Metal-organic framework adsorbents and membranes for separation applications
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With versatile chemical and engineering design, the more attention of metal-organic framework (MOF) material is shifting from its fundamental studies to industrial applications, such as engineering MOF adsorbents and membranes for selective guest capture and separations. Learned from zeolites, various effective strategies in material design, adsorbents assembly, and membranes fabrication have enabled the MOFs gradually to approach high industrial standards, bearing their unique chemical and physical properties. In this review, we focus on the important factors that may affect the practical applications of MOF adsorbents and MOF membranes.

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Introduction
Separation process, such as CO₂ removal from natural gas, chemicals purification, hydrocarbons separation and so on, played significant roles in industry and daily life, which cost more than 15% global energy production [1]. Typically, the strategy of distillation was the first choice in current processes of chemical industry. However, during the boiling process, the huge energy consumption and possible chemicals decomposition demand rapid developing of effective and safe separation technologies. As two energy-efficient and cost-effectiveness methods, adsorption-based and membrane-based separations have been considered as the most promising alternatives [2**,3,4]. Both have been investigated widely in lab research and industrial development. To achieve highly desirable separation, it is important to design the rational process of unit operation and also to screen and synthesis the matched porous materials for relevant targets.

Metal-organic framework (MOF) materials, built from the coordination matrix of various organic linkers and metal ion/clusters, have been emerged as a new kind of platform for practical separation usage, as they usually feature high surface area, tunable pore size/shape and chemical diversity [5,6**,7**,**8]. Remarkably, according to the summary study of deposited structures on Cambridge Structural Database, almost 70 000 MOFs have been reported, such as the iso-recticular MOFs (IRMOFs) [9], zeolitic imidazolate frameworks (ZIFs) [10] and porous coordination polymers (PCPs) [11]. However, only very a few of them are commercially available [12–14]. In addition, in combining with their poor water stability, crisp properties, and some engineering issues, such as scale up synthesis, the development of MOF industrialization remains not easy, but the future is bright [14], as most of the ongoing challenges are addressing through various versatile strategies and techniques [15]. Here, in the following section, govern factors, progress and problems in the development of MOFs adsorbents and membranes will be discussed.

MOF adsorbents
For MOF-based adsorptive separations, most reports focused on selective adsorptions that derived from the difference of their single-component measurements [16–18]. A few studies reported the co-adsorption performance for evaluating the capability of static mixtures adsorption [19]. It should be noted that both of them are equilibrium experiments. However, gas separation by MOF adsorbents under dynamic condition, called pressure swing adsorption (PSA), is more powerful process to fully utilize the fixed-bed space and minimize the energy request for regeneration [20]. Facing the high standard chemical engineering applications, the candidate MOFs should meet the following requests.

High selective uptake
In many porous materials, the phenomenon of trade-off between adsorption capacity and selectivity makes them difficult to achieve high separation efficiency. Therefore, to maximize the separation capacity with high selectivity is very important and challenging. Generally, the separation capacity depends upon the porosity and BET surface area of involved MOF materials, while separation selectivity lies on the preferred interaction from internal porous surface toward specific component from mixtures.
or the molecule sieve effect. The simple integration of these factors in a single domain doesn’t work well; in contrast, the optimal material is not necessary the one with highest surface area, which has high adsorption capacity for a gas and less/no adsorption to another gas. For example, adsorptive separation of C1 methane from C2 and C3 hydrocarbons is comparatively easier, given the fact that methane is the smallest molecule and therefore has weaker interactions with microporous MOF adsorbents [21]. However, facing the extremely difficult separation of C2H2 and CO2 (similar size and physicochemical properties) mixtures, the general MOFs showed good gas uptakes with low selectivity, as they show very similar adsorption isotherms. To overcome these issues, a new kind of mesoporous MOFs with increased density of open metal site was rational established [22°]. The promising structural characteristics (apparent surface area: 2800 m² g⁻¹ and high dense open metal site: 3.76 mmol g⁻¹) enables PCP-31 to show highest selective and effective enrichment of C2H2 from C2H2/CO2 mixtures at 298 K (Figure 1a–c). But for process of kinetic separation, the function of pore size and effective sites was further amplified, while, the surface area effect of the material is weakened as the accumulated sample bed can compensate for this defect. Zaworotko group developed two hybrid ultramicroporous materials of SIFSIX-3-Ni (220 m² g⁻¹) and variant TIFSIX-2-Cu-i (680 m² g⁻¹) with distinct sorbate binding sites and lower surface area that exhibit exceptional CO2/C2H2 and C2H2/CO2 selectivity [23°]. SIFSIX-3-Ni sets a benchmark for CO2/C2H2 selectivity at low partial pressures, whereas TIFSIX-2-Cu-i ranks among the best porous materials in the context of C2H2/CO2 selectivity. This Yin-yang inversion of selectivity can be rationalized to the distinct sorbate binding sites in SIFSIX-3-Ni (favorable C–H⋯F interaction for C2H2 versus single SiF6²⁻ binding site for CO2) and TIFSIX-2-Cu-I (two TiF6²⁻ bind a C2H2 versus one TiF6²⁻ bind a CO2), as revealed by Grand canonical Monte Carlo (GCMC) simulations studies. The separation performances of them were well confirmed by dynamic breakthrough experiment (Figure 1d–f). For
further promoting the separation capability, recent studies showed that MOF materials that exhibit cooperative binding sites have substantial energetic benefits over traditional adsorbents. Based on this idea, Long group reported high selective adsorption of CO in a series of MOFs featuring coordinatively unsaturated iron(ii) sites [24]. These materials exhibit large CO separation capacities with only small changes in temperature, as the Fe-MOF undergoes spin-state transition above a threshold CO pressure (Figure 1g-i). In addition, as another process of cooperative adsorption, the sharp adsorption step was also observed in the MOFs with coordinated amine species. This is because CO2 molecules can insert into metal-amine bonds to form ammonium carbamate chains [25]. As a consequence, those series of versatile strategies can enable the MOF adsorbents to achieve high efficiency for various separations not only in equilibrium but also under kinetic conditions.

