacture of MOF have been published. In a study, MOF: UiO-66-NH_2 was created on metallic oxide flicks, increasing the permeability & superficial zone on textiles without sacrificing adsorption effectiveness or adding any extra functionalization. A homogeneous and conformal thin film is first formed using atomic layer deposition to coat the layer on polypropylene fibre, and then UiO-66-NH_2 is created using solvothermal synthesis. These fabrics can subsequently be used for gas adsorption, separation, and catalysis [45].

4.3 Electrochemical Method

Due to its straightforward operation conditions, which include mild reactions at ambient temperature and pressure, shorter reaction times of up to 2 h, high yields, and low energy requirements without the need for specialized equipment, the electrochemical synthesis of MOFs has provided several benefits as shown in Fig. 4 [46]. This method also had an impact on the continuous real-time reaction, enabling the direct creation of thin films without cracks in the lack of pre-treated surfaces and high temp. With solvo or hydrothermal techniques, a longer reaction time and higher reaction temperature resulted in thermally induced cracking on the films. By removing problematic counter ions like nitrates or chlorates in the inclusion of metallic positive ions created in situ by anodic oxidation, electrochemical techniques also frequently display a regulated synthesis of MOFs. It is proposed that the morphology & production of MOFs after the response was significantly influenced by electrochemical factors such as the stabilizing agent & current density [47].

4.4 Ultrasonication Method

One of the several MOF synthesis techniques is ultrasonication, which is known to be economical and environmentally benign and capable of producing a high yield in a solvent-free response at room temperature & compression [48]. In comparison to other methods, ultrasonication-based MOF mixture is applied, manageable, & requires a short response time to produce the creation with high produce [49]. In a study, cupric acetate and H_3BTC were used in a mixture of DMF/ethanol/water with a measured reaction duration of 5–30 min to synthesize the 3D MOF, $Cu_3(BTC)_2$ in the occurrence of ultrasonication at ambient temperature & compression. Findings showed the production of MOF ($Cu_3(BTC)_2$) & that produced nano-crystals had sizes between 10 and 200 nm [50]. The dimension of these nano-crystals created by microwave irradiation was less than the size created by the traditional solvothermal approach, which needed high temperatures of 383–453 K & lengthy response times of 12–18 h for $Cu_3(BTC)_2$ to operate [51]. In addition, employing a metal salt & a chemical linkage, the effectiveness of ultra-sonication in the mixture of $Zn_4O(BDC)_3$ (MOF-5) was demonstrated. When making polycarbonate diol, the resultant hard MOF nano-crystals worked well as compounds [52].

4.5 Microwave Method

The process of synthesizing MOFs using microwave assistance provides several benefits, including unchanging scattering, cleanser goods, & greater produce [53]. Microwave irradiation during the synthesis method enables phase selectivity, quicker crystal nucleation kinetics, and size-controlled crystal development as shown in Fig. 5. Researchers working on the synthesis of significant MOFs using a microwave-assisted synthetic technique have been interested as a result of this [54–56]. In general, the microwave approach for MOF synthesis is straightforward and takes very little time to produce nMIL-101 nanocrystals. In a Teflon autoclave, chromium trichloride & terephthalic acid are combined with double-distilled water. The pH is then raised to 4 before being heated in a microwave. The reaction is started & held on hold for 3 min at 210 °C before being repeated 5 times. To create mesoporous nMIL-101 nanocrystals, the green reactant solution is extracted, cleaned, rinsed, & spun at 10,000 rpm for 30 min [57]. To create a new recyclable adsorbent, Linh Ho Thuy Nguyen et al. effectively & quickly synthesized the Zr-based metal–organic framework nanomaterial using the microwave technique. The material characterization revealed that Zr-NDC with an average particle size of 100 nm was a severely flawed framework because linkers were lacking during synthesis. As of its larger extreme bulk & reusability during numerous cycles of adsorption, the MOF demonstrated remarkable efficiency with cheap

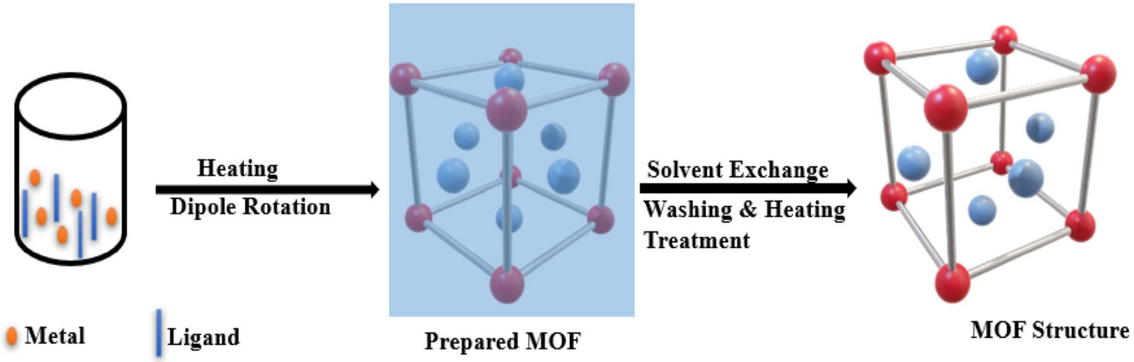


Fig. 5 MOF structure synthesis with microwave assistance

cost for the adsorption of carbon-based dyes like MB, & MO. According to the findings of adsorption tests, the defect sites in the frame & the physisorption nature of Zr-NDC towards the dyes are responsible for its high adsorption activity. According to this investigation, faulty Zr-NDC was very successful at eliminating both cation & anion dyes. The framework faults that introduce a strong contact between the faults & molecules of dye were the main contributors to this remarkable capability. Defect-free Zr-NDC had MB & MO adsorption capacities of 585.45 & 537.80 mg g^{-1} & defect-free Zr-NDC had MB & MO adsorption capacities of 746.30 & 725.95 mg g^{-1}, respectively. Zr-NDC possesses greater MB & MO adsorption capabilities than previously examined Zr-MOFs. Notably, the substance's ability to function across a wide pH range from 2 to 7 highlighted how effective it was at eliminating the two dyes. Additionally, it was demonstrated that Zr-NDC could be recycled up to five times not experiencing any performance loss. Due to its effectiveness and viability, zr-NDC flourishes as a suitable adsorbent for eliminating pollutants in water treatment flourishes as a suitable adsorbent for eliminating pollutant in water treatment due to its effectiveness & availability [58]. Metal–organic frameworks based on Hf & Zr are extremely sturdy & permeable substances that have garnered many uses, particularly in biomedicine. The materials are often made using a solvothermal reaction among Hf or Zr ions & organic linkers; however, this process has a long reaction time, produces heterogeneous particles, & yields a low amount of material, making it challenging to make nano MOFs. To improve the efficiency of the synthetic process & maintain particle homogeneity in the nano UiO-66 framework, Y Thi Dang et al. used the microwave approach. The nano MOFs, known as Hf-UiO-66 & Zr-UiO-66, could be created under microwave irradiation in a matter of minutes & had extremely small sizes, high yields, & highly homogenous nanoparticles. SEM, XRD, etc. analysis results exposed that the materials' porosity & structure were comparable to those of the original framework. Furthermore, Hf-UiO-66 & Zr-UiO-66 demonstrated high efficacy in the prevention of curcumin excess by adhering the drug from a solution of water with maximal adsorption capacities of up to 463.02 & 466.39 mg g^{-1}, accordingly, compared to the reported Zr-UiO-66 (393.22 mg^{-1}). Additionally, it was discovered from the adsorption mechanisms that the defect placed in the MOF structure had an impact on the adsorption of curcumin by UiO-66 [59].

