**INVESTIGATION OF METAL-ORGANIC FRAMEWORK**

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**Abstract:**

The metal-organic framework (MOF) family includes zinc imidazole framework-8, often known as ZIF-8. Zinc metal is properly coupled with an organic ligand or fragment in ZIF-8's chemical structure, creating a cage-like three-dimensional network with distinctive porosity. Due to its unique architecture and physicochemical properties, ZIF-8 has recently been researched in a variety of applications, including gas storage, catalysis, electrochemical sensing, drug delivery, etc.

**Introduction:**

Porous materials have gotten a lot of scientific interest during the last five decades because of their inherent properties including large surface areas, massive pore volumes, and tuneable hole sizes, and the research will continue to develop in the future [1]. They are defined as any solid that has pores and voids and serves as the foundation for porous materials. Microporous, mesoporous, and macroporous materials are the three categories of porous materials. In microporous materials, micropores with widths or diameters of 2 nm can be discovered [2-3]. Mesoporous materials feature holes ranging in width from 2 to 50 nm, and macroporous materials have pores larger than 50 nm. The term "nanoporous" has lately become popular. Moreover their catalytic activity and absorption, porous materials have attracted the interest of many researchers to be developed for commercial application [4]. Zeolites, which are now widely employed in commercial water softening and purification as well as hydro-cracking catalysts in the petrochemical sector, are an example of a success story of this evolution and have grown into a giga-dollar international market. Assembled from metal ions and organic ligands, metal-organic frameworks (MOFs) are a type of nanoporous materials that show interesting characteristics, tuneable topologies, and a variety of functions [5]. Zeolitic imidazolate frameworks (ZIFs), a novel and distinct type of MOFs made up of metal ions and imidazolate linkers, have recently been discovered. ZIFs have a variety of structures that are similar to those of standard aluminosilicate zeolites. In zeolite frameworks, M2+ ions typically play the role of silicon while imidazolate anions create bridges that play the role of oxygen, with the M-Im-M angle being around 145o [6-7]. Numerous ZIF materials offer a variety of possible uses due to their inherent porous properties, extensive functionalities, and remarkable thermal and chemical stabilities. Due to their molecular-like organic-inorganic crystal structure, ZIFs have also been shown to be efficient precursors or sacrificial templates for the development of porous carbon-based nanocomposites [8].

**Development of Metal-Organic Framework (MOF):**

Due to their tremendous uses, metal-organic frameworks, or MOFs, are incredibly dynamic materials. When an inorganic component is joined to organic ligands by coordination bonds, MOFs organic-inorganic crystalline porous materials are developed. Two of the many intriguing aspects of these materials are their high and persistent porosity, as well as their flexibility in pore design and function. Due to their qualities, they may be used for a wide range of tasks, including encapsulation, medication administration, gas detection, and catalysis. The surface area per gram of the MOFs developed by researchers is around 7800 square meters. For example, a full soccer field's worth of surface area may be filled with just a teaspoon-sized amount of this MOF compound [9].

Numerous applications, including gas storage and separation, liquid separation and purification, electrochemical energy storage, catalysis, and sensing, take advantage of the cage-like structure of MOFs. In addition to their direct applications, MOFs have been used as exceptional precursors for MOFs and have been exploited as excellent precursors for the manufacture of inorganic functional materials with unmatched design possibilities, such as carbons, and metal-based compounds, and their composites, in addition to their direct uses. Adsorption, catalysis, batteries, fuel cells, super capacitors, drug delivery, and imaging are just a few of the many uses for carbonaceous materials. Because they are so directly linked to human health, several sensors are crucial applications for carbonaceous materials [10–11].

Some of the essential ideas guiding the development of MOFs were derived from concepts found in the more venerable domains of coordination chemistry and zeolite chemistry [12].

