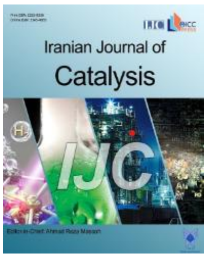

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Spotlight

Fluorescent Metal–Organic Frameworks (FL-MOFs): Multi-Purpose Compounds

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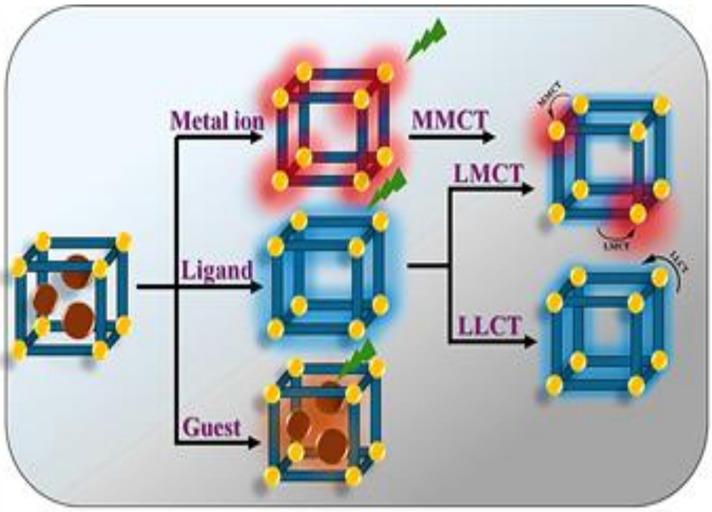
1. Introduction

"Metal-organic frameworks" are a class of inorganic porous materials in which metals are joined together by organic binders in this class of porous compounds. These frameworks can be synthesized at temperatures up to 221°C, pressures up to 21 atmospheres, and pH values between 1 and 11 [1]. Also, the characteristics of this group of compounds include low density, high surface area, diverse design capabilities, orderliness, flexibility, and stability. Despite these characteristics, these metal-organic frameworks can be used in various fields such as gas storage and separation, drug release, as catalysts, selective separation, fuel cells, petrochemicals, and in sensors, etc [2-11]. About fluorescent MOFs: MOFs that exhibit fluorescence are called fluorophores. This property is due to the presence of fluorophore groups in their structure, or due to the presence of specific metal ions that can absorb light and then re-emit it as visible light, or even ligands in the structure that have fluorescent properties. In recent years, fluorescent MOFs have attracted significant attention, including from chemists, as they have been used in the fields of sensors to identify anionic and cationic pollutants, environmental pollutants, antibiotic identification, biomarkers, targeted drug delivery, and photothermal catalytic systems [12,13].

In FL-MOF, the source of fluorescence signals can be classified into metal-centered emission (MC), ligand-centered emission (LC), and guest-induced luminescence (GI) change. Called charge transfer (CT), it involves non-radiative energy and electron transfer processes.

In fact, these transfers are from metal to ligand (MLCT), ligand to metal (LMCT), ligand to ligand (LLCT), metal to metal (MMCT), or ligand to guest molecules (Scheme 1) [14]. When discussing the response mechanism in FL-MOF, it's important to recognize that it can be categorized into three types based on variations in fluorescence signal intensity and wavelength: turn on, turn off, and radiometric. Among these, the turn-off type is the most frequently observed response [15]. FL-MOF was first synthesized in 2013 by Ghosh and co-workers, who used it to investigate and identify nitro-containing explosive compounds [16]. Finally, in this article, we will discuss the application of FL-MOF as a sensor for pH or for the detection of some anionic and cationic pollutants, such as CN-, HClO-, Bi^{3+}, Al^{3+}, or for the detection of environmental pollutants such as as NH_2NH_2, chloroethylethyl sulfide (CEES),, or detection of antibiotics and nitrophenol compounds, even as a drug carrier in targeted drug delivery and catalytic systems (Scheme 2).



