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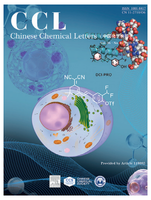

MOFs helping heritage against environmental threats

Kunpeng Zhou[a,b,c], Zhihao Shi[b], Xiao-Hong Yi[b], Peng Wang[b], Aiqun Li[b,c],
Chong-Chen Wang[b,*]

[a] *School of Humanities, Beijing University of Civil Engineering and Architecture, Beijing 100044, China*
[b] *Beijing Key Laboratory of Functional Materials for Building Structure and Environment Remediation, Beijing University of Civil Engineering and Architecture, Beijing 100044, China*
[c] *International Joint Laboratory of Safety and Energy Conservation for Ancient Buildings, Beijing University of Civil Engineering and Architecture, Beijing 100044, China*

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ABSTRACT

The heritage preservation is of great intractability to the conservators as each kind of heritage material has unique and diverse requirements on temperature, humidity and air cleanliness. It is promising for metal-organic frameworks (MOFs), the multifunctional environment remediation materials, to be applied in heritage environmental protection. The advantages of MOFs lie in their multifunction like adsorption, photocatalysis, sterilization, as well as the controllable structure and properties that could be flexibly adjusted as demands, helping the heritage against various environmental threats. Thereby, the applications and the corresponding mechanisms of MOFs in cultural heritage preservation were reviewed in this work, including harmful gas adsorption, surface waterproofing, particulate matters (PM) removal, anti-bacterial and humidity control of environment. Finally, the selection principles and precautions of MOFs in heritage preservation were discussed, aiming to provide a forward-looking direction for the selection and application of MOFs.

1. Introduction

Cultural heritage provides us with unique insights into history and civilization, as well as abundant information in history, science, art and so on [1]. The protection of cultural heritage is of great significance to the continuation of human civilization and the diversity of world culture. Nevertheless, heritage protection is a careful and tricky thing due to the un-renewability or scarcity of heritage [2]. Each kind of heritage material (wood, stone, paper, silk, *etc.*) has its own diverse and strict requirements on temperature, humidity and air quality of preservation environment. The present materials used for heritage environment protection are mainly some traditional reagents, such as preservatives (formaldehyde, camphor), desiccants (silica gel, calcium chloride), adsorbents (activated carbon, zeolite and activated aluminum oxide). These materials could work well to deal with a single environmental threat. However, most of them may be powerless to help the heritage against diverse environmental threats because of their relatively single function. Meanwhile, they may not be able to meet the rigorous and precise environmental requirements of heritage because of their limited functionality and inability to be accurately modified [3,4]. Therefore, designing and synthesizing novel materials with multifunctionality and adjustable properties, that could be used for control and clean of heritage environment, is of great interest to conservators [5].

Metal-organic frameworks (MOFs), constructed from inorganic metal ions/clusters and organic ligands [6,7], are promising multifunctional environment remediation materials due to their unique advantages of large pore volume, great specific surface area, abundant active sites and hydrophilic/hydrophobic behaviors [8–10]. Different from the above traditional reagents, the advantages of MOFs lie in multiple functions. For instance, HKUST-1 is known for its extraordinary versatilities like the capture of carbon dioxide, the catalysis of methanol dehydration reaction, the sensing detects of harmful gases, and the use as light-emitting materials [11]. And an increasing number of MOFs have been developed for extensive applications in pollutant adsorption [10,12,13], harmful gas capture [14–16], humidity control of environment [17,18]. Moreover, MOFs display excellent performances in flexible controllability of structure and properties, which could be easily modified according to specific requirements. Mandal et al. reviewed that the majority of MOFs' properties could be adjusted to satisfy specific requirements *via* post-synthetic modification [19]. Besides, MOFs could exist in

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* Corresponding author.
E-mail address: wangchongchen@bucea.edu.cn (C.-C. Wang).

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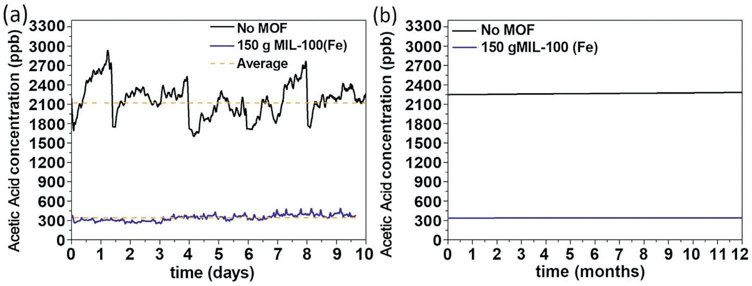


Fig. 1. (a) Validation test at IVC without MOFs and with MOF (MIL-100(Fe)). (b) Model predictions with IVC storage conditions as input with and without MOF. Reproduced with permission [28]. Copyright 2024, Elsevier.

nanoforms, harnessing the benefits of size, surface and quantum effects, along with the unique advantages, like multiple functions and controllable properties not typically found in other nanomaterials [20]. These advantages bestow MOFs extraordinary potential upon heritage preservation. Up to now, there are several cases adopting MOFs as functional materials to accomplish cultural heritage protection. This work will introduce the typical cases and propose the research trend of this field.