Coordination chemistry, which focuses on the interactions of organic and inorganic ligands with metal centers and examines topics like isomerism and bonding in coordination compounds, is ascribed to Alfred Werner (1913 Nobel Laureate). Werner is also credited with founding the field of chemistry. Some of the earliest MOFs feature an inorganic component that contains lone polyhedral or tiny clusters similar to what is seen in coordination chemistry. Zeolite chemistry pioneered the idea of SBUs, leading to the creation of over 40 naturally occurring and 190 artificial zeolite frameworks with distinctive structural and topological characteristics. In the context of MOFs, this relates to the architecture of the units indicated by the point of extension, including the carboxylate C atoms in the vast majority of carboxylate MOFs [13-14].

**Zeolite Imidazole Framework (ZIF):**

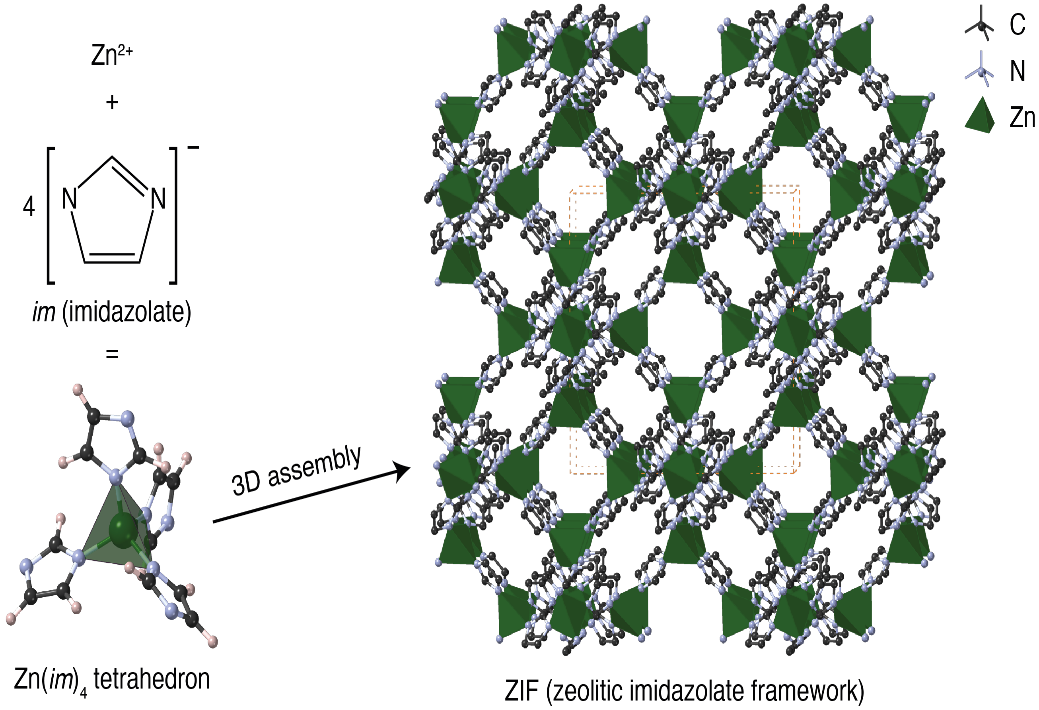
A particular kind of MOF named ZIF-8 was produced in my most recent work and subsequently used in other syntheses. Copolymerizing zinc and cobalt ions with imidazole-type linkers yielded the zeolitic imidazolate frameworks that served as the foundation for the ZIF series MOFs. The ZIF structures are made up of nets of seven distinct aluminosilicate zeolites, with the tetrahedral Si/Al clusters replaced by Zn or Co and the bridging O replaced by bridging imidazolate [15].

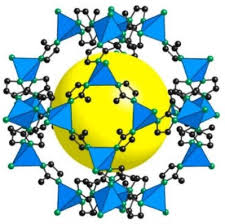
Since then, ZIF glass has received substantial interest from researchers as an unearthed form of well-known material. ZIF-4, ZIF-62, ZIF-76, and perhaps ten additional MOF family members have all been successfully converted to their glassy states. Glass can be categorized into three main groups in conventional materials science: inorganic, organic, and metallic. As chemical bonds, the structure is made up of mixed ionic/covalent, covalent, or metallic bonds. MOF glass, a relatively novel organic-inorganic coordinated glass, differs greatly from the three previously described glasses in structure. It is known as the fourth type of glass [16].