Scheme 1. Schematic diagram showing the different sources of fluorescence signals in MOF-based fluorescence sensors

Scheme 2. Various applications of FL-MOFs

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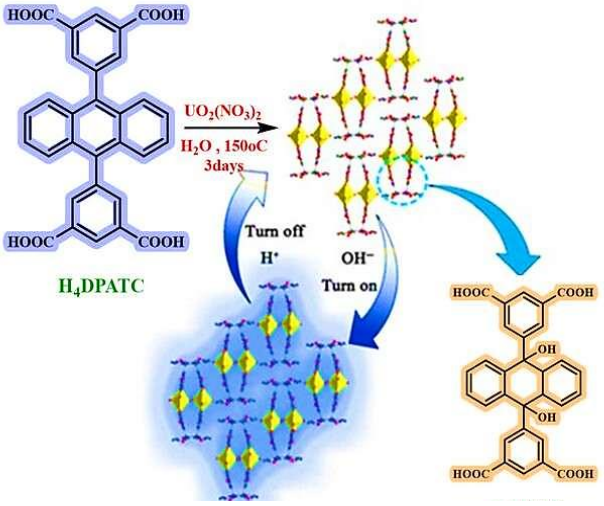
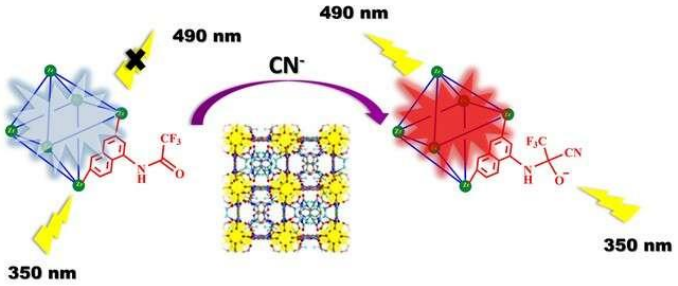
Abstract

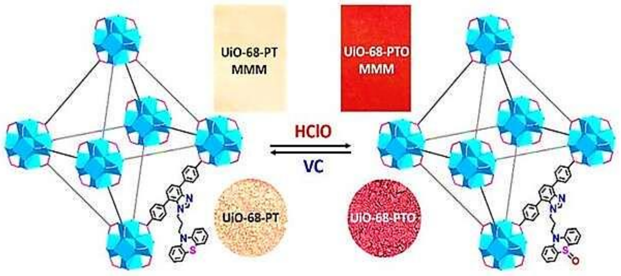
(A) pH sensors are capable of measuring the concentrations of H$^+$ and OH$^-$ in aqueous solutions. A suitable pH sensor can be developed by utilizing the protonation and deprotonation of the ligand within the MOF. For instance, in 2020, Pan *et al*. reported a uranyl-based MOF known as HNU-39. This MOF not only facilitates the in-situ synthesis of the H$_4$DTATC ligand but also has its carboxyl hydrogens from the ligands coordinated to the uranyl group, which can interact with OH$^-$ under alkaline conditions and become dissociated. HNU-39 is effective for detecting pH levels ranging from 9.4 to 11.5 and can be applied in wastewater treatment facilities [17].



(B) The cyanide ion (CN-) is recognized as one of the most toxic anions. CN- can attach itself to the enzyme cytochrome oxidase, inhibiting the use of oxygen. Consequently, cells perish from an insufficient oxygen supply. Thus, it is crucial to create sensors for detecting CN-. For this purpose, in 2021, Biswas et al. developed a stable Zr-MOF (DUT-52) that demonstrates distinct selectivity and exhibits bright blue fluorescence that is responsive to water containing CN-, with a response time of approximately 2 minutes. Organic molecules modified with trifluoroacetamide, a potent electron-withdrawing group, decrease emission intensity due to the photoinduced electron transfer (PET) mechanism occurring from the aromatic system to the trifluoroacetamide group. However, the literature suggests that upon introduction of CN−, organic molecules modified with trifluoroacetamide exhibit a strong attraction to the cyanide ion, leading to the trifluoroacetamide group being readily transformed into a cyanohydrin as the nucleophilicity of the cyanide ion increases, making it a strong electron donor. As a result, the PET process is suppressed. Consequently, a notable rise in fluorescence intensity and a marked red shift in the emission spectrum were detected [18].