5 MOFs & their Dimension

The development of sophisticated MOF architectures, also known as tightly packed meso- & macro superstructures with nanocrystals as their building blocks, is greatly facilitated by the steady & distinctive physical methods of MOF. These MOF structures also possess intrinsic microporosity, which enhances physical presentation & apps in the occurrence of the proper dimensionalities. These dimensionalities include zero- MOFs in the arrangement of resonating microparticles, one-MOFs in the type of nanorods & fibers, two MOFs as tinny films & membranes, & three MOFs as constant & protracted resources [60, 61].

5.1 Zero Dimensional

Very specialized hollow-structured MOFs include closed, solitary- or multilayer resonating ranges, resonating compasses with a single hole, mesoporous hollow spheres, & resonating spheres with a yolk-shell pattern. They can be made of organic or inorganic materials [62]. The existence of static contacts, hydrogen bonds, etc. stabilizes colloidal particle assembly onto templates or at interfaces [63]. Also, to reinforce & steady the exterior skin of resonating ranges, the majority of the synthesis of hollow spheres uses polymer monomers, block polymers, & cross-linked polymerized surfactants. In a study, semipermeable hollow structures were created by growing poly (2-hydroxyethyl methacrylate) brushes using Pickering emulsified interface-initiated radical atom transfer polymerization [64]. In a different work, Si NPs suspended in 3-methacryloxypropyl trimethoxisilane were shaped into resonating silica microspheres with regular overhangs on the inner & external surfaces. This produced surface-modified microspheres with a multilayer projectile of Si elements. Tetraethoxysilane was used in a sol–gel reaction with calcination to link Si particles to the surface of the microparticle while eliminating essential polymer. Resulting hollow micro-spheres remained noted to feature consistent protrusions on the internal & external sides of the shell, interconnected Si NPs, and rapid heating that caused breaking at the connecting layer between Si NPs [65]. The surface shape of microspheres was also seen to improve as the concentration of tetraethoxysilane was raised between 0.04 and 0.48 mmol L^{-1}. Smaller concentrations of tetraethoxysilane led to extremely fractured Si microsphere particles with thin, brittle shells that could not tolerate the shrinkage of the polymer core during the calcination.

5.2 One Dimensional

1D MOFs often have porosity and porous nano fibrillar structures that are additionally beneficial for the deployment of storing vigor & alteration strategies because they offer additional vigorous places & shorten the track of figure & charge transfer compared to certain other sizes (0D, 2D, and 3D) [66]. A versatile, straightforward, and scalable process for creating electrospun Mesoporous porosity or hollowed carbon nanowires (P or HCNFs) is electrospinning combined with carbonization [23]. MOFs with high specific areas and adjustability onto the structure, like ZIF-8 & ZIF-67, have been used in recent research efforts to construct 1D PCNFs or HCNFs. According to studies, the electrospinning method increases the particular area of the surface of nanofibers and prevents micro- and mesopores from obstructing the surface [67, 68].

5.3 Two Dimensional

The focus on 2D nanosheets in MOF research may be a result of the special and crucial characteristics that 2D MOFs possess, including their atomic-ultrathin width with a strong adjacent size, motorized elasticity, huge superficial area, & visual transparency [69]. These features type 2D MOFs ideal for usage in electronic devices, catalysis, energy conversion, power storage, gas separation, and medical applications [70, 71]. The solvothermal approach was used by Natour et al. to create MOF nanosheets utilizing isonicotinic acid as a binder & copper (II) as a metallic particle that was crystallized & luminous in the exfoliated state [72]. In a work by Deng et al., carbon nano-walls atop Ni foams were created via plasma-assisted chemical vapor deposition, and the resulting 2D MOF nanosheets were highly vertically co-oriented. The margins of carbon nano-walls also serve as a mold for the orientated production of MOFs with better conductivity. Carbon nano-walls often operate as dopants & suitable seedbeds for MOFs that develop uniformly [73]. The margins of carbon nano-walls also serve as a mold for the orientated production of MOFs with better conductivity. Carbon nano-walls often operate as dopants a suitable seedbed for MOFs that develop uniformly [74].

5.4 Three Dimensional

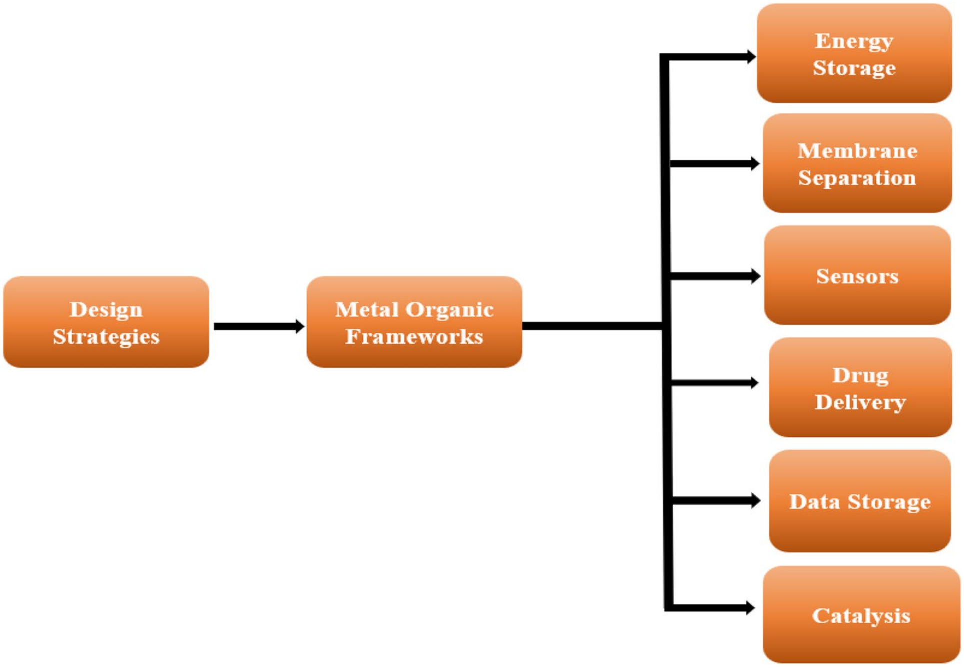
Due to a variety of cutting-edge technologies in sensors, hydrogen fuel, Carbon dioxide storing, gas parting, catalysis, magnetism, medication administration, & other fields, 3D MOFs with their extremely ordered construction, crystal-like nature, & permeability have been popular in a recent study [75]. Although there are several ways to create 3D MOFs, application-oriented MOF superstructures that can effectively carry out essential duties are still required. The following are some examples of 3D MOFs with viable development plans for 3D hierarchy nano-architectures & useful applications.