2. The existing applications of MOFs in heritage protection

2.1. Harmful gas adsorption

The primary application of MOFs in heritage protection is the adsorption of volatile organic compounds (VOCs) in museum [21]. It is commonly considered that VOCs which are common in environment and contain hundreds of organic compounds, could exert serious threats to museum collections, such as corrosion and discoloration of surface, oxidation and decomposition of structure components [22,23]. The microporous MOFs are capable of efficiently adsorbing VOCs with their ultrahigh porosity (up to 90% free volume) and enormous internal surface areas extending beyond 10,400 m^2/g [24]. Especially, compared with commercial adsorbents, their unique frameworks could selectively capture VOCs even at trace levels. Typically, in the capture process, the specific guest molecules could be confined into the pore size, attracted by the functional groups on organic ligand, captured by the surface interactions (H-bonding, van der Waals, π-π interactions), or adsorbed by the open metal sites or coordinatively unsaturated sites (Lewis acid sites) [25,26]. It was reported that most of volatile organic pollutants have their corresponding MOFs adsorbents [26]. For example, acetic acid, one of the major pollutants in museum, could be produced from the decomposition of wood and lead to the degradation of paper cellulose and stone calcium [27]. Mohtar *et al.* explored the absorption of MIL-100(Fe) toward acetic acid in film conservation of museum, through loading MOFs on cellulose based composite paper membranes. It was observed that MIL-100(Fe) could efficiently capture acetic acid molecules through abundant open metal sites or coordinatively unsaturated sites. As is shown in Fig. 1a, the acetic acid concentrations decreased from 2120 µg/L to 340 µg/L after the introduction of MIL-100(Fe). And the concentration could be maintained for 10 days or even months (Fig. 1b) [28].

Another case is the removal of α-pinene which can be released from glue, paint and air fresheners commonly used in museum. The α-pinene inclines to react with ozone and hydroxyl, resulting in harmful by-products, like formaldehyde and acetic acid [29]. Conti *et al.* explored several MOFs (DUT-4(Al), UiO-66(Zr), and MIL-125(Ti)-NH_2,) for the capture of α-pinene with the dual experimental/modelling approach. It was testified that the three MOFs could capture α-pinene at higher analyte concentration of 1.6 mg/L to 10 mg/L, while MIL-125(Ti)-NH_2 was proved as the best candidate for removing α-pinene even at low concentration of 0.05 mg/L to 1.08 mg/L [30].

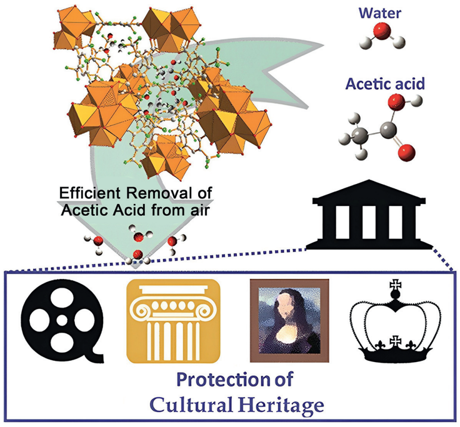


Fig. 2. The graph of UiO-66–2CF_3 removing acetic acid from air inner museums. Reproduced with permission [4]. Copyright 2018, American Chemical Society.

However, majority of MOFs are quite sensitive to water, which might lead to competitive adsorption between water and guest molecules on the same adsorption sites. The best way to overcome the challenge is to adjust the hydrophobicity of MOFs, reinforcing the interactions between MOFs and guest molecules. Dedecker *et al.* investigated a series of typical water-stable MOFs with various topologies, hydrophobicity abilities and pore sizes, to find the right strategy of selectively capturing acetic acid. The experiment was carried out to compare the adsorption efficiency of MOFs powder to water and acetic acid. It was shown that MOFs consist of inorganic nodes without polar groups and lipophilic organic linkers functionalized with polar groups (*e.g.*, -CF_3, -NO_2, -X), displayed the best selective absorption for acetic acid. MIL-140B and UiO-66–2CF_3, proved as the best candidates, could capture acetic acid molecules in the presence of moisture, revealing a broad prospect in efficient removal of low concentration acetic acid from indoor air in museums (Fig. 2) [4]. Besides VOCs, the inorganic pollutants like SO_2, H_2S, Cl_2, CO, NO_2, O_3, NH_3 in museum can be selectively adsorbed by multiple MOFs adsorbents (Table 1) [15,31–50], indicating enormous prospect for MOFs in air purification of museum environment.