(C) Dong *et al*. in 2019, reported the MOF UiO-68-PT for detecting the reactive oxygen species HClO$^-$. The MOF UiO-68-PT exhibited negligible fluorescence. The luminescent intensity is reduced due to the electron-donating ability of phenothiazine to benzimidazole through the PET mechanism. Upon the addition of the ClO$^-$ anion to the system, the linked phenothiazine component was converted into phenothiazine sulfoxide (UiO-68-PTO). Consequently, the PET effect was entirely abolished, leading to a notable enhancement in fluorescence properties. Fascinatingly, when VC was added, the phenothiazine sulfoxide reverted back to phenothiazine, causing a reduction in the emission



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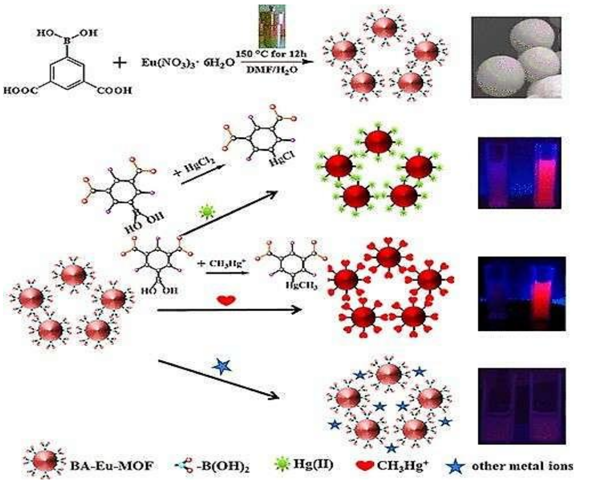
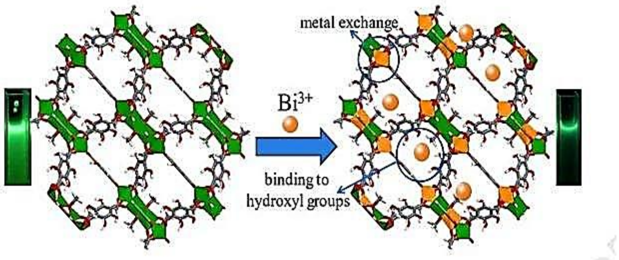
intensity. This reversible redox transformation was also evident through a noticeable color change [19].

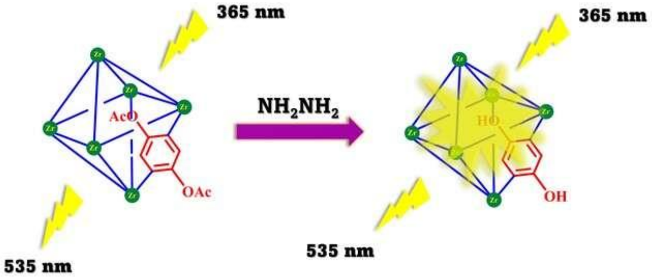
(D) Qu *et al*. in 2020, synthesized a Eu^{3+} ion-based MOF (BA-Eu-MOF) with boric acid (BA) functionality for ultrasensitive “light-on” detection for CH_3Hg^+ and Hg^{2+}. This MOF is metal-based and exhibits the antenna effect well, but the antenna effect is deactivated due to the electron-withdrawing effect of BA. However, with the addition of CH_3Hg^+ and Hg^{2+} ions, the C-B bond of BA is broken, and the formation of the C-Hg bond occurs. As a result, the electron-withdrawing characteristic of BA is entirely removed, while simultaneously, the ligand's antenna effect is renewed, leading to an improvement in red emission [20].



(E) The quenching of fluorescent MOFs by metal ions can mainly be caused by (1) the destruction of the MOF structure by the breakdown of the metal ion, or metal exchange; (2) the formation of strong interactions between the incoming metal ions and the ligands in the MOFs. Huang *et al.* In 2018, the solvothermal production of an Al^{3+} metal-organic framework (MOF), known as CAU-1-$(OH)_2$, was reported, where the ligands' hydroxyl and carboxyl groups form strong bonds with Bi^{3+} due to Bi's greater affinity for oxygen compared to the MOF's metal center. Bi is capable of substituting Al within the MOF, which results in the quenching of fluorescence. CAU-1-$(OH)_2$ is able to detect Bi^{3+} in water within 24 seconds [21].