In a work by Mahata et al., the centers of 2 geometrically distinct Mn^{2+} ions were connected by only a particle of trimellitic acid, resulting in 3D antiferromagnetic MOFs with deformed Kagome layers [76]. Surface-mounted MOFs are thin films of MOFs that have been deposited on pre-treatment substrata with semiconductors, metal/metal oxides, & polymer exteriors in the recent creation of 3D SURMOFs. One such study produced a strongly graphitic nitrogen-doped carbon construct by catalyst Co-Nx moieties using cobalt-based MOF (ZIF-67). Unfortunately, the structure experienced unwanted aggregating of metal Oxide NPs & carbon agendas through pyrolysis, which prevented ions from diffusing into porous structures and sterically blocked active sites. Jia et al. created a three-dimensional macro-porous ZIF-67 thin layer on a polymeric substrate to combat such aggregation and obstruction, using a melamine sponge's 3D macro-porous structure as a scaffold to encourage the formation and development of vertical alignment nitrogen-doped carbon nanotubes-derived SURMOF crystals [77]. Moreover, NaOH was applied to SURMOFs to improve surface functionalization, and Co ions were applied to organic surfaces with terminated hydroxyl groups to stabilize nucleation and growth. According to a work by Feng et al., MOF morphologies structures were created using an unusual small-angle branched mechanism in addition to solid framework 3D MOF synthesis [41]. By causing solvent breakdown, spherulite nucleation, & directed growth via a simple solvothermal reaction procedure, the assemblage of MOF nanorods remained precisely regulated. Well-organized MOF crystallites demonstrated effective catalysis, drug transport, & sensing and displayed a "Maltese cross" pattern of characteristic spherulites under polarised light.

6 Hybrid MOFs

A type of very porous crystalline material called MOF has been characterized as being effectively used in storing energy, hydrogen separation, catalysis, and biomedicine. They are controlled by organic and metal linkers. Unfortunately, some limitations, including poor chemical & thermal stability & low electrical conductivity, prevented MOFs from demonstrating effective & greater useful features & applications. Current developments in the fusion of MOF hybrids combine MOFs with important purposeful components like metal & oxide Nanoparticles, carbon fluids, ionic liquids, etc. [77–80]. The application of these MOFs-based composite materials for catalysis, electrochemistry, storage systems, gas adsorption, biomedical devices, diagnosis, bio-competency, & drug administration has also been demonstrated to be effective [81–84]. It has been found that multifunctional additional groups & MOFs work together synergistically to improve the characteristics of MOF composite materials. In the biomedical industry, metal–organic outline nanomaterials remain increasingly being studied and exploited by way of medication movers. Traditional medicine frequently uses curcumin, a turmeric ingredient

Fig. 6 Applications of MOFs



produced from turmeric, to help cure cancer. ZIF-8 nanomaterial remained successfully altered with a fluorescent organosilica varnish, known as ZIF-8@BPMO, in the study by Trang Thi Thu Nguyen et al. to rise bio-interaction & avoid material flocculation. The synthesized materials were studied using PXRD, FT-IR, TGA, & isothermal nitrogen adsorption at 77 K. ZIF-8@BPMO nanomaterials with a particle size of 100 nm possessed strong crystallinity, a large surface area, & great thermal stability, according to a property study. The study found that this substance had an excellent curcumin retention ability of 666 mg g^{-1} for 15 min. Pseudo-second-order kinetic & Freundlich models were used to predict the adsorption of curcumin on the nanomaterial. Investigations into thermodynamics also revealed a spontaneous & endothermic adsorption mechanism. These findings suggest the fluorescent ZIF-8@BPMO nanoparticle is a material with promise for use in biological applications [85].

7 Application of MOFs Materials

MOFs are often a combination of organic & inorganic porous resources with a remarkable total area of 6000 m^2 g^{-1}. Because of this, MOFs are used extensively in the adsorbed of massive amounts of gases including hydrogen, methane, & carbon dioxide, which helps with energy storage [86]. As will be discussed in more depth below, MOFs have also originated use as devices, high conduction, membrane filtration of gases and fluids, catalysis, & medication delivery as shown in Fig. 6.

7.1 Sensors

The creation of non-enzymatic living devices using MOFs has been broadly used to detect a variety of volatile gases, & eco-friendly toxins, gauge air quality, & make health diagnoses. It has also been demonstrated that ZnO nanowires combined with Pd NPs & ZIF-8 molecular sieve membranes are effective in H detection, where Pd NPs incline to boost compassion or indication, while ZIF-8 improves selectivity [87]. Another work used MOF: MFM-300(X) with different metal centers coupled in the vicinity of biphenyl-3,3′,5,5′ -tetra carboxylate to accomplish the electric detection of iodine gas. Based on I2 gas that has been adsorbed and desorbed, the variability in electronic configuration was determined. The resistance of MFM-300(Al) and (In), where the adsorption efficiency was maintained for the 5 I2 adsorption cycle in air, changed the most [88]. Novel MOF: ZIF-67 functionalized semiconducting oxide (Co_3O_4) as hollow nanostructures encumbered with Pd NPs in the identification of acetone in the breath of diabetic patients. These ZIF-67-laden Pd NPs were calcined to produce PdO NPs that were loaded onto the walls of Co_3O_4 hollow nanocages, functionalizing them. In comparison to PdO-Co_3O_4 powders, Co_3O_4 hollow nanocages, & Co_3O_4 powders, these new MOF assemblies with the large surface area & strong catalytic movement offered better acetone sensing performance of Rair/Rgas = 2.5–5 ppm [89]. In addition to improving the sensitivity & selectivity of gas sensors, MOFs & hybrid materials based on MOFs are important for identifying other environmental pollutants and components. In the biomedicine field, MOF-based sensors have been created to diagnose & treating diseases by detecting bio-analytes such as malignant cells, DNA, etc. A highly effective fluorescent DNA detecting platform was made using iron-based MOF: MIL-88B nanorods with a nano-porous structure in a work by Tian et al. [90]. The entire "mix-and-detect" operation took the sensor about 4 min to complete, and it had a detection limit of 10 pM and good single-point alteration insight. Several studies on MOF-based sensors have revealed that they can accurately detect contaminants, nutrients, heavy metals, & other substances in a variety of samples. These findings demonstrated the consistent and dependable nature of MOF [91].