MOF prilling

Due to the small crystallites or powder of as-synthesized MOFs (cannot be put to use in most applications), the prilling process is one of the main challenges, which offers great promotion for feasible industrialization of MOF materials [26]. The shaped MOF can not only increase the packing density of MOF powders from typically 0.2–0.4 g cm⁻³ to 0.5–0.8 g cm⁻³, but also not be easily blown away as its microparticles [27]. The prilling process made the target features good resistance to pressure (2–100 N), and also keeps the size of the body in the range of 1.5–50 mm in all directions [28]. As far as the reported prilling process of zeolites, spherical or cylindrical bodied are preferred. In addition, the pellets, hollow bodies and honeycombs are also acceptable.

To fulfill the prilling process, two main methods, such as mechanical pressing of the powder materials with or without binders and compacting of moistened powdery materials by rotating movements, can be employed. Generally, an organic viscosity-enhancing compound for converting the materials into a paste can be added to the MOFs, with the mixture being subsequently compacted in a mixing or kneading apparatus or an extruder. Preferably, the dried binders have porosity for guest diffusion. Importantly, no matter what kind of binders used, the highest priority is to keep the original porosity during shaping the MOFs. Such as, ZIF-8 pellets, produced by Bazer-bachi, have good surface area (1300 m²/g) and force resistance (0.7 daN/mm) [29]. Interestingly, Fairen-Jimenez reported the sol–gel strategy for engineering HKUST-1 to form pure monolithic structures of up to about 1 cm³ in size without using high pressures or additional binders. The shaped HKUST-1 with lower gravimetric BET areas (1193 m²/g) showed significant enhanced CH₄ uptake (259 cm³/g) and mechanical robustness [30].

Water stability

Despite the good separation capacity and good selectivity, assessing MOF adsorbents to be feasible candidate for gas separation requires rational design and understanding of good water stable MOF materials [31–32]. This is because the practical separations, such as production of light hydrocarbons and selective carbon dioxide capture from flue gas systems, contain varied degree and even saturated water vapour [33]. According to comprehensive surveys of precise MOF structure and their water stability tests, two main strategies were believed as good choice for preparing stable MOF materials: firstly, introducing stronger coordination bonds between the ligands with high pKa value and/or the metals with high oxidation state [20,34,35]; secondly, installing hydrophobic moiety around the coordination sites or on the surface of the crystals [15,36]. In addition, the ligand rigidity, metal coordination geometry and network interpenetration can also influence the final framework stability. Among the strategies, a hierarchy sequence will significantly help in designing stable MOFs. In other words, if stronger coordination bonds exist in the generated MOFs, other factors can be ignored. However, if stronger connection is not formed, introducing hydrophobic moiety and/or combining relevant structural factors could benefit the preparation of stable MOFs. For example, a chemically stable MOF (NbOFFIVE-1-Ni) was designed by utilizing fluorinated ligand in Eddaoudi group (strong Ni–N coordination bond and hydrophobic ligands) [7**]. The restricted window of this MOF, enclosing a periodic array of fluoride anions in contracted square-shaped channels, resulted in high selective molecular exclusion of propane from propylene at atmospheric pressure. This is a typical example of water stable MOF that has significant effect of molecular sieve effect.