2.2. Surface waterproofing

The waterproofing on surfaces of cultural heritage is another typical innovative application for MOFs. It is indisputable that heritage both indoor and outdoor are highly sensitive to external water from condensation and wet precipitation, which could cause microorganism breeding in wooden or paper relics, corrosion in

Table 1
Harmful gases in museums and the corresponding MOFs as potential adsorbents.

Harmful gas	Damage to heritage	MOFs with selective adsorption	Ref.
SO_2	Producing sulfuric acid with the water, resulting corrosion of metal, stone, murals and organic cultural relics	NOTT-300 ($[Al_2(OH)_2(C_{16}H_6O_8)]$), MFM-300(In) ($[In_2(OH)_2(C_{16}O_8H_6)]$), MOF-74(Mg), DUT-67($C_{25}H_9O_{32}S_4Zr_6$), *etc*	[31–33]
H_2S	Producing hydrosulphuric acid with the water, resulting the color fading of writing and paint	NbOFFIVE-1-Ni ($[Ni(NbOF_5)(pyz)_2]n$), MIL-53 (Al,Cr, Fe), MIL-100(Cr) *etc*	[34,35]
Cl_2	Reacting with metals and non-metals relics and accelerating the oxidation and hydrolysis of cellulose in paper	IRMOF-3 ($Zn_4O(C_8H_5NO_4)_3$), Co_2Cl_2BTDD ($Co_2Cl_4(C_{12}H_4N_6O_2)$), *etc*	[36,37]
CO_2	Producing carbonic acid with the water, which could dissolve limestone of stone relics and murals	SIFSIX-1-Cu ($[Cu(dpa)_2(SiF_6)]_n$), Mn $(HCOO)_2$, NOTT-202(a) ($C_{73.5}H_{52.5}In_{1.75}N_{1.75}O_{14}$), MIL-102, MIL-96, ZIF-68, ZIF-95, ZIF-100, ZIF-20, *etc*	[15,38–40]
NO_2	Producing nitric acid with the water, accelerating the hydrolysis of plant cellulose of paper relics	HKUST-1, UiO-67, UiO-66, MFM-300 (V^{III}) ($[V_2(OH)_2(C_{16}H_6O_8)]$), MFM-300($V^{IV}$) ($[V_2(O)_2(C_{16}H_6O_8)]$), MFM-300(Al) ($[Al_2(OH)_2(C_{16}O_8H_6)]$), *etc*	[41–44]
O_3	Leading to oxidation deterioration of organic cultural relics and oxidation rust of metal cultural relics	PCN-250(Fe_2Co), ZZU-281($[Mn_3(\mu_{3-}OH)_2(TTPE)(H_2O)_4]\cdot 2H_2O$), *etc*	[45,46]
NH_3	Forming ammonium hydroxide with water, which corrode zinc, copper, bronze and other alloys	Cu(cyhdc)(cyhdc^{2-}=*trans*-1,4-cyclohexanedicarboxylate), MFM-300(M) (M = Fe, V, Cr, In), UiO-66, MOF-808, MOF-199, *etc*	[47–49]
HCHO	Leading to discoloration of painting and textile cultural relics, yellowing and brittle breakage of paper cultural relics, corrosion of copper and silver metal cultural relics	[CAM][Cl]@MIL-101(Cr)−15% ([CAM][Cl] = H_2NONH_3Cl), HKUST-1, $LaFeO_3$/UiO-66-NH_2, *etc*	[50]