In agricultural insecticides and pesticides, 4-Nitrophenol, a hazardous substance, is present. The environment and public health, therefore, depend on the removal and detection of this chemical from water sources. To remove & detect 4-NP, Tien Thi My Le et al. created fluorescence-incorporated mesoporous nano-silica. Techniques used to characterize the fluorescent nanomaterial include SEM, thermal gravimetric analysis, nitrogen adsorption isotherms, & FT-IR. The isotherm & kinetics analysis revealed that the multilayer adsorption & the pseudo-second-order model were well suited to the 4-NP adsorption of the nanomaterial with high capacity. Additionally, by controlling the amount of fluorescein isothiocyanate on the nanomaterial, 4-NP at low concentrations may be detected [92]. The research by Linh Ho Thuy Nguyen et al. establishes the capability of a novel iron-based metal–organic framework to efficiently detect low concentrations of volatile organic compounds, particularly acetone. Fe (II)/Fe (III) & two different linkers namely benzene-1,4-dicarboxylate & naphthalene-2,6-dicarboxylic acid were synthesized using a simple solvothermal method. First, the structural & morphological features of Fe-MOFs were characterized to ascertain their pure phase production. With strong crystallinity, good thermal stability, polyhedral crystal-shaped surface morphology, & a surface area of 735 m^2g^{-1}, solvothermal-processed Fe-MOFs have properties that make them appropriate for gas-sensing applications. Fe-MOF powder was printed onto patterned interdigitated electrodes to create laboratory-scale gas-sensing devices. This study offers fresh perspectives on gas-sensing technology by demonstrating the viability of using innovative MOF-based sensing routes as low-temperature gas sensors [93]. For several actual time gas monitoring applications, low-temperature functioning chemo-resistive gas sensors are appealing due to their low control consumption, productivity, & device diminishment. In this connection, Minh-Huy Dinh Dang et al. created a low-temperature working H_2 gas sensor utilizing a unique zinc-based metal–organic framework that has undergone solvothermal processing. The 2-amino terephthalate acidic linker and Zn_4O secondary building units make up the 3D frame structure of the Zn-BDC-NH_2 structure. Before conducting sensing experiments, several conducting sensing experiments, several approaches were used to describe the arrangement, surface form, thermal resistance, area of surface, and chemical composition of the synthesized Zn-BDC-NH_2 materials. Zn-BDC-NH_2 has been demonstrated to be a superior chemo-resistive sensor for the efficient detection of small amounts of H_2 at 50 °C, benefiting from the straightforward synthesis procedure & higher surface area with sufficient porosity. Additionally, the sensor demonstrated full recuperation features at 50 °C, a response value of 2.93–10 ppm H_2, & substantial sensitivities to identifying sensitivities to the identification of lesser H_2 concentrations of 1–10 ppm. The processes for achieving superior H_2 sensing were covered by the author. A possibility exists for the synthesis of Zn-BDC-NH_2 materials with appropriate functionalities and their application in low-temperature H_2 sensors thanks to the room-temperature solvothermal method that was used [94]. The study of M. H. D Dang et al. suggests a solvothermal approach for producing hafnium-organic frameworks with sulphate functionalities for use as low-temperature NH_3 gas sensors. Various approaches are used to characterize solvothermal-processed Hf-BTC-SO_4 to learn about its structural, elemental, morphological, & thermal stability before learning about its fundamental, elemental, morphological, & thermal properties before the gas-sensing research. The functional transformation of SO_4 in the Hf-framework results in good crystallinity & great thermal stability in Hf-BTC-SO_4, according to structural & thermal stability research results of structural and thermal stability research. Microstructural examination demonstrates that nanoparticles of Hf-BTC-SO_4 congregated to form compact clusters. Due to its improved surface reactions, Hf-BTC-SO_4 also possesses an ultra-high exact superficial area of 1100 m^2g^{-1}, making it appropriate for gas detection. The built Hf-BTC-SO_4 sensor demonstrates selective NH_3 gas detection at a lower operating temperature of 100 °C, according to investigations on gas sensing. The Hf-BTC-SO_4 sensor had high response reversibility and could detect NH_3 up to 1 ppm. Strong bonds are formed with NH_3 by the functionalized sulphate bonds & Hf-clusters inside the framework, improving how it interacts between the metal–organic frameworks. This finding may stimulate further investigation into the synthesis of organic functional frameworks for use in low-temperature NH_3 detection systems [95]. A desirable tactic for chemical sensors is incorporating fluorescent organic compounds on a platform to trap metal ions. Chemo-sensors for identifying the presence of cations & anions are manufactured and based on curcumin. In this instance, Duyen Thi Nguyen et al. used the homogeneous nanoparticle porosity zeolitic imidazolate frames ZIF-8 and ZIF-11 with a lower than 100 nm particle dimension as a substrate for curcumin loading. XRD, N_2 sorption isotherms, & thermal gravimetric analyses were used to characterize the ZIF compounds &

