



Porous Crystals Provide Potable Water from Air

Jenna L. Mancuso and Christopher H. Hendon

Department of Chemistry and Biochemistry, University of Oregon, Eugene, Oregon 97405, United States

A metal–organic framework-based device harvests water from dry air, running on solar energy.

Human health and quality of life depend on the availability of potable water. Yet, almost 3 billion people lack access to this critical resource, and by 2050 half the global population is expected to live in water-stressed areas.¹ Have you ever considered what you might do if you happened to be part of this 50%? It turns out that approximately 0.04% of freshwater on Earth has already been distilled and exists in gaseous form in our atmosphere. While this may not sound like much, it equates to approximately 1.3×10^{16} L at any given time: the development of materials and devices capable of capturing and condensing this water has been an outstanding grand challenge and opportunity for scientists.

Technologies to compress and condense water vapor have existed for some time, but these systems often require high vapor pressures (i.e., humid air) and tremendous energy expenditure (i.e., access to the energy grid), making them unfeasible in many geographical locations. In a recent report in *ACS Central Science*,² Yaghi and colleagues have made a significant advance toward providing access to sustainable clean water through the construction of a solar-powered device that catches H₂O out of dry air. The water harvester features an exchangeable sorbent cartridge containing solid-state sorbent powders. These cartridges employ forced air and heating elements to expedite water collection and, in the presented embodiment, provide access to approximately 1.3 L kg_{MOF}⁻¹ day⁻¹ in the lab, or 0.7 L kg_{MOF}⁻¹ day⁻¹ in the Mojave Desert.

The development of materials and devices capable of capturing and condensing this water has been an outstanding challenge and opportunity for scientists.

In order to realize this technology, the authors drew on their interdisciplinary knowledge of both engineering and chemistry. The first barrier to designing such a device is discovering a material capable of effectively concentrating atmospheric water vapor in ambient conditions. Metal–organic frameworks (MOFs), known for their exceptional porosity, synthetic tunability, and resultant chemical and structural diversity, are ideal platforms for modulating both the kinetics and thermodynamics of water sorption.³ Prior work developing MOFs as water harvesting materials focused on the synthesis of scaffolds whose pore apertures were less 2.1 nm.⁴ Although not immediately obvious, ideal water sorption materials should feature several small, moderately polar pores. Larger pores do give access to higher uptake capacities, but they adversely promote the formation of microscopic reservoirs of confined liquid water within the scaffold, resulting in difficulties in the desorption process (i.e., hysteresis).⁵ Additionally, the authors had to select a material with a high water affinity, while maintaining metal–ligand bond stability (i.e., the MOF is not hydrolyzed upon adsorption). Most MOFs will rapidly absorb water; however, they subsequently decompose, or the water binds too strongly to the scaffold. This potpourri of chemical properties all define the most important measurement of all—the water adsorption isotherm (Figure 1).

Yaghi and colleagues elected to use MOF-303 [Al(OH)-(PZDC), PZDC ≡ pyrazolatedicarboxylate], a framework constructed from abundant building blocks. Recalling lessons gleaned from two decades of isoreticular chemistry, MOF-303 can be thought of as an intelligent modification to two other structurally similar MOF scaffolds: MIL-160⁶ and CAU-10.⁷ Indeed, MOF-303 differs from these scaffolds by the incorporation of a pyrazolate core, in turn featuring different hydrophilicity and improved chemical stability. As a result, MOF-303 features a steep, rapid, and reversible adsorption event at $\sim 0.2 P/P_{\text{sat}}$ (20% RH, similar to the humidity found in arid regions, Figure 1). Furthermore, the omission of hysteresis in the desorption curve suggests that

Published: September 23, 2019

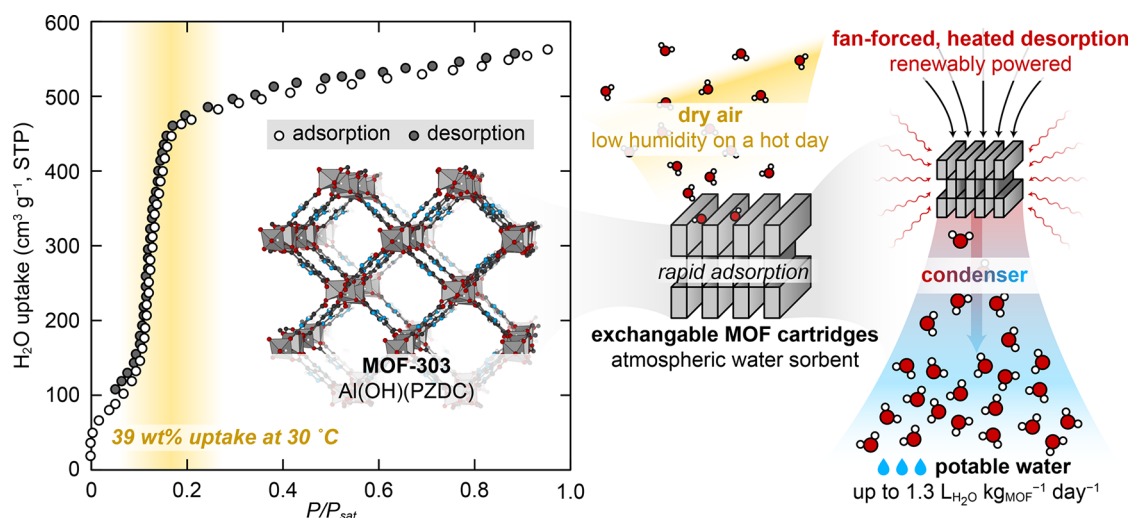


Figure 1. The water sorption isotherm MOF-303 [Al(OH)(PZDC)] shows a steep, reversible water uptake at low partial pressures. The device is constructed using cartridges of MOF-303 that are periodically desorbed by active heating. The humid air is condensed, achieving a maximum of 0.7–1.3 $L_{\text{water}} \text{ kg}_{\text{MOF}}^{-1} \text{ day}^{-1}$, depending on the environment. Isotherm data is reproduced with permission from ref 2. Copyright 2019 American Chemical Society.

the polarity and resultant framework–water interactions are ideally tuned such that the MOF releases water under moderate heating/pressure changes.