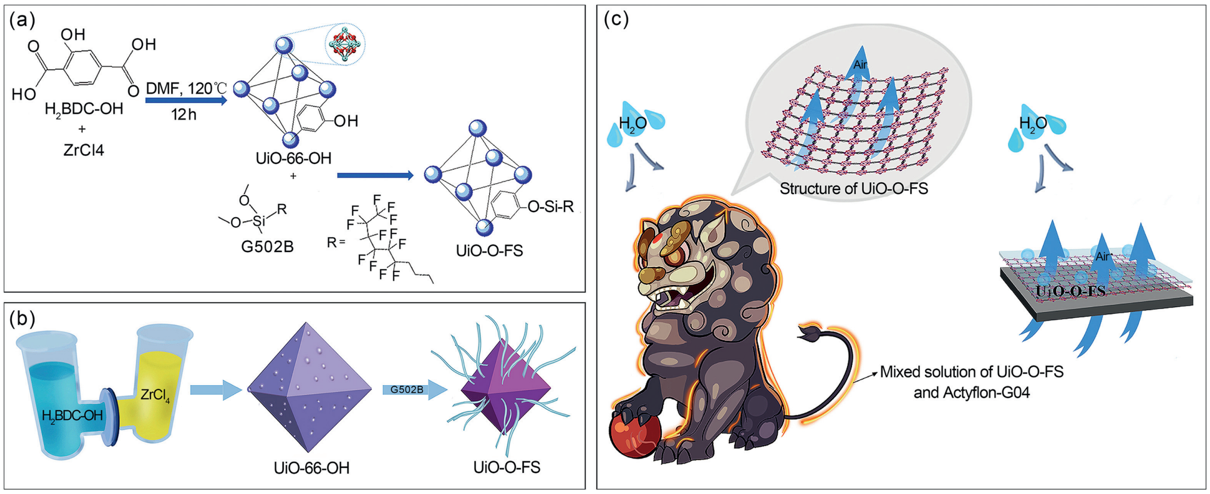


Fig. 3. (a) Schematic illustration of the chemical reaction process of UiO-O-FS. (b) Schematic illustration of the synthetic process for UiO-O-FS composites. (c) Effect of UiO-O-FS protection material in practical application. Reproduced with permission [3]. Copyright 2023, Chinese Chemical Society.

metal relics, and structure decomposition in stone relics [51,52]. The common method of repelling water is to coat waterproofing material on surfaces, which would usually block the pore windows of material surface, preventing internal moisture volatilization from heritage [53,54]. Some hydrophobic and water-stable MOFs with larger pore structures could precisely deal with this problem due to their unique structure. The porous MOFs could not only repel water through hydrophobic groups on metal sites and organic linkers, but also provide channels for outward water vapor and air through their structure pores [55], avoiding the damage caused by water inside the heritage. MOFs should be fabricated in the film form when used as a waterproof coating for heritage. For instance, Zuo *et al.* synthesized UiO-O-FS by modifying the Zr-based UiO-66-OH containing 2-hydroxyterephthalic acid linkers with G502B (dodecafluoroheptyl-propyl-trimethoxysilane). The synthesized MOFs powder was then turned into mixed solutions through the combination with Actyflon-G04 solution, forming a polymer waterproofing film layer on the surface of rock relics by the way of mixed solution brushing (Fig. 3) [3].

The synthesized MOFs was featured in porous molecule structure and attached with abundant hydrophobic groups. They displayed excellent hydrophobicity with water droplet contact angle of 133.78°, which is higher than those of the parent MOFs, UiO-66 and UiO-66-OH (Fig. 4). Moreover, the clear permeability (BET specific surface area of 249 m^2/g and average pore size of 4.5486 nm) for water evaporation and air flow, and great resistance against physical abrasion and acids/salts erosion were proved as well in test [3]. Furthermore, it is reported that more than 50 MOFs, such as NMOF-1 [56], UiO-66/Pd/PDMS [57], UHMOF-100 [58], were developed with mature strategies of designing and synthesizing. These MOFs have been tested to be capable of protecting the surfaces of heritage with good stability, hydrophobicity and

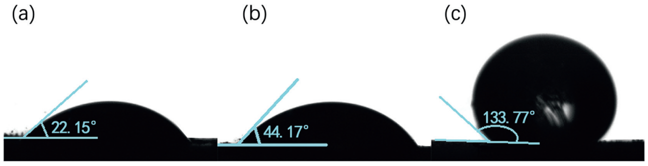
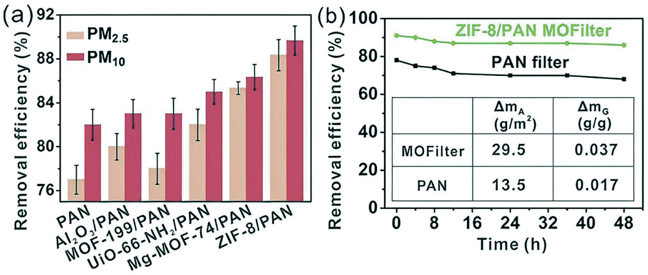


Fig. 4. Contact angles of water droplets for (a) UIO-66, (b) UIO-66-OH, and (c) UIO-O-FS. Reproduced with permission [3]. Copyright 2023, Chinese Chemical Society.



	Δm_A (g/m^2)	Δm_G (g/g)
MOFilter	29.5	0.037
PAN	13.5	0.017

Fig. 5. (a) PM removal efficiencies of different kinds of MOF-filter. (b) Long-term PM2.5 removal efficiencies of PAN filter and ZIF-8/PAN MOF-filter. Reproduced with permission [63]. Copyright 2016, American Chemical Society.

porous structure, indicating the promising application of MOFs in waterproofing of heritage surfaces [59].