evaluate their potential for liquid adsorption. The curcumin concentration, duration, & temperature of the adsorption procedure have been carried out by liquid adsorption inquiry to offer the adsorption characteristics & ability to adsorb two materials. With reported faster adsorption rates compared to different adsorbents, the highest amount of adsorption for both ZIFs is up to 4.5 mg mg^{-1}. Surprisingly, ZIF-8 shows stronger packaging, intraparticle propagation, & reduced parameters of k_2 compared to ZIF-11. The dimensions, area of coverage, & reactivity of the 2-methyl imidazolate binder in ZIF-8 in comparison to the benzimidazole binder in ZIF-11 are used to explain this phenomenon. The dissolution of curcumin under 2% for 24 h in pH 5.5 & pH 7.4 conditions demonstrated the consistency of curcumin's stability in the nanocarrier. Furthermore, the ZIF-8 & ZIF-11 curcumin-based sensors demonstrated effective fluoride ion detecting capabilities with a limit of detection as low as 100 ppm. A significant amount of fluoride ions present in water at pH 5.5 & 7.4 was detected by colorimetric fluorescence sensing in ON/OFF mode, demonstrating in water at pH 5.5 and 7.4 was detected by colorimetric fluorescence sensing in ON/OFF mode, which demonstrated the intriguing perspective of Cur-based ZIF materials [96]. Tan Le Hoang Doan et al. created ZnO/CuO nanocomposites from a metal–organic framework (MOF) using a straightforward precipitation technique. The gas sensing capacity of several gases was impacted by the mesoporous nature, crystallinity, and tiny particle size of the synthesized ZnO/CuO nanocomposites. On low quantities of H_2S gas, it was discovered that the ZnO/CuO gas detector displayed the maximum sensing capability about reaction, selectivity, & repeatability. The texture coefficients of the ZnO and CuO phase works of art, which led to the development of a significant number of p-n junctions & quantum-confined effects in the nanocomposite in addition to the lower binding power of H_2S, were used to explain the strong sensing efficiency, the quick response time, & the recovery time. The quick sensing capability of a low H_2S solution emphasizes the practical significance of these ZnO/CuO nanocomposites generated from MOFs [97]. Tan Le Hoang Doan et al. successfully synthesized & well-characterized nano-heterojunctions of n-ZnO/p-Co_3O_4 with various molar ratios of Co_3O_4 produced from a zeolitic imidazolate framework. Then, several gases, including ethanol, were sensed using the heterojunction-based gas sensors. The heated n-ZnO/p-Co_3O_4 with 30 mol% ZIF-8/ZIF-67 structure is one reason for this. In terms of high responsiveness, exceptional selection, & good persistence for low ethanol concentrations at 300 C, Co_3O_4 was the best sensor. According to a thorough analysis, the excellent ethanol-sensing achievement of the n-ZnO/p-Co_3O_4 the nanocomposite could be assigned to the sensing materials' high porosity, the p-n heterojunction formation at interactions, the catalytic properties of Co_3O_4, & the elevated crystallinity of the ZnO phases in the nano-heterojunctions [98]. It has been widely employed as an effective strategy to increase their applicability to functionalize & incorporate noble metals into metal–organic frameworks. Here, a Pd-embedded composite and a sulfone-functionalized Zr-MOF framework designated Zr-BPDC-SO_2 were successfully synthesized by modifying their functional groups. To evaluate the compounds' potential for use in gas sensing applications, they were characterized. The new sensor materials were characterized using XRD, FT-IR, SEM, & thermogravimetric analyses. The novel modified sensor materials ' gas sensing capabilities were comprehensively examined under varied levels of concentration, temperature, & gas-type conditions the novel modified sensor materials' gas sensing capabilities were comprehensively examined. Zr- BPDC-SO_2 has become a successful sensor for the detection of ethanol due to the potent hydrogen bonds formed by the sulfonyl group & Zr6 clusters in the framework with the hydroxyl groups of ethanol. What's more, the facts demonstrated a stronger sensing retort to hydrogen than to other gases, emphasizing the critical function of Pd in the Zr-MOF-based hydrogen sensor. The findings of the detection experiments conducted in this research show that the materials in use have a promising future for applications in real-world gas monitoring [99].