Zeolites are particularly useful in catalysis. Zeolites are limited in size because of the continuous tetrahedral coordination of the Si/Al connecting points and the two-coordinated oxide linkers. There are only roughly 200 zeolites that have been identified. In contrast, MOFs feature more diverse coordination geometries, polytopic linkers, and auxiliary ligands (F, OH, H2O, to name a few). Furthermore, obtaining zeolites with pore sizes bigger than 1 nm is challenging, restricting zeolitic catalysis to relatively small organic compounds (usually no larger than xylenes) [17].

**Structure and Different Forms of ZIF:**

ZIFs have superior thermal and chemical stability when compared to other MOFs. For instance, ZIF-8 maintained its complete crystallinity when suspended for 7 days in boiling water and several chemical solvents. In comparison to MOF-5, which has a porous cubic structure and decomposes at 450 °C in N2, ZIF-8 can withstand temperatures of up to 550 °C. ZIFs feature persistent porosity similar to zeolites and consistent pore size. For many years, the industry has relied on zeolites due to their durability in harsh environments. The similarities between zeolites and ZIFs have aided in understanding the fundamentals of ZIFs, as many of the concepts may overlap with those of zeolite chemistry, and will eventually aid in the implementation of ZIFs for industrial purposes [18].

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**Figure-1: Structure of Zeolitic Imidazolate Framework (ZIF)**

Additionally, ZIF materials would make excellent templates and precursors to generate porous carbon materials under the right synthesis circumstances because of the highly organized porous structures with rich organic species. Additionally, carbon composites containing nanostructured metal/metal oxide species are more likely to occur during the in situ carbonization process because of the regular arrangement of metal species in ZIF precursors. Under specific controlled synthesis conditions, the pure metal or metal oxide could likewise be produced from ZIF precursors. Future nanomaterial preparation and application will be made easier by these simple synthetic methods [19]. Due to structural variances, ZIF was categorized into numerous categories. ZIFs include ZIF-70, ZIF-69, ZIF-9, ZIF-14, ZIF-68, ZIF-90, ZIF-64, ZIF-11, ZIF-8, ZIF-L, ZIF-7, and ZIF-67. ZIF-8, ZIF-L, and ZIF-7 contain Zn2+, but ZIF-67 contains Co 2+. Unlike the others, ZIF-7 was produced in dimethyl formamide rather than water. The organic linker used for ZIF-8, ZIF-L, and ZIF-67 was 2-methyl imidazole, but ZIF-7's was benzimidazole [20].

**Synthesis Methods of ZIF – 8:**

This chapter investigates and presents the most recent breakthroughs in ZIF material synthesis, applications, and ZIF derivatives.

**ZIF Powder Synthesis:**

Most ZIF materials, particularly in the early stages of ZIF research, were created as powders that were isolated from reaction mixtures after solvents or other contaminants were removed. To date, both solvent-based and non-solvent-based synthesis techniques for powder-based ZIF materials have been developed [21].

**Solvent-Based Synthesis:**

**Solvothermal Method:**

ZIF-1 to ZIF-12 crystals were produced using organic solvent systems such as N, N-dimethylformamide (DMF), N, N-diethyl formamide (DEF), and N-methyl pyrrolidine (NMP). 55 DMF/DEF/NMP were also utilized as solvents in the synthesis of various ZIF materials, including ZIF-60 to ZIF-77, 56 ZIF-78 to ZIF-82, 66 ZIF90, 25 ZIF-95, and ZIF-100. Later, several researchers synthesized ZIFs with DMF or DEF to examine the method of production and relative characteristics. Modified recipes based on Yaghi's approach have recently been created Organic amines like pyridine and triethylamine (TEA) were added to the DMF or DEF solvent as deprotonating agents to boost material synthesis. For example, ZIF-78, a micron-sized hexagonal rod-shaped crystal, was produced using TEA, whereas ZIF-90 was produced by adding pyridine to DMF at ambient temperature [22].