3. Potential prospects of MOFs protecting heritage

3.1. Particulate matters (PM) removal

PM distributing universally in air is a great threat to heritage in museum as it could adhere to surfaces with the absorption of moisture and microorganisms, causing erosion of heritage [60,61]. Consequently, some valuable heritage in museum (paintings, fabrics, films, manuscripts) must be reserved in dust free environment. It has been found that some MOFs with large cavities and high zeta potential have shown enormous promise for PM removal with high adsorption efficiency of several times over traditional adsorbents [62,63]. It is known that the main ingredients of PM consist of organic carbon (OC), elemental carbon (EC), nitrates, sulfates, ammonium salts and sodium salts (Na^+), which are highly polar due to the exist of water vapor and multiple ions [64]. Thereby, MOFs could electrostatically interact with particulate matters through the unbalanced metal ions on MOFs' surface and the defects in MOFs, both of which could provide positive charges and polarize the fine particle surfaces [63]. The PM affinity of MOFs endows them with great application potential in air filtration system of museum. Zhang *et al.* prepared MOFs-Filters with several kinds of MOFs through the way of embedding MOFs powder in polymer and producing the MOF/polymer electrospinning by the technique of "priming". The ZIF-8/PAN MOF-filters prepared in such approach exhibited high removal efficiency (88.33% ± 1.52% for PM2.5 and 89.67% ± 1.33% for PM10) followed by MOF-filters loaded with Mg-MOF-74/PAN, UiO-66-NH_2/PAN, Al_2O_3/PAN, MOF-199/PAN and so on (Fig. 5a). Simultaneously, the high removal efficiency could be kept for 48 h in real air-polluted environment (Fig. 5b) [63].

To overcome the problem of difficult mass production of MOFs-Filters with electrospinning, Chen et al. further developed multiple MOF-filters with ZIF-8 *via* adding the plastic mesh covered with MOFs' precursors powder between two rollers, producing five kinds of commercially available, cheap, and flexible substrates in roll-to-roll hot-pressing process (Fig. 6). The obtained MOF-filters revealed great application potential with excellent removal efficiency of PM2.5 99.5% ± 1.7% and PM10 99.3% ± 1.2% in room temperature. Moreover, the MOF-filters also displayed superior robustness in efficiency even at 200 °C or after sandpaper grinding, more than 100 twists and many cleanings [62].This work provides sufficient evidences for the potential application of MOFs for removing PM in museum.

3.2. Anti-bacteria

Bacteria growing inside museum is of great concern to heritage conservators as well, which would cause multiple losses to heritage, such as metal relics corrosion aroused by thiobacillus, paper and fabric organic matter degradation resulted from acid-forming bacteria. Furthermore, bacteria could freely pass through air filtering systems [65,66]. MOFs are promising to be used in museum air sterilization, as their broad-spectrum antibacterial and various sterilization mechanism (Fig. 7) [67]. It has been well studied that some special metal-MOFs, like silver(I)-MOFs, copper (II)-MOFs, can release metal ions with their metal clusters. The metal ions could inhibit nicotinamide adenine dinucleotide (NADH), causing in structure changes of cell membrane and resulting the death of bacteria with an imbalance of the materials exchange inside and outside the cell [68]. What is more, the metal ions could penetrate through cell membrane and react with functional groups on bacterial DNA [69,70], influencing the antimicrobial activity and providing a long-lasting antibacterial effect at a controlled release pace [71]. Moreover, some MOFs could inactivate bacteria by loading antibacterial organic ligands like norfloxacin (HNorf) and nalidixic acid (HNDX), encapsulating some biocidal guest in structure pores (antimicrobial, antibiotic, *etc.*), or inducing cell bacte-