7.2 Catalysis

The MOF structure's porous & crystalline nature enables an equitable distribution of catalyst surface across the framework & makes it simple for substrate & products to reach active sites. According to a rising number of papers on the catalytic process of CO, CO_2, & CH_4 into unsoiled fuels & elements, both pure & modified MOF are more effective than typical homogeneous catalysts in a variety of heterogeneous catalysis reactions. By way of the instance of C1 chemistry, there is an increasing quantity of reports on the catalytic transformation of CO, CO_2, & CH_4 into renewable energy sources & chemicals. The unique characteristics of pristine & improved MOF have been initiated to be more effective in different mixed catalysis processes than conservative same catalysts. This heterogeneous catalysis uses MOF metal nodes as catalytic spots to carry out C–H bond activation, which necessitates integrating biochemical sites into organic struts before integrating effectively vigorous classes into the pores of MOFs [100]. In addition to their use in C1 chemistry, MOFs were also found to be highly effective in acid–base consecutive catalytic processes produced via grafting & condensation techniques [101]. The dimensions of MOFs have a crucial influence on the activation of a reaction & the production of the goods rather than just being dependent on the permeability & modified ligands on the agenda. The relationship between the dimensionality & the vigorous places of the MOF catalyst for the CO_2-epoxide cycloaddition response was examined by Babu et al. At varied coordination environments, seven distinct dimensional In (II) based MOFs were employed as solid acid substances. The catalytic efficiency of In3 + /TBAB in a CO_2-PO reactive system demonstrated that 1D MOFs with unsaturated metal centers had healthier catalytic activity than 2D and 3D MOFs, changing 91% of propylene at 50 °C during 12 h [102]. Therefore, detailed analysis in scheming MOFs' dimensions, functionalization, & other outlines is necessary to create MOF catalyst-based reactions that can outperform those of conventional catalysts now in use. These findings highlight the need for detailed study while building MOF dimension, functionalization, & other frameworks to create MOF catalyst-based reactions that can perform more effectively than those currently utilizing conventional catalysts. At this stage, it is also significant to highlight those innovations in MOFs, such as precise ligand substitutions & functionalization, has produced more unpremeditated versions of MOFs & increased their catalytic activity even for living particles [103]. These altered MOFs tend to improve catalytic efficiency, prolong shelf life, & stabilize enzymatic molecules [104, 105]. In recent years, MOF-based multi-component reaction catalysts have been stated & shown to be effective at producing numerous organic compounds in a single pot while performing dual functionality [102, 105]. In addition to this, extremely permeable MOFs provide unchanging reactant dispersal into the inner superficial that interacts with metal centers, resulting in an outstanding catalytic performance with length & stereo-selective organic compounds. In research of Taher et al., it was shown that the oxidation of numerous alcohols, fluctuating from hetero-aryl to long-chain alkyl elements, to their respective products, was highly effective when 2,2,6,6-tetramethyl-piperidinyl-1-oxy was used as a co-catalyst. This Cu-MOF catalyst was discovered to be effective without bases, discerning, affordable, and reusable a minimum of five times without losing any catalytic activity [106]. By spreading the sulfone-functionalized MOF in Pd $(OAc)_2$ solution, Minh-Huy Dinh Dang et al. successfully created the Pd-incorporated Zr-based metal–organic framework Pd (II)BUT-11. The characteristics of the Pd-incorporated MOF were studied using XRD, SEM, etc. In the catalytic investigations, Pd (II)@ BUT-11 was demonstrated to be a highly effective heterogeneous catalyst for the cross-coupling Heck process using deep eutectic solution generated from DABCO as a green solvent. Particularly, both the catalyst & the solvent were recoverable and reusable, and their structure and activity remained constant throughout the course of numerous tests. The procedure yields a green and effective way to synthesize stilbenes by offering an alternative to traditional catalysts & solvents. Due to the limited solubility of DES in ethyl acetate, the stilbenes were additionally isolated by extraction [107]. Due to their strong catalytic activity, functionalized metal–organic frameworks have recently attracted a lot of attention in heterogeneous catalysis applications. In the study of Minh-Huy Dinh Dang et al., a Hf-MOF called Hf-BTC made of Hf6 clusters and 1,3,5-tricarboxylate linkers was sulfated to create a sulfate-functionalized Hf-cluster-based metal–organic framework. As a result, it was shown that the Hf-BTC-SO_4 material worked effectively as a superacid catalyst for a one-pot, three-component pyramid [1,2-a] benzimidazoles synthesis reaction. The sulfated Hf-BTC was able to catalyze a reaction in benign, solvent-free conditions that produced excellent results on a variety of substrates. According to a thorough examination, the high porosity framework and the extremely active regions of the customized clusters are likely the causes of the sulfated-functionalized MOF's good catalytic performance. The functionalized framework could be recovered and used numerous times with very modest alterations to the catalyst's catalytic performance [108]. Diverse chemical compounds have been prepared using green chemistry & other techniques. The use of heterogeneous catalysts, ecologically friendly reactions, & high-yielding techniques are gaining popularity. Linh Ho Thuy Nguyen et al. successfully synthesized & characterized a faulty 6-connected Hf-MOF called Hf-BTC for heterogeneous catalysis with microwave irradiation. The MOF properties of a structural defect, porosity, acidity, & stability were examined by using XRD, N_2 sorption isotherms, acid–base titration, & structural defect analysis. In the catalytic investigations, the Brnsted-Lewis dual acidic HfBTC was successfully used for the cycloaddition & condensation processes that produced the heterocyclic compounds. In a short period, the reactions went smoothly with the Hf-MOF present, producing the desired products with moderate to high yields, & the catalyst was simple to recycle across numerous subsequent reactions without losing its reactivity [109]. In his research, Linh Ho Thuy Nguyen and colleagues concentrated on employing VNU-11-SO_4 to optimize the transformation of glucose and fructose into HMF while utilizing a liquid with ions as a green solution. With the employment of a VNU-11-SO_4 catalyst in an ionic liquid containing 1-ethyl-3-methylimidazolium chloride, the maximum yield of HMF from glucose & fructose was achieved at 28% & 27%, respectively. When the catalyst was examined after recycling, the HMF production decreased only marginally, indicating a potential industrial use for it in the conversion of biomass [110].

7.3 Membrane Separation

The exceptional porosity, variable pore size, and functional sites of MOFs-based membranes are widely sought after because they maximize selectivity and the relationship of a liquid or gas molecule with the membrane. When it comes to gas storage & separation, MOFs are linked to energy storage for methane and hydrogen, which produces clean energy, environmental protection for CO_2 separation, & industrial production for CO & NH_3 gases linked to pollution prevention and chemical synthesis [111]. Polymers dominate membrane technologies because of their low cost & simple processing requirements. However, these polymeric membranes have poor gas permeability & selectivity when used for gas separation [112]. Due to this, researchers are now combining polymers with MOF to provide the gas permeability & selectivity needed for desirable gas separation and storage. Altintas & Keskin conducted a molecular simulation of MOF membranes in recent works & made predictions about polymer-combined MOFs for separating CO_2 from a CO_2/CH_4 combination [113]. In a work by Hu et al., 2D ZIF-8/GO hybrid nano-sheets were used as seeds to create a free of flaws ZIF-8/GO membrane with a width of 100 nm. Fast crystal intergrowth is often made easier by placing a hybrid seed in the membrane, which also tends to remove flaws through the contra-diffusion procedure. The outcomes demonstrated that these molecular filters effectively separated gases with a high CO_2/N_2 selectivity of 7.0 [114].

A sequence of Zr-based MOF membranes with the ability to separate gases was created by Ghalei et al. in a different work by altering their organic ligands & functionality. Because of the molecular sieving result brought on by the presence of large linkers, the Zr-based MOFs demonstrated better hydrogen selectivity. However, more benzene rings prevented larger penetrants besides hydrogen from diffusing [115]. In addition to gas separation, the application of Nanoparticles & polymer-based mixture MOF membranes in liquid parting procedures like pervaporation, the action of water, & solvent-based nano-filtration in biological refineries, petrochemical productions, & drugs have been described. The type of membrane material selected, high flow rate & substance refusal, module, etc. are the variables affecting the efficiency of MOF membranes in liquid parting.