(F) Hydrazine is a dangerous substance that is extensively utilized in areas such as organic synthesis, pharmaceuticals, and catalysis. Because of its high enthalpy, it serves as a fuel in rockets and spacecraft. However, despite its numerous beneficial properties, it is considered to be both carcinogenic and hazardous. Consequently, detecting hydrazine is crucial. In 2020, Biswas *et al.* discussed the selective and sensitive identification of hydrazine through a luminescence "turn-on" process utilizing the zirconium-based metal-organic framework, Zr-UiO-66-$(OCOCH_3)_2$. The sensing process involves a nucleophilic attack by hydrazine on the acetoxy group, which subsequently transforms into a hydroxyl group. Thus, the H_2BDC-$(OCOCH_3)_2$ bond is converted to H_2BDC-$(OH)_2$; in effect, a type of deprotection occurs. The increase in MOF luminescence is due to the formation of H_2BDC-$(OH)_2$ [22].



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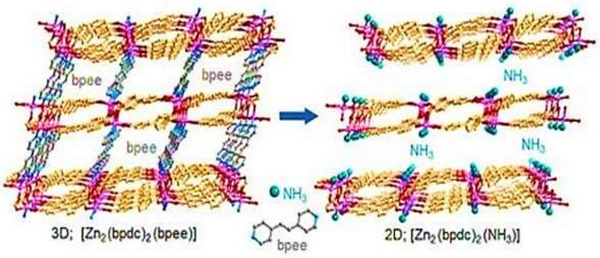
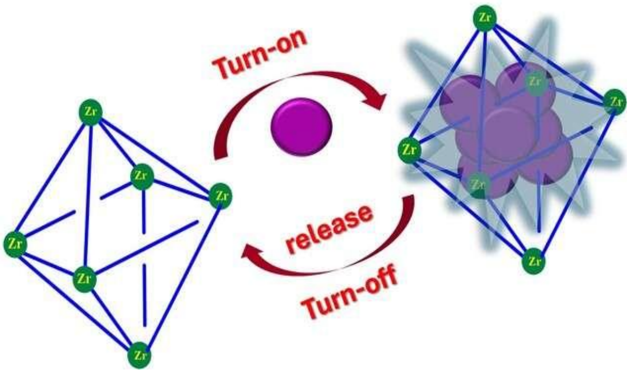
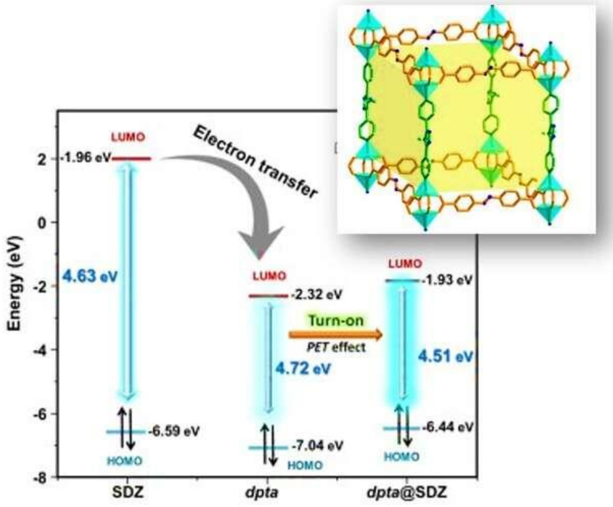
(G) In 2019, Silva *et al*. reported a sensor designed for ammonia gas that alters its emission wavelength by swapping the ligands in the metal-organic framework with ammonia. This sensor is capable of detecting amines at sub-ppm levels in both gas and aqueous environments within a time frame of ten seconds. Two ligands have been synthesized with the 1,2-bipyridylethene and 4,4-biphenyldicarboxylic acid moieties, where ammonia is replaced with the 1,2-bipyridylethene ligand, which causes the destruction of the 3D state of the MOF and converts it to a 2D state, thereby detecting ammonia [23].