Scale up synthesis

As high potential absorbent, large scale and efficient MOF production is one of the crucial pre-requisite for accessing its practical application (Table 1). Typically, solvothermal reaction, as the most popular method for MOFs synthesis, is known as the heating of mixed metal salt and organic linker within corresponded solution in a sealed reaction vessel. During reaction, the higher temperature and auto generated pressure promote the solubility of involved coordination segments, nucleation growth and final assembly in high crystalline manner. However, the barriers of which remain difficult to overcome, as the extended long reaction time (at least several hours or days) and large amount solvents consumption. Scale up synthesis inclined to produce different product, even the synthesis conditions are same as that of the small vessels reaction (proceed well for MOF screening in lab scale). Following the rapid development of MOF chemistry, solvent limitation has been overcome by alternative method of mechanochemical synthesis [37]. Ball milling technique promotes the MOF formation with high
efficiency (kilograms per day) from mixture of metal salts and organic linkers, but leads to decreased pore volume frequently, as the synthesis conditions are obstacle to the formation of high crystalline and porous structures. Electrochemical synthesis, as another attractive and viable method, showed continuously operation and lower demand of solvents treating [38]. Interestingly, continuous flow chemistry showed significant advantages for the scale up synthesis of MOF materials [39,40]. A continuous flow reactor comprises the continuous pumping of starting materials into a tubular reactor and the isolation of products. Despite the rapid synthesis (several mins or hours), the generated MOFs could keep well of its inherent surface area and also allow excellent control of the particle morphology. For example, the high porous MOFs of HKUST-1 (1670 m²/g) [41], NOTT-400 (1070 m²/g) [42] and UiO-66 (1100 m²/g) [43] can be prepared within 5–15 min under defined and easy controlled conditions. However, the two factors that consist of processing of crucial reaction mixtures for pure MOF isolation and solvents recycling made the continuous flow chemistry problematic to develop.

Reusability of MOF
As efficient absorbents, the persistent reusability is very important, as it could affect the finical issue of the involved industry. For MOF absorbents, the reusability is directly related to the water/chemical stability of the frameworks and also the condition of adsorption and regeneration. For example, the water stable NTU-14 could keep stable dynamic CO₂ uptakes during 10 cycles in the temperature range of 293–393 K [15]. Fe-MOF-74 showed extremely steep O₂ adsorption at 298K (9.5 wt% at 0.01 bar). But, the strong connection of open Fe sites and O₂ molecules makes the regeneration difficult. The increased temperature, up to 473 K under dynamic vacuum, ultimately leads to decomposition of the framework. However, when the adsorption occurred under 211 K, the amount of adsorbed O₂ decreased only 0.7 wt% after eight cycles of experiments [44]. Facing selective water capture, the Y-shp-MOF-5 exhibits hundreds of adsorption/desorption cycles without loss of efficiency [45]. More interestingly, the well-constructed devices based on MOF-801 can capture 2.81 of water per kilogram of MOF daily from the atmosphere at ambient conditions. During the 80 cycles, the device showed stable moisture capture [46].

In addition, for compressed MOF absorbents, the capillary forces and the penetration of the solvents can destroy the original shape. In the other words, such kind absorbents are not suitable for the usage in presence of water or liquid solvents. However, the mechanical strength of shaped MOFs that conferred by polymer binders can withstand for long time, as the polymer binders are not easy to be solved by water or common organic solvents. Despite the problems, the rational selection of MOF structure, working/regeneration conditions and separation targets would significantly promote the key indicators of MOF absorbents, such as efficiency, reusability and perdurability.

Facing the important factors we mentioned above, the design or selection of MOF absorbent and membrane should follow the consideration of target composition and working environment. For example, the MOFs with right pore size, good water stability and hydrophilic interior surfaces are more preferred for moisture capture in air even at low humidity. To further improve the capacity, the pores should be large enough, but not so big, as the water condensation will clog the pore. Distinctly, ultramicroporous MOFs (5–7 Å) exhibited excellent performances for some challenge separations. This is because the well-defined structural features of small pore size with diverse shapes, varied flexibility/rigidity and functionality have close connection with the nature properties of the adsorptive gas molecules.

