MOFs UNLOCKED: NEXT-GEN MATERIALS DRIVING A NEW ERA IN PHARMACEUTICAL PROTECTION

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Metal-Organic Frameworks (MOFs) are a class of crystalline materials composed of metal ions coordinated to organic ligands that form highly porous structures (Figure 1). Their modular architecture allows for precise control over pore size, shape, and chemical functionality, making them ideal for applications in gas storage, separation, catalysis, and environmental remediation.[1,2] Recently, the Nobel Prize in Chemistry was awarded to Susumu Kitagawa, Richard Robson, and Omar Yaghi for pioneering the development of MOFs, recognizing their transformative impact on material science and their potential to solve global challenges.[3]

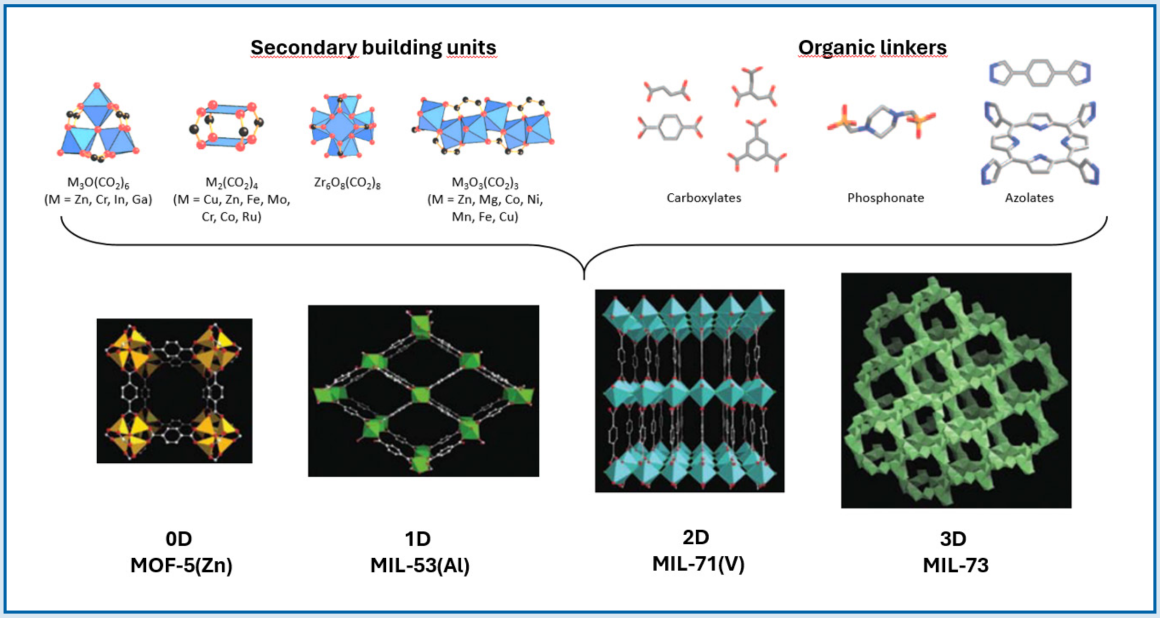

Figure 1: Schematic representation of the building block units of MOFs and examples of the different dimensionality

Metal-Organic Frameworks offer vast internal surface areas (up to the size of a soccer field per gram) enabling them to trap, separate, and store molecules with extraordinary efficiency. MOFs have been used in catalysis, separation and purification (remove “PFAS” (Per- and polyfluoroalkyl substances) from water), drug delivery and as antimicrobial agents.[4,5] They are also known for their ability to trap volatile species in their porosity (e.g., harvest water (humidity) from desert air, capture carbon dioxide and store hydrogen).[2] Their tunability and versatility have led to the synthesis of over 90,000 unique MOFs, with computational models predicting hundreds of thousands more.

One of the most promising applications of MOFs lies in pharmaceutical packaging, where they can serve as scavengers for humidity, volatile organic compounds (VOCs), and harmful gases. These contaminants can degrade sensitive drugs, reduce shelf life, and pose health risks to patients. For instance, nitrosamines (carcinogenic compounds formed from nitrosating agents reacting with secondary or tertiary amines) have been found in several drug products, prompting global recalls and regulatory scrutiny.

MOFs can be engineered to selectively adsorb these molecules, acting as molecular sieves that protect pharmaceuticals from degradation.[6] Their high porosity and chemical specificity allow them to capture trace amounts of moisture, VOCs, and nitrosating agents, maintaining drug stability and ensuring patient safety. This is particularly critical for drugs with narrow therapeutic windows or those administered via inhalation, where exposure to carcinogens can be especially dangerous.