The omission of hysteresis in the desorption curve suggests that the polarity and resultant framework–water interactions are ideally tuned such that the MOF releases water under moderate heating/pressure changes.

Another impressive aspect in this report lies in the careful design of the device. Decisions were made at every level, from the atomic design of the MOF, to the device scale implementation of the heating apparatus. Earlier reports used ambient heat differentials to harvest water once per day.^{8,9} One of the significant advances made in this paper is the development of a water harvesting strategy that capitalizes on the steep and reversible uptake of MOF-303 by actively desorbing the material using a solar-rechargeable battery-powered heater. This new device was found to harvest $0.7 L \text{ kg}_{\text{MOF}}^{-1} \text{ day}^{-1}$ of clean water operating continuously in the Mojave Desert for 3 days—a 10-fold increase in water production over the single cycle system.⁹ While $0.7 L \text{ kg}_{\text{MOF}}^{-1} \text{ day}^{-1}$ may not sound like it is going to single-handedly solve the global water crisis, it is a tremendous step forward. We agree with the authors, “... it is a lot of water, if you don’t have water.”

Overall, the device reported here is a thrilling example of applied science seeking solutions to global issues. Perhaps the most exciting aspect of this Paper is that it highlights that there is

One of the significant advances made in this paper is the development of a water harvesting strategy that capitalizes on the steep and reversible uptake of MOF-303 by actively desorbing the material using a solar-rechargeable battery-powered heater.

still much more work to do. For example, the free MOF exhibited superior sorption kinetics compared to its implementation in the device ($\sim 10 \text{ min cycle}^{-1}$ vs $\sim 1 \text{ h cycle}^{-1}$), emphasizing that there is room for device optimization. In addition, the number of possible sorbent materials is seemingly endless. This study encourages the fundamental syntheses of new MOFs with high volumetric uptakes and ideal sorption thermodynamics. These syntheses should be inspired by the framework’s properties, rather than the current economics of chemical commodities. In any case, the report by Yaghi and colleagues is certainly the best example of a water harvesting device capable of producing enough drinkable water for at least one, albeit small, person per day.

Author Information

E-mail: chendon@uoregon.edu.

ORCID

Christopher H. Hendon: [0000-0002-7132-768X](https://orcid.org/0000-0002-7132-768X)

REFERENCES

- (1) WWAP (UNESCO World Water Assessment Programme). *The United Nations World Water Development Report 2019: Leaving No One Behind*; UNESCO: Paris, 2019.

(2) Hanikel, N.; Prévot, M. S.; Fathieh, F.; Kapustin, E. A.; Lyu, H.; Wang, H.; Diercks, N. J.; Glover, T. G.; Yaghi, O. M. Rapid Cycling and Exceptional Yield in a Metal-Organic Framework Water Harvester. *ACS Cent. Sci.* **2019**, in press. DOI: [10.1021/acscentsci.9b00745](https://doi.org/10.1021/acscentsci.9b00745)

(3) Furukawa, H.; Gándara, F.; Zhang, Y.-B.; Jiang, J.; Queen, W. L.; Hudson, M. R.; Yaghi, O. M. Water Adsorption in Porous Metal-Organic Frameworks and Related Materials. *J. Am. Chem. Soc.* **2014**, *136*, 4369–4381.

(4) Rieth, A. J.; Wright, A. M.; Skorupskii, G.; Mancuso, J. L.; Hendon, C. H.; Dincă, M. Record-Setting Sorbents for Reversible Uptake by Systematic Anion Exchanges in Metal-Organic Frameworks. *J. Am. Chem. Soc.* **2019**, *141*, 13858–13866.

(5) Kalmutzki, M. J.; Diercks, C. S.; Yaghi, O. M. Metal-Organic Frameworks for Water Harvesting from Air. *Adv. Mater.* **2018**, *30*, 1704304.

(6) Cadiau, A.; Lee, J. S.; Borges, D. D.; Fabry, P.; Devic, T.; Wharmby, M. T.; Martineau, C.; Foucher, D.; Taulelle, F.; Jun, C.-H.; Hwang, Y. K.; Stock, N.; De Lange, M. F.; Kapteijn, F.; Gascon, J.; Maurin, G.; Chang, J.-S.; Serre, C. Design of Hydrophilic Metal Organic Framework Water Adsorbents for Heat Reallocation. *Adv. Mater.* **2015**, *27*, 4775–4780.

(7) Reinsch, H.; van der Veen, M. A.; Gil, B.; Marszalek, B.; Verbiest, T.; de Vos, D.; Stock, N. Structure, Sorption Characteristics, and Nonlinear Optical Properties of a New Series of Highly Stable Aluminum MOFs. *Chem. Mater.* **2013**, *25*, 17–26.

(8) Kim, H.; Yang, S.; Rao, S. R.; Narayanan, S.; Kapustin, E. A.; Furukawa, H.; Umans, A. S.; Yaghi, O. M.; Wang, E. N. Water Harvesting from air with metal-organic frameworks powered by natural light. *Science* **2017**, *356*, 430–434.

(9) Fathieh, F.; Kalmutzki, M. J.; Kapustin, E. A.; Waller, P. J.; Yang, J.; Yaghi, O. M. Practical water production from desert air. *Sci. Adv.* **2018**, *4*, No. eaat3198.