MOF membranes
For MOF-based polycrystalline membranes, due to MOF’s exceptional thermal and chemical stabilities coupled with ultra-microporosity, more interests moved from
their synthesis strategies to potential separation applications. In view of this, water-resistant MOF membranes are essential for gas/liquid separations. Membranes with high gas-permeance and selectivity are desired to cut down process-cost. The easy scale-up for MOF membrane is also an important factor to determine the successful implement of the potential application.

**Improved selectivity**

Similar to the polycrystalline zeolite membrane, defect-free membrane is one of the main challenges in obtaining highly selective MOF membranes, mainly due to the difficulty in controlling their microstructures of polycrystalline membranes (e.g. grain boundary structure). By optimizing synthesis parameters, Jin et al. [47**] found that the evaporation of solvent inside the cavity of ZIF-78 framework to activate porosity of ZIF-78 membrane is vital for the appearance of defects, similar to template removing in zeolite membrane. Pan and Lai [48] also systematically investigate the influence of evaporation rate of solvent in ZIF-8 membrane on the quality of membrane for C3H6/C3H8 separation. They found that the slower the evaporation the better the quality. Finally the saturated-solvent activation method was applied for activation of ZIF-8 membrane, which exhibit a separation factor of 90 for equal-molar C3H6/C3H8 mixtures. Pan et al. [49] also prepared high-quality ZIF-67 membranes for the effective separation of propylene/propane mixtures. Due to the tiny contraction of effective pore aperture of the parent ZIF-67 framework by zinc-substitution, the separation factor for propylene/propane mixtures was significantly improved on zinc-substituted ZIF-67 polycrystalline membranes with the increase in the zinc content.

In addition, the defect-abatement strategy is also promising for improving the separation selectivity on MOF membranes. Huang and Caro [50] first used graphene oxide (GO) nano-sheets to seal the gaps between ZIF-8 crystals by virtue of its capillary forces and covalent bonds, improving the hydrogen selectivity on the ZIF-8/GO composite membrane. Recently, Pan and Li [51**] found that the polydimethylsiloxane (PDMS) coating on ZIF-8 membrane can significantly improve the separation selectivity for C3H6/C3H8 from 3 (original selectivity on pristine ZIF-8 membrane) to 55 without any sacrifice of gas permeance. The sharp raise of this performance is due to not only the blockage of the intercrystalline defects by PDMS layer but also the hindering of flexibility of the ZIF-8 framework, resulting in an unusual and highly desired increase in the separation selectivity of C3H6/ C3H8 mixture under high feeding pressure (Figure 2a).

**Improved permeance**

The gas permeance, as another important factor, determines the separation performance of MOF membrane, which is related to the membrane thickness for defect free membranes. However, thinner membrane could give poor selectivity due to more inter-crystalline defects. Fine-adjustment of the composition of synthesis solution and synthesis conditions to decrease the thickness of MOF membrane will be important for greater separation efficiency in real-world processes.

Recently, Jeong et al. [52] proposed a defect-induced ripening of seeds through vapor-phase secondary growth for the successful fabrication of ultrathin ZIF-8 membrane. Following the Ostwald-ripening-like crystal growth mechanism, in the presence of a ligand vapor, the pre-adsorbed seeds will grow bigger at the expense of smaller ones. Then, the crystals will inter-grow to form a continuous ZIFs layer through a vapor-phase secondary growth. The thickness of the resulting membrane is 300–400 nm, and the separation factor for C3H6/C3H8 is 120. However, the reproducibility of this synthesis strategy for high-quality MOF membrane is poor, since the poorly packed seed crystals. Recently, Zeng and Zhang [53**] proposed a gel–vapor deposition strategy for the successful fabrication of high-quality ZIF-8 membranes with nanometre-thickness (~87 nm). Zinc precursor was first sol-gel coated on the surface of PDVF hollow fiber to form zinc-gel layer. Then this layer was transformed to ZIF-8 membrane directly through the vapor-deposition of 2-methylimidazole by heat treatment (Figure 2b). The resulting ZIF-8 membrane exhibits Unprecedented H2 permeance of ~2 × 10–5 mol/m2 s Pa and H2/C3H8 selectivity of 3400.