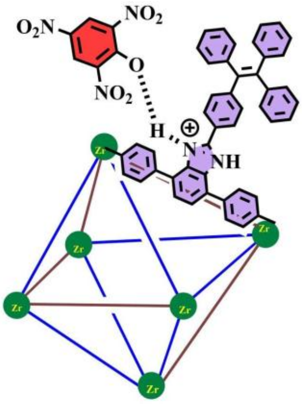
(H) Drug delivery systems (DDS) represent an alternative approach in drug research that can stabilize medications and specifically direct them to injured tissues, which helps reduce side effects and enhance their therapeutic benefits. Numerous drawbacks associated with small-molecule drugs can be alleviated through the utilization of these systems. Sun and *et al.* in 2021, showed that the prepared cationic framework UiO-67 CDC-$(CH_3)_2$ has a relatively high surface area, hierarchical pore structures, and positive surface properties, and can effectively and sensitively encapsulate the electron-rich drug 5-fluorouracil (5-Fu) through electrostatic attraction with a very high loading, up to 56.51% (wt%), and secrete the drug at a pH close to the body's natural pH, such that the LUMO of the electron-deficient methylated ligand 9*H*-carbazole-2,7-dicarboxylic acid is lower than the LUMO energy level of 5-Fu. Therefore, with 5-Fu as the electron donor, the electron is transferred from the LUMO of 5-Fu to the LUMO of the electron-deficient ligand, and PET occurs, leading to an increase in fluorescence [24].



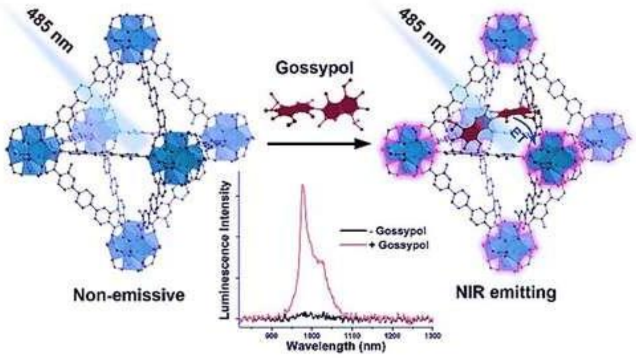
(I) Due to the growing global population, there has been a notable rise in antibiotic consumption, which negatively affects the environment. In this context, Neogi *et al.* in 2019 innovatively created a highly luminous porous zinc-based framework featuring free amino groups. The activated metal-organic framework (MOF) can identify sulfadiazine (SDZ) antibiotics through a process called "fluorescence enhancement." The lowest unoccupied molecular orbital (LUMO) of SDZ has a higher energy level compared to that of the MOF. As a result, electron transfer happens from the LUMO of SDZ to the LUMO of the MOF, leading to an increase in luminescence in the MOF. The existence of free amino groups in the MOF framework facilitates intermolecular hydrogen bonding interactions with the analytes, bringing them into closer proximity. This proximity enables the possibility of charge or electron transfer between the MOF and the analyte [25].



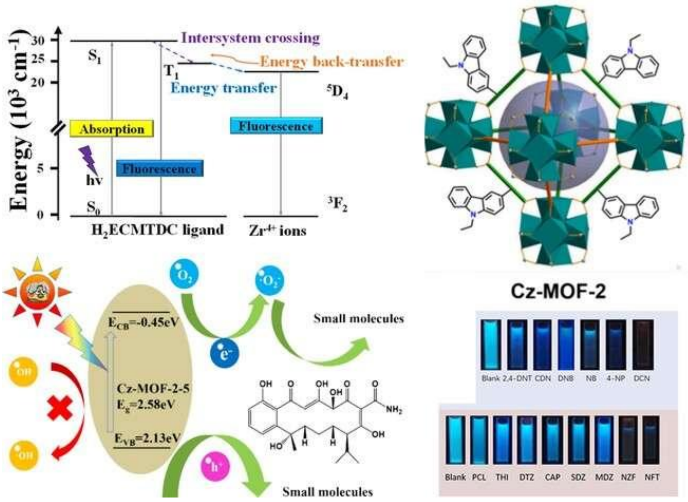
(J) Nitro explosives encompass a variety of types, with nitrophenols frequently used in many industrial settings, such as 2,4,6-trinitrophenol (TNP), which carries considerable mutagenic and carcinogenic risks to human health. Consequently, it is vital to create a quick and effective method for detecting TNP. Wang *et al*. reported in 2016 on a Zr-MOF sensor, referred to as UiO-68-mtpdc/etpdc, designed for TNP detection. It was found that these two explosives diminish the fluorescence of the MOF by establishing a coordination bond through the hydroxyl group with the NH group of the MOF ligand [26].