7.4 Drug Delivery

In the discipline of biological medicine, methods for delivering drugs are an important step in treating or controlling the condition, disease, or infection that has been detected. In this instance, MOFs have efficient construction, a high superficial area, & a big pore capacity that makes them stand out from other materials. These frameworks can trap drug molecules in the pores & adsorb useful molecules to the surface. Furthermore, to be environmentally friendly & biodegradable, MOF's porosity allows it to contain large amounts of anti-neoplastic medicines [116]. According to reports, the most frequent methods for functionalizing MOFs include covalent bonding, superficial adsorption, pore encapsulation, & using useful molecules as structure blocks in one-pot or post-synthetic variation processes [117]. MOFs could be referred to as interest nanocarriers that in an effective drug delivery system to achieve embattled drug distribution, improved cellular approval of drugs, & precise proclamation of medicine dosage, including antimicrobic substances, chemotherapy medicines, anti-glaucoma substances, metabolic describing of particles, & hormones [118, 119]. Zr-based MOFs remained functionalized with bromo, nitro, & amino linkers in a work by Orellana-Tavra et al., & their suitability for biological & controlled drug administration was evaluated. To control the drug distribution, functionalized MOFs were burdened with the fluorescent model compound calcein & the anticancer medication -cyno-4-hydroxycinnamic acid. In the instance of Bromo- & nitro-functionalized MOFs, the results only showed a small portion of the entire loaded drug, whereas amino-functionalized MOFs showed a 15-day slow & progressive drug release. The balance between the MOF pore size & the guest particle's molecular size that must be put inside the MOF framework plays a crucial role in the successful & long-lasting issue of the medicine, according to the researchers. Additionally, the endophytic pathway, which is still crucial for MOF entry into cells, results in drug distribution to a variety of cell types, which in turn has a variety of therapeutic benefits. This necessitates the need to comprehend cellular mechanisms & develop more efficient MOFs for delivering medications tailored to particular cells or tissues [120]. In one of their most new research, Nagata et al. created MOF: UiO-66 that had been post-synthesized to include N-isopropyl acrylamide (NIPAM) & acrylic acid (AA). By being pH & thermos-responsive, the polymer in MOFs demonstrated a quick & reversible coil-globule transition, which released the guest chemical procainamide in a one-off fashion. The polymer adopted "coil form" & liberated guest molecules from the MOFs at a pH level of 6.86 & low temperatures below 25 °C, whereas it took on "globule form" at a pH level of 4.01 at a high temperature of >40 °C & inhibited the announcement of guest particles. Additionally, it was claimed that the UiO-66-P(NIPAM-AA) retorted to outside stimuli in a way that allowed drug release to be stopped even afterward it had begun. As a result, innovations and further progress in the design of MOFs would make targeted medication delivery as well as controlled diffusion of therapeutic agents possible [121]. Metal–organic frameworks that have been combined with biomolecules, or "b-MOFs," are becoming more and more popular for use in biomedical applications. However, because of the intricate architectures made of lengthy organic linkers, these materials are problematic and difficult to synthesize at the nanoparticle scale. Here, Linh Ho Thuy Nguyen et al. show that b-Zn-BPDC & b-Zn-azoBDC, nano-b-MOFs comprising nucleobase adenine as biomolecular components, can be easily & successfully synthesized by the use of cleansers & a post-synthesis linker-exchange technique.

The linker-exchanged MOF nanotechnology demonstrated a better loading ability for paclitaxel, an insoluble in-water anticancer medication, than its original framework because of its large pore size. A rise in PTX solubility was also seen in the issue profiles of PTX-loaded b-MOF nanoparticles in phosphate-buffered saline, with a significant early medicine proclamation trailed by a gradual issue over time. These findings suggested that hydrophobic anticancer medicines can be delivered using nano-b-MOFs [122]. Metal–organic frameworks at the nanoscale have shown promise in biological & sensing applications. Y Thi Dang et al. successfully synthesized a nano Zn-BDC-NH_2 imprinted MOF utilizing the co-surfactants approach, and curcumin adsorption was studied. The nanomaterial displayed alike structural & other physical properties to its original framework, but the size of its particles was very small at about 50 nm, according to an analysis of the synthesized MOF using characterization techniques like SEM, XRD, FTIR, etc. The nanomaterial demonstrated an excellent capacity for adsorption on Zn-BDC-NH_2 up to 179.36 mg g^{-1} as well as quicker adsorption in comparison to other adsorbents as a consequence of the curcumin adsorption experiment. According to the findings, the tiny Zn-BDC-NH_2 MOF is a potential material for use in biological applications [123].

7.5 Energy Storage

Because MOFs are an excellent synthetic tunable material that is amenable to both biochemical and structural control, they have achieved a significant milestone in the cumulative need for renewable energy storage & distribution. Recently, scientists have optimized MOFs' distinctive qualities, including their permeability, area of coverage, constancy, morphology, conduction, & scalability, for use in energy storage [124]. The adaptability of the MOFs framework, redox-active functionalities, & remarkable host–guest chemistry pushes it toward metal-ion anodes when constructing MOFs-based metal-ion batteries. Redox-active metal centers & ligand moieties that stabilize lithium are said to increase the overall quantity of lithium ions stored, increasing the theoretical capacity [125]. Additionally, the reversible storage of metal ions in MOFs is made possible by their porosity, which also exhibits interfacial interaction with the electrolyte solution to facilitate ion movement. In one work, POM-based MOF composites were created by including POM at the node construction, which improved Li^+ insertion/extraction & the durability of POMs encouraged the long-term cycling capabilities [126]. In a work by Park et al., conjugated coordination between Co (II) as metallic centers and hexaaminobenzene (HAB) as a redox-active linker was used to create Co-based 2D MOF [127]. Co-HAB were shown to have reversible three-electron redox reactions per HAB that are stable, accessible, and have dense active sites. Consequently, it emerges as a potential material for electrodes for sodium-ion storage. Co-HAB has an electric conduction of 1.57 S cm 1 and an unusually highrate capability, bringing 214 mAh g^{-1} in 7 min or 153 mAh g^{-1} in 45 s. The application of metal oxide films as a possible material for electrodes for electrolytic energy storage devices is hampered by their instability. Zheng et al., manufactured an extremely alkaline steady metallic oxide-based MOF complex, Co_3O_4@Co-MOF, in an extremely alkaline state using., a controllable one-pot hydrothermal technique. Exceptionally, the aforementioned prepared MOF exhibited alkaline durability in 3.0 M KOH for 15 days retaining its same structure [128]. Additionally, Co_3O_4@Co-MOF demonstrated remarkable cycling stability with just 3.3% deterioration after 5000 cycles at 5 A g^{-1}, a specific capacitance that was as high as 1020 F g^{-1} at 0.5 A g^{-1}, and a huge surface area. Experiments have been carried out using a molecular simulation technique to evaluate the thermal storing capability of pure & complex MOFs using the grand canonical Monte Carlo method & traditional molecular dynamics simulation. R125/UiO-66 and R125/MOF-5 were MOFs that were tested for their ability to store thermal energy. R125/UiO-66 proved to retain a smaller amount of energy than R125/MOF-5, despite the temperature variation being between 30 and 50 K [129]. For methane storage, metal–organic frameworks must strike a compromise between their density, adsorption thermodynamics, internal pore environment, & porosity. Here, the author describes the creation of a new Zr-MOF, known as MOF-700, that was mutilated with various Cu (II) salts to form an is reticular sequence comprising three new, highly permeable MOFs. By using X-ray absorption spectroscopy to pinpoint the locations of the metallated sites, it was discovered that the metallated frameworks have high-volume methanol retention operating capacities. This is a 50% improvement over the parent MOF-700's performance & emphasizes the possibility of optimizing biogas working storage capacity through post-synthetic metalation [130].