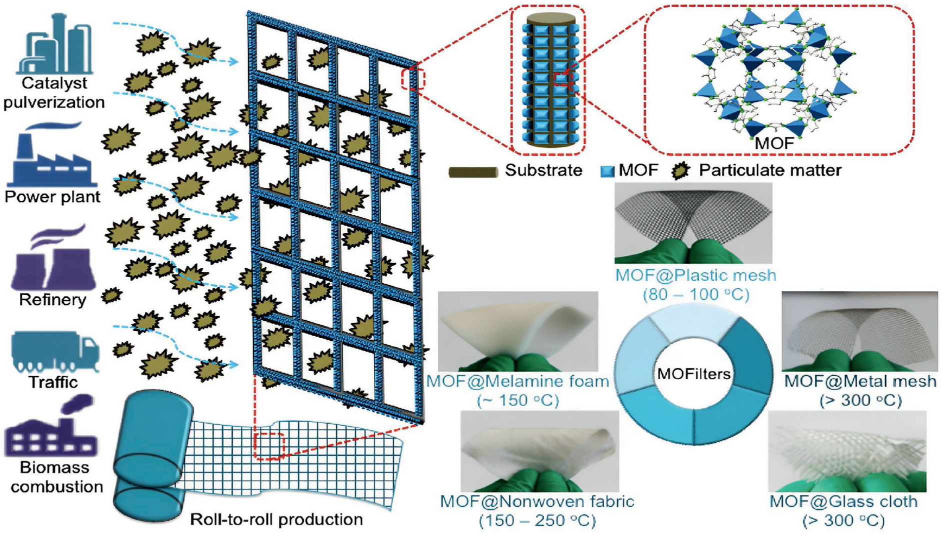


Fig. 6. The schematic representation of the roll-to-roll production of various MOF-based filters (MOF-filters) for PM removal. Reproduced with permission [62]. Copyright 2017, Wiley.

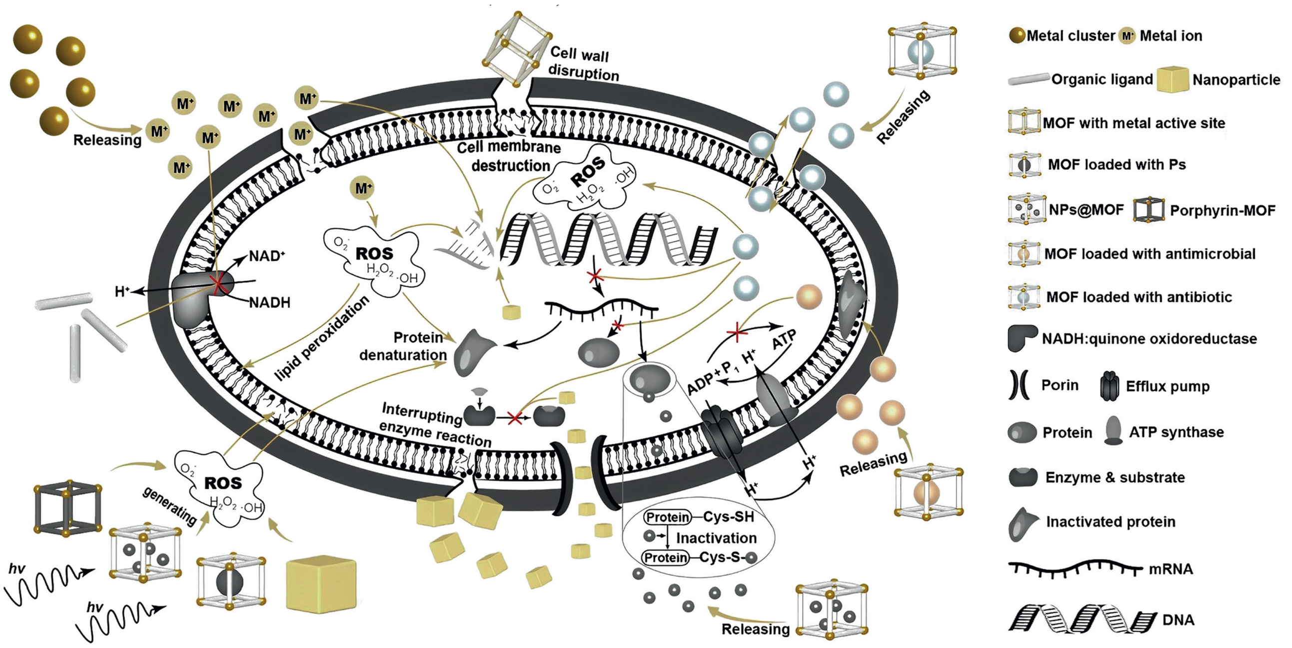


Fig. 7. Schematic diagram summarizing the antimicrobial mechanisms of MOFs. Reproduced with permission [72]. Copyright 2021, Elsevier.

ria lysis in nanoform, *etc.* [72]. Furthermore, MOFs are capable to devitalize bacteria *via* increasing reactive oxygen species (ROSs). The ROSs ($O_2^{\bullet}$, $^1O_2$, and $^{\bullet}OH$) could be generated from the photocatalytic process of Porphyrin-MOF or MOFs loaded with antimicrobial in pore, which damage microbial cells by combining with a series of biological molecules of microbe (proteins, RNA, DNA, NADH/NADPH, *etc.*)[72,73].