(K) Gossypol (Gsp) is a toxic compound and biomarker found in cottonseed, posing a risk to human health. Since cotton is commonly utilized in the food sector, it is crucial to monitor GSP levels in cottonseed. Rosi *et al.* in 2020 demonstrated the selective "bright" detection of Gsp using a Yb-NH$_2$-TPDC red-peaked bandgap when the MOF has been combined or bound with Gsp, the luminescence intensity of Yb^{3+} changs from a non-luminous state to a highly luminous state in the presence of Gsp upon binding [27].



(L) A fluorescent metal-organic framework based on carbazolyl, identified as Cz-MOF-2, has been synthesized and examined by Yang *et al.* in 2024. Cz-MOF-2 demonstrates enhanced sensitivity for the fluorescent detection of organic contaminants such as 2,6-dichloro-4-nitroaniline (DCN), nitrofurazone (NZF), and nitrofurantoin (NFT), achieving detection limits of 3.37 × 10^{-7}, 1.64 × 10^{-5}, and 1.76 × 10^{-5} M, respectively. The mechanisms behind the fluorescence quenching in this photocatalytic process encompass electron transfer and competitive adsorption. The incorporation of carbazolyl groups into the framework has enabled Cz-MOF-2 to effectively photo catalyze the degradation of organic contaminants. Experiments involving radical trapping and electron spin resonance (ESR) detection have confirmed that the primary active species in this photocatalytic reaction are O_2^{-} and h^{+}. This study emphasizes the possibilities of metal-organic frameworks (MOFs) in the customized creation and advancement of fluorescent sensors and photocatalysts aimed at environmental monitoring and clean up. It is important to highlight that this photocatalytic process not only demonstrates high effectiveness in degradation but also features low toxicity and is comparatively inexpensive [28].



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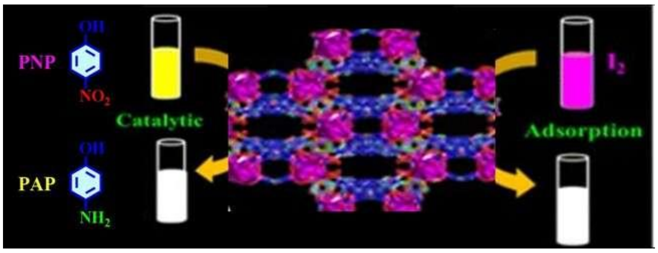
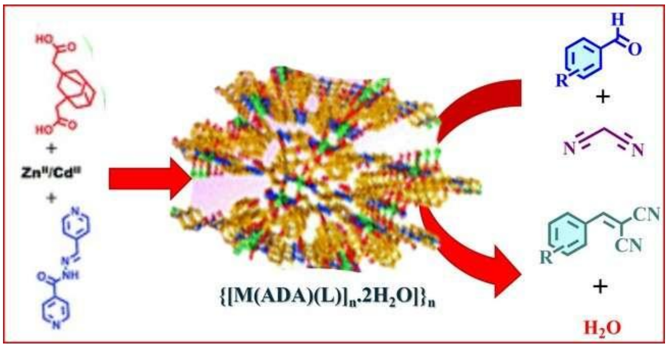
(M) Flexible triazine carboxylic acid ligands are adaptable ligands that can simultaneously coordinate to multiple metal ions due to their significant binding capabilities. In 2023, Bai and *et al.* developed and created a new cobalt-based three-dimensional FL-MOF utilizing this ligand, which successfully catalyzed the transformation of para-nitrophenol (PNP) to p-aminophenol (PAP) in a single reduction process, achieving a yield of 90%. This outstanding catalytic activity was ascribed to the optimal interaction between the ligands and PNP, which facilitated electron transfer during the reduction reaction and effectively reduced the energy barrier for the reaction. Moreover, the distinct π-electron structure and carboxyl groups present in the triazine carboxylic acid ligand contribute to the impressive adsorption capacity of this FL-MOF, which Bai et al. have utilized for the adsorption of iodine in a cyclohexane solution [29].