7.6 Data Storage

a multi-mode memory device for a variety of tasks in integrated circuit applications, current–voltage characteristics are crucial. However, academics have always found it difficult to study producing and managing multipurpose devices. This investigation modulates charge transfer processes in thin films by uric acid (UA) molecules that reside within the UiO-66 matrix. The Ag/UiO-66-UA-PVA/Ag device demonstrated bipolar & self-rectifying resistance switching behavior under the applied voltage, which has applications in minimizing current leakage in high-density crossbar systems & non-volatile data storage [131]. A memory with a cross-bar array design is urgently needed in the era of big data to enable high-density data storage. Threshold switching-based selectors & resistive switching memories have both been used for eliminating the sneaky path power of integrated circuits. In the study by Hau Huu Do Ho et al., uric acid was successfully absorbed into an UiO-66 matrix at room temperature without causing any damage to the host crystal structure. While the peak frequencies in the X-ray diffraction spectrum of the (111) & (200) index planes were slightly moved to the lower 2q values, showing that the effect of the UA on the system is occupied porous cages and free volume structures, FT-IR revealed the existence of UA based on the communication of its carbonyl group within the UiO-66 matrix. The considerable decrease in surface area from 1299 to 950 cm3 g1 and the virtually complete disappearance of UiO-66 porous cages of 12.5 by BET analysis have been used to estimate the occupancy of UA in the porosity volume of the framework. The data from photoluminescence spectroscopy showed that the electronic transitions from intermediaries to metallic and intramolecular between closest intermediaries of UA-absorbed UiO-66 were significantly reduced. These modifications in morphological & electronic density cause the conduction of electricity mechanism, the voltage of operation, & resistant switching characteristics of the Ag/UiO-66 ePVA/Ag & Ag/UA@UiO-66 ePVA/Ag device, respectively, to transition from memories switches to the threshold. The development and management of silver metallic filaments via the UA@UiO-66 ePVA matrix are hampered by the reduction and disappearance of porosity cages and free volume. To manage the conversion switching behavior between memory and thresholds in metal–organic framework elements for high-density cross-bar architecture, a new method is presented in this study [132]. The advantages of possessing excellent insulative qualities, well-defined buildings, an extensive particular surface area, & changeable pore size have recently drawn a lot of attention for application in resistance random access memory. The storage technology based on zirconium (IV)-carboxylate MOF nanoparticles in Tram Nhu Hoang Tran et al.'s paper has low operation voltage, a high ON/OFF ratio, great durability, & long-term retention. Conducted atomic force microscopy was utilized to better understand the resistive switching process of the Ag/PVA-MOF/FTO device. The results show that the resistance-switching behavior is simultaneously influenced by all of the electrodes, Zr6 clusters of UiO-66, PVA, and conjugation. The formation/rupture of the metal filaments in the bipolar mode of switching or the electron hopping mechanism between Ag + ions and Zr6 nodes in threshold mode can both regulate the resistance switching. Unexpectedly, the high porosity and big cages (octahedral, tetrahedral) of MOF materials have a significant impact on the device's switching mechanism and transport properties. Future research and applications could benefit greatly from a complete understanding of these UiO-66 resistive switching properties and mechanisms, not only for UiO-66 but also for all other MOF materials [133].

8 Future Advancements & Possibilities for MOF

Scientists have tagged MOFs to match the properties of wanted materials in their pursuit of novel adaptable materials that are tuneable for a larger variety of applications. For evidence, both pure & hybrid MOF synthesis has improved recently, and the expansion of MOF-based product applications has outpaced that of the manufacturing revolt. The distinct & extremely structured characteristics of MOFs, like their surface area & permeability, as well as post-synthesis changes like functionality, managed structure/frameworks, & metal-based nodes, as well as their synthesis using designs or self-sacrificing materials, as well as the layout & experimentation of pure & mixed MOFs based on their physicochemical properties using molecular simulation methods, open up a wide range of potential applications. Typically, self-sacrificing materials like carbon-based substances, oxides of metals, metallic NPs, metallic carbides, & sulfide mixtures are investigated for the purpose to create highly focused nanostructures that can be used in heterogeneous catalytic actions, storage of energy, empathy, & selectivity-based separating the membranes, detectors, drugs create, & numerous other fields. It is difficult to fully comprehend the mechanisms underlying modification, change in structure, regulation of fine structures, open-metal sites & compositional structure, aligned pores, & a substantial surface area. The instabilities of MOF-based goods in water, poor electrical conductivity, the absence of multiple or multi-metallic sites, & vulnerability to certain chemicals are a few of the problems that have prevented their widespread use. A successful mount in the manner of nano-porous-based goods needs environmentally friendly improvements in MOF layout, even though recent advances show that water-stable MOFs have appeal for creating fluid separation pores, based on carbon & metallic NP-based MOFs improved conductivity, & a high level of thickness metal sites-based MOFs offered multifaceted compassion in radars, & steadiness to high alkalinity. In terms of the commercial or industrial market, MOFs still show a gap between theoretical development & actual use. This could be a result of difficulty starting a straightforward synthesis technique & cost-effectiveness. The mathematical & theoretical approach to removing MOFs in their natural & combined states will be the gap-filling method in New years that will offer an in-depth consideration of their creation process, functioning sites, designs, positioning of pores, & the area of the surface.

9 Conclusion

The scope of the current review includes a varied choice of info about MOFs, from their meaning to their use & potential applications in the future. The cited literature would then go on to describe the composition of MOFs, methods researchers used to get around instability & a wide range of selectivity, as well as the specific characteristics of MOFs. These characteristics would include their dimensions, functionalities, & applications. A countless arrangement of research has been done on MOFs, which have become increasingly popular over the past 10 years, reflecting the efforts of the scientific community to develop a material that is superior to what is now available.

Because of this, hundreds of MOFs have been synthesized & their structural orientation has undergone multiple modifications to suit various particular uses. The future possibilities & advancements of MOFs, which must be started by colleges & colleges, government-funded research institutes, & organizations in together emerging nations & established Nations, examine the problems and breaches that remain. Without a doubt, the development of MOF applications has helped to address environmental problems, but going forward, it will be important to identify more environmentally friendly methods for producing and discarding MOF-based products. This can be taken into account specifically in the increased use of syntheses and MOFs. However, the majority of the materials produced using these alternative methods are copies of well-known ones. Therefore, it is certain that MOFs will be made in an easy, quick, inexpensive, and environmentally friendly manner. To meet all of the requirements, a significant number of MOFs will be prepared.

Additionally, MOFs are poised to excel in five areas: adsorption, catalysts, devices, electrochemical charge storage, & drug distribution systems. Numerous other MOF applications apply to & are relevant to these examples. The difficulties & directions that MOF chemistry faces are what drive its sustained growth in popularity and promising future.

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Declarations

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