Remarkably, the intriguing antibacterial property and strong PM removal capability can be combined in some MOFs with large cavities and photocatalytic property [74], endowing MOFs with tremendous potential to produce multi-functional and efficient integrated air filtration system of museum. Li *et al.* fabricated an air MOF-filter with ZIF-8 through synthesizing MOFs particles on textile substrates, which could efficiently adsorb PM and inactivate bacteria by producing ROSs. Mechanism study showed that ROSs were produced by activation of O_2 through electron transfer from the photoinduced Zn^+ centers within ZIF-8 under light conditions. Compared to blank non-woven fabric (NWF), the fabricated MOF-filter displayed remarkable performance under the condition of light and air flow (Fig. 8a). The removal efficiencies for PM2.5 and PM10 were 96.8% and 97.7%, respectively (Fig. 8b). Meanwhile, the photocatalytic sterilization reached a killing-efficiency exceeding 99.99% within 30 min, and the validity could be maintained even after 5 cycles (Figs. 8c and d), shedding the light on MOFs' anti-microbial prospect in heritage protection [74].

3.3. Humidity control

Keeping the proper humidity of air is extremely important to heritage. Excessive humidity may promote the microorganism breeding in wooden or paper heritage and the corrosion in metal relics, while low humidity may cause the water-loss shrinkage damage to some organic heritage (animal specimens, plant specimens, bamboo, ivory, bone and so on) [75,76]. Some MOFs with regulated hydrophilicity/hydrophobicity could act as environmental desiccants to control indoor humidity [29,77]. Shi *et al.* reported that water-sensitive MOFs, like MOF-801, MOF-841, Co_2Cl_2BTDD, CAU-10 and MOF-303, could efficient absorb water through various mechanisms, such as chemisorption by open metal sites, hydrogen bonded adsorption by hydrophilic organic ligands and physical adsorption by structural pores (Fig. 9) [78].

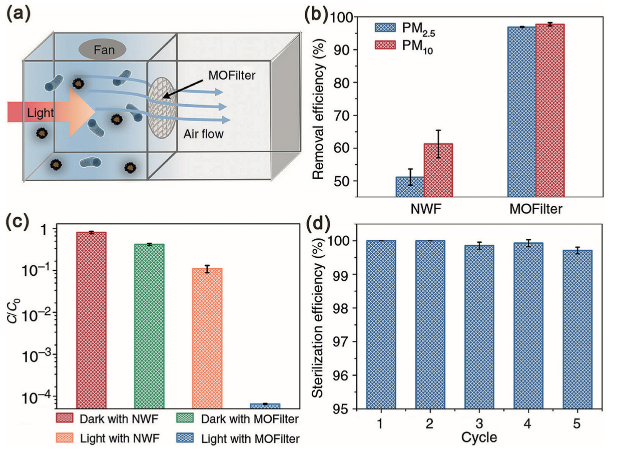


Fig. 8. (a) Schematic representation of the air cleaning system. (b) Comparison of PM removal efficiency between MOF-filter and NWF. (c) Comparison of air disinfection performance between MOF-filter and NWF under light and dark conditions. (d) Air sterilization efficiency of MOF-filter for 5 cycles. Reproduced with permission [74]. Copyright 2019, Springer.

Tao *et al.* further designed an air humidity control experiment with MOF-801 powder. The results shown that the water adsorption amount of MOF-801 was respectively 190% and 132% of that of silica gel and 13X molecule sieve in condition of extremely low humidity (RH 20%–40%) and constant temperature (20–40 °C). The water desorption amount of MOF-801 were 109% and 146% of those of silica gel and 13X molecule sieve in thermostatic drying environment of constant temperature (75–115 °C) [79]. It is well known that some metal relics, like bronze, iron, gold and silver, must be reserved in constant temperature of 20 °C and low humidity condition of RH 0%–40%. Therefore, it is much suitable for MOF-801 to be used as desiccant in dehumidification of such environment. Zhu *et al.* developed a moderately hydrophilic MOF (UiO-67–4Me-NH_2–38%) with prominent thermal, hydrolytic and acid-

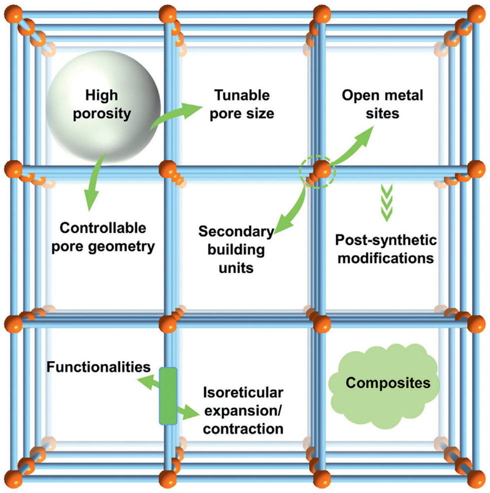


Fig. 9. An overview of water adsorption using metal-organic frameworks. Reproduced with permission [78]. Copyright 2023, Elsevier.