(N) FL-MOFs have been used as effective heterogeneous catalysts for the novonagel condensation reaction. In 2018, Parmar *et al.* designed and created two luminescent 2D FL-MOFs, one containing Zn (II) and the other Cd(II). They have been used environmentally friendly mechanochemical methods with the flexible ligand 1,3 adamantane diacetic acid (H_2ADA), pyridyl-based Schiff base ligand, and 4-pyridylcarboxaldehydeisonicotinoylhydrazone (L) as linkers. Subsequently, they have been employed aldehydes alongside malononitrile at ambient temperature for novonagel condensation, achieving remarkable catalytic performance, high yields, and excellent recyclability of the FL-MOFs, along with the notable stability of the catalysts. The proposed catalytic mechanism is thought to involve the interaction between the Lewis acidic metal center and the amide functional group present in the ligand during the condensation reaction [30].



Competing Interests
The authors declare no competing interests.

Ethics approval
Not applicable

Conflict of Interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. No conflict of interest exists.

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References

[1] N. Stock, S. Biswas, Chem. Rev. **112** (2012) 933-969.
https://doi.org/10.1021/cr200304e

[2] Y. Bai, Y. Dou, L. H. Xie, W. Rutledge, J. R. Li, H. C. Zhou, Chem. Soc. Rev. **45** (2016) 2327-2367.
https://doi.org/10.1039/C5CS00837A

[3] N. A. Khan, Z. Hasan, S.H. Jhung, J. Hazard. Mater. **244** (2013) 444-456.
https://doi.org/10.1016/j.jhazmat.2012.11.011

[4] E. Tavakoli, H. Sepehrmansourie, M.A. Zolfigol, A. Khazaei, A. Mohammadzadeh, E. Ghytasranjbar, M.A. As' Habi, Inorg. Chem. **63** (2024) 5805-5820.
https://doi.org/10.1021/acs.inorgchem.3c03742

[5] F. Jalili, H. Sepehrmansourie, M. Zarei, M.A. Zolfigol, A. Khazaei, M.A. As' Habi, Arab. J. Chem. **17** (2024) 105635. https://doi.org/10.1016/j.arabjc.2024.105635

[6] S. Kalhor, H. Sepehrmansourie, M. Zarei, M.A. Zolfigol, H. Shi, Inorg. Chem. **63** (2024) 4898-4914. https://doi.org/10.1021/acs.inorgchem.3c03988

[7] M. Mohammadi Rasooll, H. Sepehrmansourie, M. Zarei, M.A. Zolfigol, M. Hosseinifard, Y. Gu, ACS Omega. **8** (2023) 25303-25315. https://doi.org/10.1021/acsomega.3c02580

[8] H. Sepehrmansourie, M. Mohammadi Rasooll, M. Zarei, M.A. Zolfigol, Y. Gu, Inorg. Chem. **62** (2023) 9217-9229. https://doi.org/10.1021/acs.inorgchem.3c01131

[9] H. Sepehrmansourie, S. Kalhor, M. Zarei, M.A. Zolfigol, M. Hosseinifard, RSC adv. **12** (2022) 34282-34292. https://doi.org/10.1039/D2RA05655K

[10] M. Farrokh, M.A. Zolfigol, M. Hajjami, H. Sepehrmansourie, M.M. Rasooll, RSC adv. **15** (2025) 27782-27794. https://doi.org/10.1039/D5RA04067A

[11] M. Farrokh, H. Sepehrmansourie, E. Tavakoli, M.A. Zolfigol, M. Hajjami, Polycycl. Aromat. Comp. **45** (2025) 1-20. https://doi.org/10.1080/10406638.2025.2547604

[12] R. Mondal, A. Shanmughan, A. Murugeswari, S. Shanmugaraju, Chem. Commun. **59** (2023) 11456-11468. https://doi.org/10.1039/D3CC03125J

