New Adsorbent Materials for Desiccant Cooling

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Objective

The primary objective of this research is to identify and characterize the properties of superior adsorbent materials that can be used to construct lower cost and/or better performing desiccant dehumidification systems. Prior work at PNNL identified metal organic frameworks (MOFs) as having superior performance to the primary commercial desiccant material, silica gel. Specifically, the prior data indicated a faster adsorption rate (5 minutes vs. 2 hours for 20 wt% loading), lower regeneration temperature (90 °C vs. 145 °C), lower regeneration energy (1000 Btu/lb vs. 1300 Btu/lb), and higher equilibrium water loading (60 wt% vs. 33 wt%). Work this year has focused on synthesizing several MOFs and conducting laboratory tests to determine room temperature water vapor adsorption isotherms up to the vapor pressure of saturated air. Preliminary cost analysis has also identified representative contributions of owning and operating costs for current desiccant dehumidification systems and the costs of raw materials required for production of the various MOFs being tested.

Incumbent Technology

The majority of desiccant dehumidification systems used for building space conditioning utilize a rotating disk as shown in Figure 1. The disk is constructed from a supporting structure coated with adsorbent material. Moist process air is dried as it passes through many small openings in the disk. Simultaneously, heated regeneration air flows counter-currently through the other part of the disk to remove and exhaust moisture to the exterior of the building. Ducting and sealing flaps, not shown in Figure 1, are used to separate the two streams.

Desiccant dehumidification warms the process air stream via heats of condensation and adsorption. Heat from the process stream is usually transferred to the regeneration air stream, which simultaneously reduces the required sensible cooing of the process air and required heating of the regeneration stream, as illustrated in Figure 2. The red line represents the temperature and the blue line the humidity of the process air as if flows through the desiccant wheel and heat exchanger. Many variants of the basic concept shown in Figure 2 have also been developed. A cutaway drawing of this type of desiccant dehumidification system is shown in Figure 3

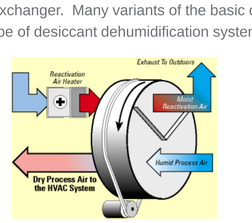


Figure 1. Desiccant Wheel

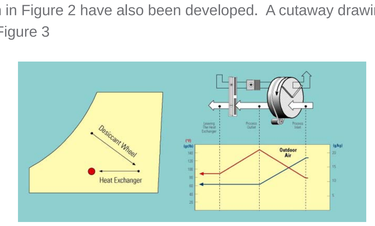


Figure 2. Wheel with Heat Recovery

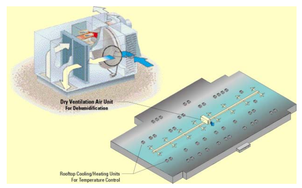


Figure 3. Desiccant Dehumidification System

Sorbent	$/kg	Sorbent	$/kg
CuBTC	20.08	CoDOBDC	13.33
CoCo	35.14	MgDOBDC	1.19
MOF-5	2.93	Mil 100	15.64
ZnDOBDC	1.90	Mil 101	4.57
NiDOBDC	6.48	Silica Gel	1.00

Table 1. MOF Raw Material and Silica Gel Bulk Purchase Costs

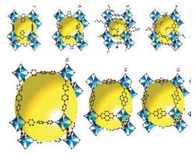
Economic Results to Date

Life-cycle costs include all costs of owning and operating a technology. Cost data reported by the U.S. Army for a desiccant dehumidification system installed at a facility in Florida indicate that initial capital costs accounted for 60% of the life-cycle cost, with regeneration energy and maintenance accounting for 27% and 13%, respectively. While this split will vary significantly depending on the specific technology, climate, and energy costs, these figures suggest that MOF advantages associated with adsorption rate and water loading , which should reduce equipment cost, may be more important than a lower heat of adsorption.

Although MOF materials present many performance advantages, they will likely cost several times more per pound than silica gel. As shown in Table 1, MOF raw material costs alone (not including any other part of MOF production cost) are several times that for silica gel. However, the impact on total system cost should be small because silica gel material costs are estimated to be less than 1% of desiccant dehumidification equipment purchase cost.

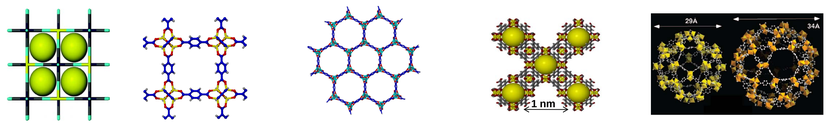
MOF Characteristics

- Similar to zeolites
- Highly porous
- Much more diverse!
- Thermally stable (>500 ºC)
- Adjustable pore sizes 5 to 15 Å
- Material have specific surface area: > 6000 m2/g.



Nanomaterials with various organic linkers
Yaghi et. al., Science 1999

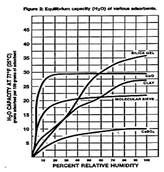
MOFs Used In The Present Study



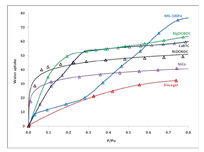
CoCo/NiCo | MOF-5 | MDOBDC (M = Zn, Co, Mg, Ni) | CuBTC | MIL-100(Fe)/MIL-101(Cr)

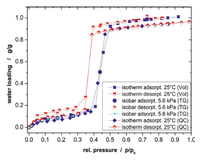
Laboratory Results

MOF Adsorption Capacities Higher Than Incumbent Desiccants



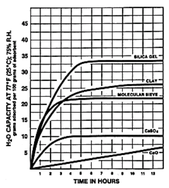
Source: Sorbent systems

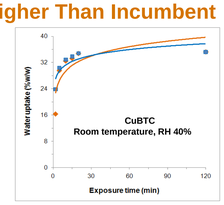


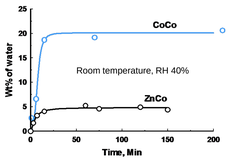


Janiak et. al. Eur. J. Inorg. Chem. 2011

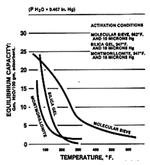
MOF Adsorption Rates Higher Than Incumbent Desiccants

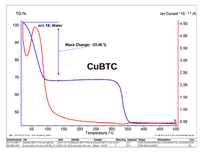


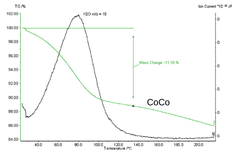




MOF Desorption Temperatures Lower Than Incumbent Desiccants







Future Work

FY 11

- Laboratory measurements
  - equilibrium adsorption of water at pressures up to the partial pressure of water in saturated air at room temperature for an additional four MOFs.
  - heat of adsorption/desorption for 3-5 of the more promising MOFs.

- Qualitatively evaluate the relative importance of adsorbent material properties for improving the cost and performance of desiccant dehumidification systems.

Future Years

- Laboratory measurements
  - water adsorption/desorption rates and heat of adsorption/desorption as a function of temperature and water vapor pressure.
  - heat capacity and density.
  - property measurements after repeated adsorption/desorption cycles.

- Down-select to 1-3 MOFs.
- Develop estimates for bulk MOF production costs.
- Quantitatively evaluate the relative importance of adsorbent material properties for improving the cost and performance of desiccant dehumidification systems.
- Work with desiccant dehumidification system vendor.