Another route for preparing ultrathin MOF membrane is to fabricate 2D MOF nanosheets on porous supports [54]. Li and Yang [55] first prepare the integral 2D MOF (Zn2(benzimidazole)4) nanosheets using a gentle exfoliation process, and then filter-stack these nanosheets on porous support using hot-drop coating method. The membrane exhibit excellent performance for H2 separation and can further sustain over 120 h. Successful in fabricating ultrathin MOF (Cu(ndc)2(dabco)) membrane have also been reported by Zhao et al. [56]. Beyond this top-down method, bottom-up method was also applied for the fabrication of MOF nanosheets [57,58*]. However, it is still challenging for controlling the integrity and purity of MOF nanosheets, and these ultrathin MOF membranes also suffered from low mechanical stability. In addition, Wang et al. [59*] proposed a strategy to fabricate ultrathin and defect-free MOF membranes by the secondary growth of a 2D hybrid ZIF-8/GO seeding layer on porous support. The thickness of the resulting composite membrane is 100 nm, and the selectivity for H2/C3H8 is 405.

**Improved stability**

Most of MOF materials suffer from insufficient hydrothermal stability, and water-tolerant MOF materials are desired for membrane application. Zirconium(IV)-carboxylate MOFs (Zr-MOFs) are considered as the
promising alternatives because of the strong bonding energy between Zr(IV) atoms and carboxylate oxygens [60**]. Li et al. [60**] have fabricated UiO-66 (Zr6O4(OH)4(BDC)6 (BDC: 1,4-benzene-dicarboxylate)) membranes on alumina hollow fibers using an in situ solvothermal synthesis method. The resulting membrane exhibited excellent multivalent ion rejection and good permeability (Figure 2c). Subsequently, well-intergrown UiO-66 metalorganic framework membranes also fabricated on prestructured yttria-stabilized zirconia hollow fibers are reported via controlled solvothermal synthesis [61]. The resulting membrane remains robust during a pervaporation stability test (~300 h), including exposure to harsh environments (e.g. boiling benzene, boiling...
water, and sulfuric acid) where some commercial membranes (e.g. zeolite NaA membranes) cannot survive. Besides the exceptional chemical stability, the developed UiO-66 membrane as a promising candidate for water desalination. However, the aperture size of UiO-66 is relatively large and not suitable for the gas-separation. Jin et al. [62] also developed a facile reactive seeding method for improving the interfacial bonding between the MIL-53 polycrystalline layer with the porous alumina support, in which the porous support acted as the inorganic source reacting with the organic precursor to grow a seeding layer. The resulting MIL-53 membranes exhibit excellent separation performance for H2/CO2 mixture and water/ethanol acetate solution (7 wt% water). ZIF-8 materials have attracted intensive research efforts in gas-separation not only its ultra-microporous feature but also robust stability, but they still can be hydrolyzed under hydrothermal conditions. Lin et al. [63] improved the stability of ZIF-8 membranes in water through utilization of a ligand exchange post-modification method which replaces methylimidazole ligands on the outer surface of ZIF-8 membranes by the more hydrophobic, bulkier 5,6-dimethylbenzimidazole. Pan and Li [51**] also found that the covering PDMS coating on the outer surface of ZIF-8 membranes also can significantly improve the stability of ZIF-8 membrane due to the intrinsic hydrophobicity of PDMS.

Scale-up fabrication
At earlier-state synthesis of MOF membrane, MOF membranes were mostly made on inorganic supports (discs or hollow fibers), which are generally too bulky and expensive for industrial gas separation. The pristine polymeric membranes and mixed-matrix membranes are robust and processable, but these generally do not exhibit sufficiently high gas selectivity and permeability, and, perhaps more importantly, their performance diminishes rapidly due to the plasticization [64]. Inorganic membranes (zeolite, silicas or carbon molecular sieve) can achieve high selectivity and permeability, but are difficult to fabricate on a large-scale due to uncontrollable intercrystalline defects [65**,66,67]. Polymer substrates take the advantage of low cost and high processing ability, and hollow fiber polymer membrane modules can be fabricated with large membrane areas. Therefore, polymer-based MOF membrane is feasible for industrial separation application [68,69]. Nait et al. fist reported an interfacial microfluidic process to in situ grow ZIF-8 layer on the inner side of the Torlon hollow fibers [65**]. Jin et al. prepared well-intergrown ZIF-8 and ZIF-71 polycrystalline membrane on ceramic hollow fiber support [47**,70]. The membrane synthesized on the inner side of the support is more feasible for safe-installation into the membrane modules. The fabricated continuous ZIF-8 membranes had good H2/C3H8 separation factors of 370. Coronas et al. [71] used similar method for the successful fabrication of ZIF-7 membranes, which exhibit high separation performance for CO2/N2 mixtures. For the concept of scale-up, larger modules with multiples MOF (CuBTC and ZIF-8) hollow fibers membranes were also successfully prepared (Figure 2d) [72]. Besides, the gel–vapor deposition methodology is often employed for the in situ production of MOF hollow fiber membrane module, which may well prevent the breakage during preparation and installation [53**].