[13] X. Zhao, X. Miao, Coord. Chem. Rev. **502** (2024) 215611. https://doi.org/10.1016/j.ccr.2023.215611

[14] T. Wu, X. J. Gao, F. Ge, H. G. Zheng, Cryst. Eng. Comm. **24** (2022) 7881-7901. https://doi.org/10.1039/D2CE01159J

[15] C. Jia, T. He, G. M. Wang, Coord. Chem. Rev. **476** (2023) 214930. https://doi.org/10.1016/j.ccr.2022.214930

[16] A. K. Chaudhari, S. S. Nagarkar, B. Joarder, S. K. Ghosh, Cryst. Growth Des. **13** (2013) 3716-3721. https://doi.org/10.1021/cg400749m

[17] D. Gu, W. Yang, G. Ning, F. Wang, S. Wu, X. Shi, Y. Wang, Q. Pan, Inorg. Chem. **59** (2020) 1778-1784. https://doi.org/10.1021/acs.inorgchem.9b02999

[18] C. Gogoi, N. Nagarjun, S. Roy, S. K. Mostakim, D. Volkmer, A. Dhakshinamoorthy, S. Biswas, Inorg. Chem. **60** (2021) 4539-4550. https://doi.org/10.1021/acs.inorgchem.0c03472

[19] Q. Li, Y. Li, Q. Guan, W. Li, X. Dong, Y. Dong, Inorg. Chem. **58** (2019) 9890–9896. https://doi.org/10.1021/acs.inorgchem.9b01032

[20] H. Wang, X. Wang, M. Liang, G. Chen, R. M. Kong, L. Xia, F. Qu, Anal. Chem. **92** (2020) 3366-3372. https://doi.org/10.1021/acs.analchem.9b05410

[21] X. Gao, H. Zhao, X. Zhao, Z. Li, Z. Gao, Y. Wang, H. Huang, Sens. Actuator B-Chem. 266 (2018) 323-328. https://doi.org/10.1016/j.snb.2018.03.139

[22] S. Nandi, S. K. Mostakim, S. Biswas, Dalton Trans. **49** (2020) 12565-12573. https://doi.org/10.1039/D0DT02491K

[23] A. Sousaraei, C. Queiros, F. G. Moscoso, T. Lopes-Costa, J. M. Pedrosa, A. M. Silva, L. Cunha-Silva, J. Cabanillas-Gonzalez, Anal. Chem. **91** (2019) 15853-15859. https://doi.org/10.1021/acs.analchem.9b04291

[24] X. Y. Sun, H. J. Zhang, X. Y. Zhao, Q. Sun, Y. Y. Wang, E. Q. Gao, Dalton Trans. **50** (2021) 10524-10532. https://doi.org/10.1039/D1DT01772A

[25] R. Goswami, S.C. Mandal, N. Seal, B. Pathak, S. Neogi, J. Mater. Chem. A. **7** (2019) 19471-19484. https://doi.org/10.1039/C9TA06632B

[26] Q. Y. Li, Z. Ma, W. Q. Zhang, J. L. Xu, W. Wei, H. Lu, X. Zhao, X. J. Wang, Chem. Commun**.** **52** (2016) 11284-11287. https://doi.org/10.1039/C6CC04997D

[27] T. Y. Luo, P. Das, D. L. White, C. Liu, A. Star, N. L. Rosi, J. ACS. **142** (2020) 2897-2904. https://doi.org/10.1021/jacs.9b11429

[28] S. Ding, G.S. Yang, S. Q. Wang, Y.T. Hui, Y. J. Wang, Z. Tang, Z.M. Su, Inorg. Chem. **63** (2024) 22572-22582. https://doi.org/10.1021/acs.inorgchem.4c04044

[29] M. Liu, H. Q. Cai, S. Jiang, Y.H. Xing, F.Y. Bai, Dalton Trans. **52** (2023) 6773-6781. https://doi.org/10.1039/D3DT00519D

[30] B. Parmar, P. Patel, V. Murali, Y. Rachuri, R.I. Kureshy, N.U.H. Khan, E. Suresh, Inorg.Chem.Front**.** **5** (2018) 2630-2640. https://doi.org/10.1039/C8QI00744F