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Metal Organic Frameworks: An overview and their applications

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Introduction

Metal Organic framework (MOFs) chemistry is an emerging field of interest and pervasive in literature due to its architecturally robust structures. The reason why MOFs chemistry is explored at large scale is because of its extensive properties of high porosity, high structural stability, large designing flexibility, enormous internal surface area and many more. Metal organic framework are class of porous solids [1-4] formed when metal ions are coordinated to organic linkers such as phosphonates, sulfonates, polycarboxylates, phenolates. Infinite MOFs can be synthesized as large number of possible combinations can be formed from variety of metal ions and numerous organic linkers. MOF chemistry is ubiquitous since it have great potential application in various fields such as therapeutic agents, biological sensing, semiconductors, methane storage, hydrogen storage, carbon capture and also in catalysis [5, 6]. In comparison to conventional inorganic porous materials such as Zeolites, the flexible porosity and tunable composition keep MOFs far ahead of zeolites. The inorganic zeolites, have been extensively used for decades for a wide variety of applications but its utility is limited since there is very restricted number of structure and channel topologies and there is difficulty in controlling the synthesis condition. However these crystalline porous solid exhibit outstanding properties of large internal surface areas, high crystallinity degree and extensive porosity [7, 8]. These intriguing properties of MOFs results in exponential increase in development of numerous of these extensive class of crystalline material and exploring their applications in various fields.

MOFs or coordination polymers have emerged as a potential alternative to conventional organic drug nano-carrier since they have highest drug loading capacities. The biomedical applications of these requires less toxic, biocompatible composition which don’t cause unwanted side effect and have enhanced therapeutic efficacy [9]. Various research groups are successful in synthesizing MOFs that are less toxic and have high loading capacities of therapeutic molecules. Currently, Fe, Zr, Mn, Mg, Zn and Cu are used frequently used for synthesizing MOFs in view

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biocompatible composition. Before clinical application numerous work is to be done on MOfs for example, exploring degradation mechanism, studying vivo toxicity, giving appropriate surface modification for MOFs and researching in vivo efficiency of drug loaded MOFs.

Synthesis of MOFs

MOFs can be synthesized by various conventional methods that are reported in literature such as hydrothermal or solvothermal, sonochemical synthesis, microwave assisted [10], electrochemical [11] and mechanochemical synthesis [12]. In hydrosolvothermal synthesis both inorganic and organic precursors are dissolved in some suitable solvent in an autoclave where crystal are slowly grown from hot solution. Factors which play major role in formation of framework structures are solvent, pressure, temperature, molar concentration, dilution pH, reaction time, stoichiometry, additives, etc. For critical nucleation concentration that enables crystal growth formation, concentration gradient is to be adjusted. The reaction kinetics can be tunned by adding some additives.

Other technique used for synthesis of micro or nanoscale metal organic framework is sonochemical synthesis. This is very efficient and environment friendly method in which ultrasonic irradiation leads to cavitation. The implosion of cavitation bubbles generates localized hot spots with very large gradient of temperature, pressure and cooling rates. MOFs produced via sonochemical route is cost effective at high yield. Regardless of the method used to synthesize the nanoparticles, the choice of the solvent is very crucial for biomedical applications.

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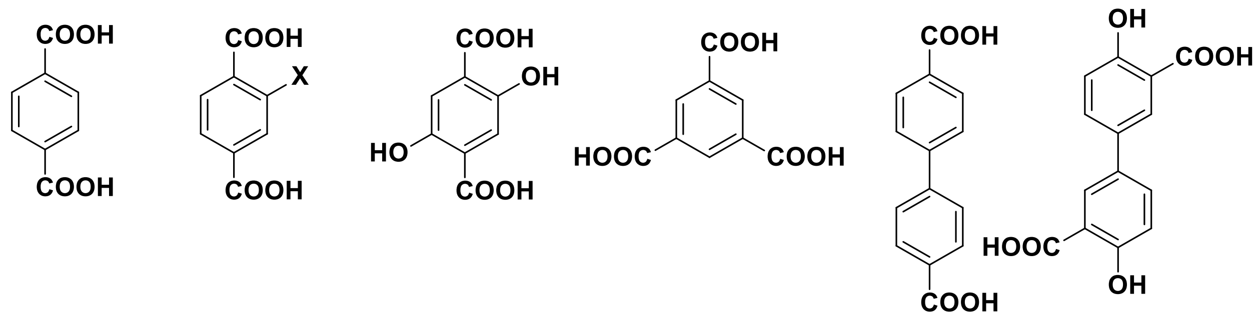

Organic Linkers

These are the examples of various organic linker that coordinate to metal ion to form one, two or three dimensional Metal Organic Framework (MOFs).

There are various spectroscopic techniques that have been used in order to elucidate the structure of MOFs. Single crystal and powdered X-ray diffraction (XRD) is notably used to determine crystal morphology, pore structure and arrangement of atoms. In order to know all the functional groups attached in MOFs, Infrared (IR) spectroscopy is used. BET is used for providing information of surface area, volume and pore width. TGA (Thermogravimetric analysis) is done to know the thermal stability and optimal activation temperature. There are several spectroscopic techniques that can be employed in order to elucidate MOFs structure.