Although MOF membranes have demonstrated attractive performance in previous studies, there is still a long way to go before these materials can be industrialized and commercialized. More importantly, simple, low-cost methods are being developed to prepare more types of large-scale MOF membrane on economical supports. The fabrication of ultrathin defect-free membrane remains crucial to enhance the separation performance. Their stability and cracking problems may be solved by improving the interfacial compatibility between the polycrystalline layer with the porous support or block the intercrystalline defects by polymer coating. We also believe that, with more research effort, MOF membranes will be further extended into other unexplored fields.

Conclusions
Given the exciting chemical/structural variability and remarkable porosity, MOFs have been proposed and exploited as adsorbents for industrial gas separations and also as promising platform for high-performance membranes. The pore structure and structural stability of MOF adsorbents and membranes are affected by the physicochemical properties of the hybrid materials, which result in incomparable separation performance. Molecular design of MOFs and post-treatment of MOF membranes using various strategies have enhanced the separation performance. However, the stability and scale-up fabrication of MOF materials will still need to be further studied before practical applications.

Conflict of interest statement
Nothing declared.

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References and recommended reading
Papers of particular interest, published within the period of review, have been highlighted as:
• of special interest
•• of outstanding interest


The paper provides a comprehensive review of exceptional advantages of reticular chemistry in MOF structural design. MOF related applications were also discussed.


This paper reports the MOFs absorbents with optimal adsorption thermodynamics and kinetics for CO2 separation. The integral structural properties were developed in this work.


This paper shows the fabrication of a chemically stable fluorinated MOF material, containing free-rotating pyrazine moieties that result in exceptional molecular exclusion of propane from propylene at atmospheric pressure.


This paper shows the stabilizing of two high-porosity meso-MOFs with high surface area, ultrahigh porosity, and high dense metal site. The generated MOFs enable channeline C2H4/CO2 separation.


This paper demonstrates the benchmark C2H4/CO2 and CO2/C2H2 separation by tuning the pore-size and surface chemistry in two MOFs.


This work reports the cooperative CO adsorption by utilizing the Fe-MOF absorbent with unique spin state transformation.


This review summarizes the strategies with different hierarchy for preparing water stable MOFs. Stable MOF based selective gas captures and membrane separations were also discussed.


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This paper first used solvent-saturated evaporation method to decrease the inter-crystalline defects for ZIF-78 membranes. This strategy can be applied for fabrication of other MOF polycrystalline membranes.


This paper shows that the covering of PDMS layer on ZIF-8 polycrystalline membranes can effectively block defects and hindering framework flexibility of ZIF-8 crystals. This defect-abatement strategy is useful for repairing other MOF polycrystalline membrane with some concentration of defects.


This paper first reports the gel-vapor deposition method to prepare ultrathin ZIF-8 polycrystalline membrane with impressive separation performance for H2/CH4. The thickness of the membrane is only ca. 400 nm, and the permeance for H2 reach to the order of 10^8 mol/m² s Pa, exhibiting promising for potential large-scale application.


This paper first applied the bottom-up method to prepare 2D MOF nanosheets with the aid of surfactants. Besides the top-down method, this method open a new synthesis way to prepare 2D MOF nanosheets.


This paper first grow MOF crystals on the GO nanosheet, and use the composite materials to prepare the ultrathin membranes with impressive performance for gas separation.


This paper first reports the MOF polycrystalline membrane for desalination.


This paper first report the ‘active-seeding’ method to effectively strengthen the bonding between MOF layer and ceramic support.


64. Bachman JE, Smith ZP, Li T, Xu T, Long JR: Enhanced ethylene separation and plasticization resistance in...

This paper first use the microfluidic technique to prepare MOF polycrystal-line inner side of the polymeric hollow fiber support. This strategy provide an facile method to prepare large membrane area of MOF membranes on inexpensive supports.