Aptar CSP Technologies has integrated MOFs into its advanced 3-Phase Activ-Polymer™ technology platform, which actively scavenges moisture, VOCs, nitrosating agents and volatile nitrosamines in packaging headspace. Figure 2 illustrates Activ-Polymer™ technology, which employs MOF active materials as fillers in composite materials to improve their physical and/or adsorption properties. The proprietary technology is delivered in a unique formulation comprised of a base majority polymer that provides the physical structure, a channeling agent, and active particles.

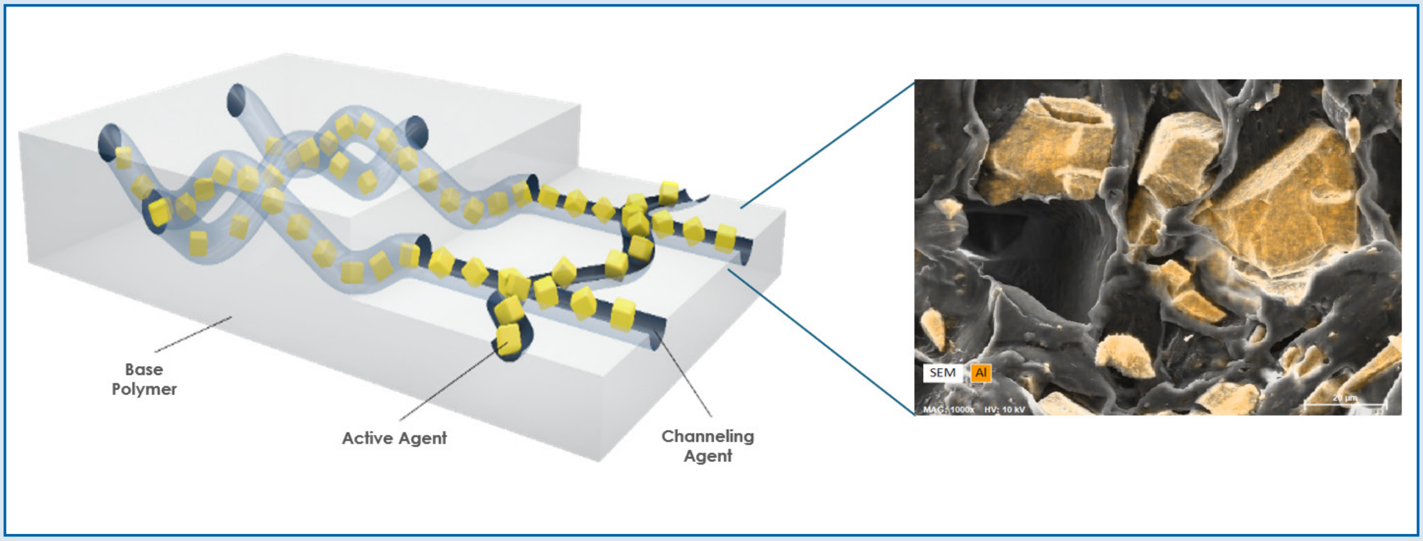

Figure 2: Representation of Activ-Polymer™ technology (left); High-resolution Scanning Electron Microscopy image coupled with EDX analyses of an Activ-Polymer™ material containing an Aluminum base MOF as active material (right)

Figure 3 shows the moisture adsorption curve at 22°C and 80% RH of Aptar CSP's Activ-Polymer™ extruded MOF-SORB films (polymers + MOF) containing up to 55 Wt.% of MOF adsorbent, deployed inside pharmaceutical packaging solutions. The adsorbent MOF material present in the Activ-Polymer™ films is able to scavenge moisture (up to 200 mg/g of film) in packaging despite the presence of polymers (no pores blocking). The adsorption kinetics can be also adjusted depending on the thickness of the composite materials and/or the nature of the polymers or the MOF (not shown here).