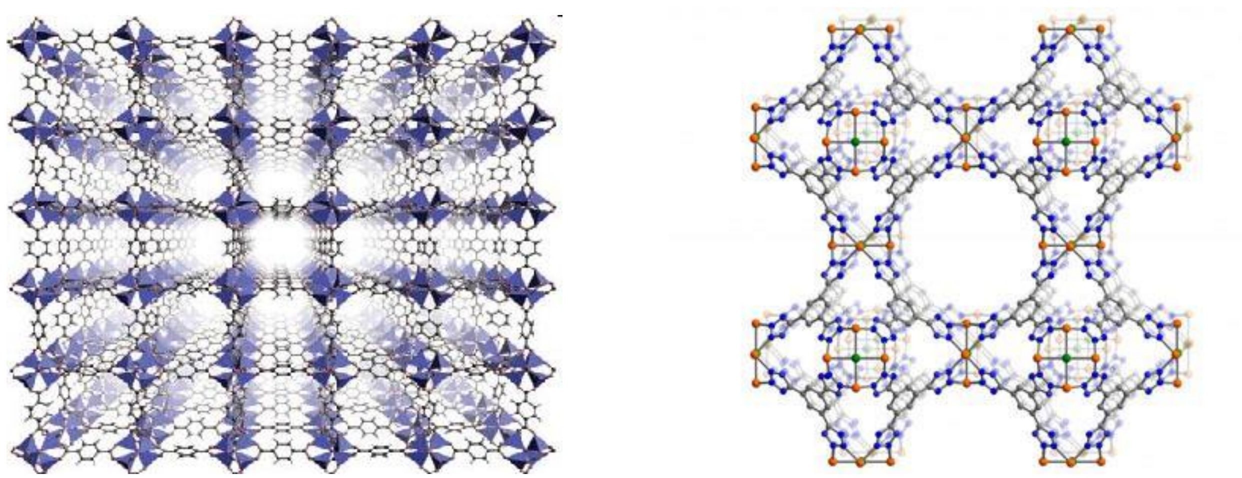

Fig: Some examples of Metal Organic Framework (MOFs)

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Applications

The precise control over assembly of MOFs has enabled us to design MOFs for a specific application. Since they possess large porosity, tunable pore size and shape, high structural stability, large designing flexibility, offers wider application in adsorption, drug delivery, catalysis, gas storage. In order to enhance the therapeutic efficiency and reduce side effects, MOFs have received extensive attention in the development of drug delivery platforms.

Initially conventional nanocarriers such as metal nanoparticles, organic micelles, quantum dots are used over few decades but they have some disadvantages of low drug loadings, poor biological barrier bypass, undesirable toxicity phenomena and unacceptable degradability [13], which restrict their use and thus MOFs emerged as potential alternative in drug delivery. An ideal therapeutic agent will be the one that have a large loading capacity, biocompatible, less side effects and easily degraded by body's metabolism. MOFs due to their higher porosity associated to large volume and surface area facilitate MOFs with high drug loading capacities and ability to control therapeutic release and due to their robust architecture structure, they have diverse morphologies and chemical properties which lead to stimuli-responsive drug controlled release. MOFs are easily degraded by body's metabolism since they are weakly coordinated. All these factors enable MOFs an ideal therapeutic agent with great efficacy.

Nowadays Hydrogen gas is emerging as a best alternative fuels to conventional fossil fuels. But hydrogen is an extremely volatile gas under ambient conditions, thus it is very difficult to store and transport it. Thus much attention is paid to design materials that can rapidly and reversibly store hydrogen. In view of this MOFs are gaining importance as promising novel adsorbents for gas storage since they have large porosity, tunable pore size, high volume and surface area. The first study of hydrogen adsorption was done in 2003 and investigated MOF was cubic carboxylate based framework MOF-5[14].

Conclusion

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Metal Organic Framework (MOFs) or coordination polymers due to flexibility in varying size, geometry, functionality , leads to a broader range of applications and thus ubiquitous in literature. Due to the precise control over the assembly, MOFs can be designed for specific application and is widening its scope.

As discussed earlier, MOFs offers very attractive properties, many remarkable MOF-based platforms have been developed for novel bioapplications. For nano-medical applications, the stability, biocompatibility and degradability are need to be emphasized and so far MOFs have shown highest loading capacities of drugs, cosmetics and even biological gases. With all these remarkable MOFs development in laboratory and their advancement, time has come to take these from laboratories to real world applications, but now also many challenges are to be overcome and many things are yet to be learned from conventional zeolite chemistry before they are deployed clinically. Despite significant advancement in MOFs synthesis for clinical application, the challenges of toxicity which should be minimal, biocompatibility i.e. no side effects and easy degradability by body metabolism are still to be addressed. Their properties can be modified by adequate choice of the metal and organic linker which will play important role in overcoming these challenges.

MOFs due to their flexibility in structural framework as they have tunable porosity, composition, large surface area and volume they possess advantages in gas transport and storage and these attractive properties offers great potential for their use in detection of range of organic molecules and ions as sensors. MOFs will play significant role in future with wider application in various fields.

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