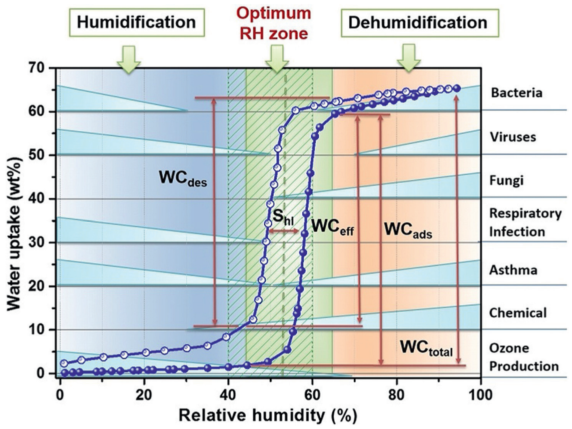


Fig. 10. Demonstration of autonomous indoor humidity control applying UiO-67–4Me-NH_2–38% (WC$_{ads}$ = Adsorption uptake at 65% RH-Adsorption uptake at 45% RH; WC$_{des}$ = Desorption uptake at 65% RH-Desorption uptake at 45% RH). Reproduced with permission [80]. Copyright 2021, Wiley.

base stability, *via* adjusting the types and ratios of hydrophobic and hydrophilic groups on organic ligands. The material promised a great potential in automatic control of museum indoor humidity, featuring S-shaped water absorption isotherm located in 45%–65% RH (the comfortable range for indoor ventilation) and 40%–60% RH (the optimal range for minimizing adverse health effects) [80]. While the majority heritage in museum, like paper, porcelain and rocks, are usually reserved in the environment of RH 40%–60%. As is shown in Fig. 10, the MOFs could achieve the automatic control of indoor humidity under the inducement of humidity levels, and work as desiccant or humidifier when the air humidity is less than 50% RH or more than 65% RH.

4. Conclusion

Due to the unique properties in the structure, surface area, pore volume, active sites and hydrophilic/hydrophobic balance, MOFs display enormous potential in harmful gas adsorption, surface waterproofing, PM removal, antibacterial and humidity control. The properties match well with the various and strict demands of heritage for environment control. Despite the precondition, prior to being used in heritage preservation, several issues still require to be considered. For harmful gas adsorption, the high cost of MOFs is a barrier to their large-scale applications. Some mass-produced MOFs, like ZIF-MOFs, would be preferred in application, as is also suitable for other applications of MOFs in heritage preservation. For surface waterproofing, the stability of MOFs should be seriously taken into account especially when MOFs act as waterproof coating material on surfaces of outdoor heritage. MOFs, with stability of great resistance to aging, alteration and decomposition, are quite necessary to be designed. For anti-bacteria, the toxicity of MOFs should be concerned, since some MOFs inactivate microorganism *via* releasing poisonous heavy metal ions, like Ag^{+}, Cu^{2+}, Cr^{2+}. Eco-friendly or non-toxic antimicrobial MOFs would be recommended in air filtering systems.

It is also worthwhile noting that any materials applied in heritage preservation are neither permitted to significantly change the color, luster and other physical characteristics of heritage, nor exerted negative impacts on the material being protected or their environment. Therefore, the compatibility of MOFs with heritage, like color, luster, texture, structure, and chemical properties, need to be carefully studied and improved as demands before application. When MOFs are applied in gas adsorption, PM removal, antibacterial and humidity control, they are mainly used as adsorbents, desiccants and fungicides in environment or air filtration systems of museum. MOFs would not directly exert influence on the original materials of heritage. However, the compatibility of MOFs should be concerned when MOFs are used as waterproof coating on heritage material surfaces. Some MOFs constructed from heavy metal ions with high redox potential are forbidden to be used, as the heavy metal ions would lead to the discoloration or degeneration of heritage material *via* oxidation. In short, the MOFs with multiple and flexible functions offer promising solutions for heritage against various environmental threats. Yet the utilization of MOFs should be seriously based on the precise selection and modification according to practical scenarios, specific needs and preservation principles, due to that the damaged heritage can never be recovered.

Declaration of competing interest

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.

CRediT authorship contribution statement

Kunpeng Zhou: Writing – original draft, Software, Resources, Formal analysis, Data curation, Conceptualization. **Zhihao Shi:** Software, Resources, Investigation, Data curation. **Xiao-Hong Yi:** Data curation. **Peng Wang:** Writing – review & editing, Visualization, Formal analysis, Data curation, Conceptualization. **Aiqun Li:** Writing – review & editing, Supervision, Investigation, Funding acquisition, Conceptualization. **Chong-Chen Wang:** Writing – review & editing, Validation, Supervision, Resources, Methodology, Conceptualization.

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