**Hydrothermal Synthesis:**

Organic solvents are undoubtedly costly, volatile, and hostile to the environment, in contrast to the straightforward hydrothermal synthesis method that was prevalent in the early phases of ZIF research. Recently, significant effort has been made to produce ZIFs in an eco-friendly and straightforward manner by using fewer or, ultimately, no organic solvents at all. Pan et al. were the first to demonstrate the production of ZIF-8 in an aqueous solution at ambient temperature using a simple procedure: after stirring for about 5 minutes, the zinc nitrate solution was combined with the 2-methylimidazole (MIm) solution, and the products were recovered by centrifugation. However, given that the stoichiometric molar ratio of zinc ions and MIm in ZIF-8 is Zn2+: MIm=1:2, it is clear that an excess of MIm (molar ratio of Zn2+: MIm=1:70) was squandered in this technique. The synthesis of ZIFs from stoichiometric molar ratios of metal ions and I'm derivatives in alkaline solutions have therefore been the subject of much effort. Miyake et al., in particular, were successful in creating pure ZIF-8 crystals in an aqueous solution at ambient temperature, and the crystalline ZIF-8 could be formed from a molar ratio of Zn2+:MIm =1:20. Furthermore, Qian's group revealed that ZIF-67 nanocrystals could be produced in aqueous solutions at room temperature using the molar ratio of Co2+: MIm: H2O =1:58:1100 [23].

The addition of chemicals to water-based systems for ZIF manufacture also changed them. To restrict the use of the ligand MIm and begin the creation of ZIFs, deprotonation agents TEA 26 and ammonium hydroxide 83 were both used. The metal ion: MIm molar ratio may be decreased to 1:4 thanks to Gross and colleagues' ability to synthesis ZIF-8 and ZIF-67 in an aqueous solution with the addition of TEA at room temperature without the production of by-products. Yao et al. also observed that in the presence of ammonium hydroxide, ZIF-8 could be synthesized in the following molar ratio: Zn2+: MIm: NH4+: H2O = 1:4:16:547. ZIFs may be generated from stoichiometric metal ions and MIm ratio in an aqueous environment with additional additions such as triblock copolymers poly (ethylene oxide)-poly (propylene oxide)-poly (ethylene oxide) (PEO-PPO-PEO) 83 and polyvinyl pyro did one (PVP) 84. For example, both ZIF-8 and ZIF-67 were synthesized from stoichiometric metal ions and MIm in aqueous ammonia systems in the presence of a triblock copolymer surfactant containing PEO groups, with the hope that the electrostatic attraction to the metal ions would promote the formation of porous ZIF-8 and ZIF-67. Shieh et al. discovered that in the presence of PVP, micro-sized ZIF-90 crystals may be formed in an aqueous solution (with a molecular weight of 4000). PVP was proposed to control crystal shape and prevent seed crystal aggregation [24,25].

We and other groups have recently effectively synthesized ZIFs from stoichiometric precursors using aqueous ammonia modulation. According to Wang's team, ZIF-8 may be produced at room temperature from stoichiometric precursors (Zn2+: MIm =1:2) in concentrated ammonium hydroxide aqueous solutions. The addition of a suitable amount of ammonium hydroxide was discovered to be crucial for the production and development of ZIF-8 crystals via deprotonation and coordination processes. It was also discovered that ZIF-8 could be easily synthesized at ambient temperature from stoichiometric precursors in an aqueous ammonia solution without the use of any other additions. By adjusting the concentration of aqueous ammonia in the synthesis mixture, the structures, particle sizes, and textural qualities of the final ZIF-8 materials could be easily modified. Without a doubt, these ZIFs' cost-effective synthesis techniques will significantly encourage their mass manufacture for useful applications [26].