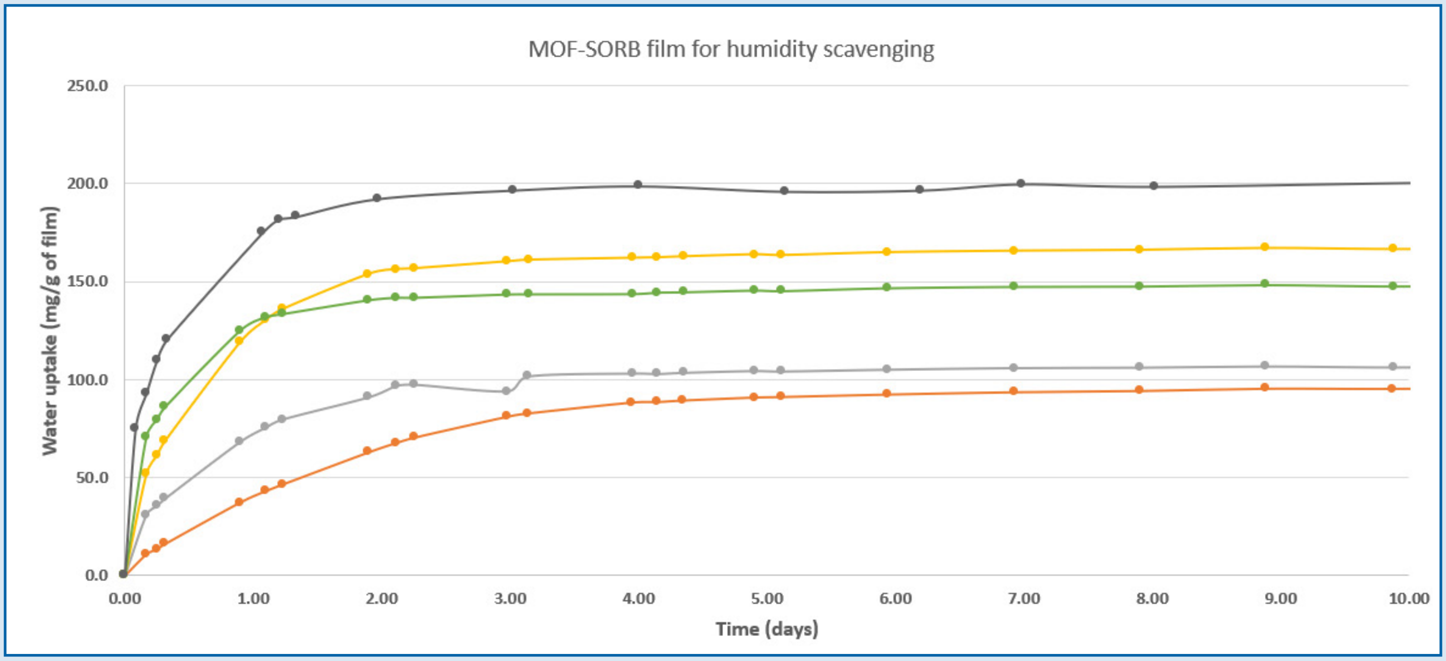

Figure 3: Adsorption kinetics of moisture at 22°C and 80% RH over several Aptar CSP porous engineered Activ-Polymer™ films (MOF-SORB) containing several amounts of a hydrophilic MOF.

Aptar CSP's use of MOFs exemplifies how cutting-edge material science can be translated into real-world solutions that enhance drug safety and efficacy.

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Conclusion

Metal-Organic Frameworks represent a paradigm shift in porous materials, offering unprecedented control over molecular interactions. Their recognition by the Nobel Prize underscores their scientific importance, while their adoption in pharmaceutical packaging highlights their practical value. As Aptar CSP Technologies continues to innovate with MOFs, patients can benefit from safer, more reliable medications protected by the invisible architecture of molecular engineering incorporated in MOF-SORB technology (Figure 4).

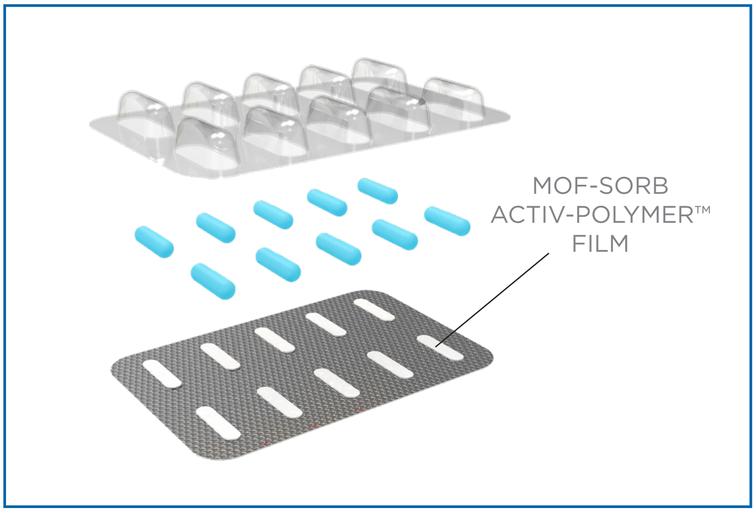

Figure 4: Activ-Blister™ solution incorporates a piece of MOF-SORB Activ-Polymer™ film into individual blister cavities, providing an optimal microclimate to enhance capsule stability within a thermoformed blister package.

References

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