**Ionothermal Synthesis:**

Recently, ionothermal synthesis, which creates ZIFs using eco-friendly solvents including ionic liquids and eutectic combinations, has been established. Ionic liquids have low vapor pressure, are non-flammable, and can serve as both solvents and templates simultaneously, preventing the competitive interactions between the solvent and template frameworks found in hydrothermal preparations. This enables the synthesis to be carried out in an open system. Ionic liquids can also be recycled for further use. The ionic liquid was first used to create ZIFs by Morris and colleagues [27].

**Synthesis by Sonochemistry:**

ZIFs can also be produced by procedures called sonocrystallization. In contrast to conventional oven heating for ZIF preparations, sonochemical synthesis can not only encourage nucleation generation but also aid in its uniform dispersion. When bubbles are created and then burst in solutions during the sonochemical synthesis, high local temperatures, pressures, and unusual heating and cooling rates follow. In Seoane's research, pure ZIF-7, ZIF-8, ZIF-11, and ZIF-20 crystals were created utilizing ultrasonic irradiation with a power of 110 W and a frequency of 47 kHz, at a lower temperature (45-60°C), for a shorter period (6-9 h), than was possible with conventional solvothermal synthesis [28].

**Solvent-Free Synthesis:**

**Solvent-Minimisation Method:**

Although the water-based system is more cost- and environmentally friendly than the organic solvent-based system, the aqueous synthesis method is ineffective due to several factors, including the overuse of imidazole sources and extensive solvent washing. As a result, solvent minimization techniques have recently been created. Shi et al., for example, used a steam-assisted conversion process to create porous ZIF-8 and ZIF-67 (or dry-gel conversion method). Contrary to the standard hydrothermal synthesis procedure, the solid phase containing excess ligands and metal salts was placed in a tiny Teflon cup and submerged in water vapor (or the organic solvent DMF) for 24 hours at 120°C. This may have caused the small amount of water to act as a structure-directing agent during the synthesis. In addition, ZIF-8 samples were produced using a vapor-assisted conversion technique in the nonpolar solvent n-heptane. In this procedure, the rate of conversion from the solid reagents to ZIF-8 was quicker than in methanol or DMF. The technique is straightforward: an evenly ground mixture of ZnO and MIm with a molar ratio of 1:2 was heated at 180°C for 12 hours, and ZIF-8 was recovered. Without further processing, the resultant ZIF-8 sample can be used for adsorptive applications. Beobide et al. also achieved the solvent-free synthesis of ZIFs, in which ZIFs were generated in a closed jar at temperatures ranging from 100 to 160°C via an acid-base reaction between ZnO/CoO/Co(OH)2 and imidazole ligands [29-30].



**Mechanochemical Synthesis:**

Mechanochemistry has demonstrated great potential as an eco-friendly and effective method of material development. As a result, a method for producing ZIFs by mechanochemical synthesis (via ball milling) has been established. In 2006, the first partial production of nonporous Zn(IM)2 was achieved through manual grinding of ZnO with a significant excess of imidazole. Adams et al. used the same nonporous Zn(IM)2 products via a two-step mechanochemical procedure that began with ZnCl2. Recognizing the limitations of oxide-based precursors for ZIF synthesis via neat grinding, Frii et al. used modified mechanochemical methods called liquid-assisted grinding (LAG) or ion-and liquid-assisted grinding (ILAG) to produce ZIFs at room temperature from a stoichiometric molar ratio (1:2) of ZnO and ligand such as imidazole, 2-methylimidazole, and 2-methyl imidazole [31-32].

**Secondary Growth Crystallisation:**

Secondary growth crystallization is typically used to make membranes in two phases. Various techniques, including rubbing, dip-coating, thermal seeding, and reactive seeding by repeated growth, are used to deposit the crystal seeds on the bare or chemically modified support in the first step. In the second step, a continuous polycrystalline layer develops under solvothermal or hydrothermal conditions. Internal spaces between seeds can be bridged by seed development, resulting in the formation of a continuous membrane. The seeded growth approach has the distinct advantage of allowing for systematic control of membrane orientation. Additionally, this method may modify the grain boundary structure and other membrane properties, which can enhance the performance of the membrane [33].

**In-Situ Crystallisation:**

The polycrystalline layer is generated on a plain or chemically modified substrate in a one-step or one-pot solvothermal or hydrothermal synthesis without any seeded growth technique when using in situ crystallization methods to create ZIF films or membranes. Many researchers have investigated in situ crystallization methods for the creation of ZIF membranes. Bux et al. used an in situ crystallization approach to creating a ZIF-8 membrane in a microwave-assisted solvothermal reaction. In conclusion, a compact ZIF-8 layer was formed on the porous titania support by charging the solution combined with the support into an autoclave and cooking it in a microwave [34].

**Applications of ZIF Material:**

Due to their high porosity, adaptable compositions, and programmable topologies, ZIF materials are finding new applications. In addition to their more common applications as adsorbents and catalysts, pure ZIFs and ZIF-based films/membranes have been created as multifunctional materials with remarkable performances that might potentially promote the development of sensing and electrical technology as well as medicine delivery. In this section, the common and novel uses of ZIF materials are highlighted and reviewed [35].

**Photo Catalysis Behaviour:**

A photocatalytic reaction typically involves the stages listed below: Pollutants can then be removed by interacting with the transportable electron or hole once the photocatalyst changes into a charge-separated state, producing a mobile electron (e) and a hole (h+). Only when incoming photon energy is greater than the band-gap energy of the photocatalysts may photo-generated electron-hole pairs occur. Because ZIF-8 has a high conversion efficiency to light energy when degrading pollutants, it is a promising co-catalyst for heterogeneous photocatalysis. ZIF-8 can quickly transfer the adsorbed light from the organic link to the metal-oxygen cluster. Later, the electrons in the valence band will be transferred to the conduction band and become conduction e-, leaving an h+ in the valence band. In its simplest form, photocatalytic degradation of pollutants is the oxidation of pollutants by active molecules generated by photocatalysts [36–37].

**Antibacterial Responses:**

Antibacterial zinc metal oxide is generally implemented in biomedical applications. The metal is biocompatible and environmentally benign. Zn2+ derived from zinc metal oxide has been shown to enhance keratinocyte mobility and aid in wound healing. Metal-organic frameworks (MOFs) having a similar appearance to inorganic porous zeolites have recently been reported as zeolitic imidazolate frameworks (ZIF-8). The zeolite structure is made up of Zn2+ metal ions linked by an imidazolate linker. ZIF-8 is used in biomedical applications. However, a few ZIFs were microporous, causing pre-mature drug release. Various procedures have been used in recent years to prepare the composite incorporating ZIF-8 and mesostructured materials. Such composites were particularly effective because they combined the benefits of micropore ZIF-8 and mesoporous materials [38].

**Gas Sensing Performance:**

The modification in overall resistance/conductivity of the sensitive layer would result from the change in energy band bending caused by the interaction of oxygen ions with CO when the micro-reaction is converted into macro-signals. When NO2 gas is tested using a polyhedral ZIF-8 nanomaterial gas sensor, the gas molecules capture free electrons from the oxygen adsorbed on the sensor's surface, leading to the formation of a substantial charge depletion layer on the ZIF materials' surface. Rapid NO2 molecule adsorption causes the surface to become negatively charged, increasing the potential barrier. ZIF materials are porous, allowing them to detect released gas molecules with ease [39–40].

**Conclusion:**

ZIFs, a novel and distinct class of metal-organic frameworks with structures similar to those of conventional aluminosilicate zeolites, are composed of imidazolate linkers and metal ions. Numerous prospective uses for diverse ZIF materials have been made possible by their inherent porous characteristics, strong functions, and outstanding thermal and chemical stabilities. In the past several years, many research initiatives have appeared in this quickly developing field, spanning from synthetic methods to alluring ZIF applications.

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