Membrane-based air dehumidification using organic ionic liquid desiccant

FFI IONIX, Inc

Oak Ridge National Laboratory

National Renewable Energy Laboratory

FFI IONIX Inc.

- Ionic Engineers
  - ‘New’ Interdisciplinary Engineering Field
- We Engineer Systems utilizing “Ionic” Materials
  - Liquid Electrolytes, Solid Polymer Electrolytes, etc.
  - Typical Applications: Batteries, Fuel Cells, Industrial Electrolysis:
    - But – virtually EVERY energy conversion application is a potential arena for Ionic Materials! Including HVAC area!!
    - Xergy: Pioneering New Applications
- IONIX: Provide Ionic Materials (resins) into Functional Forms:
  - Membranes, Tubes, Sub-Assemblies

Introduction – Why?

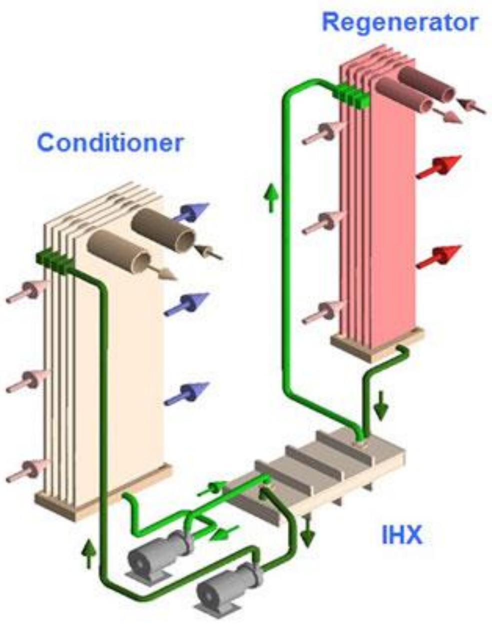
- Conventional methods of cooling provide both sensible and latent cooling
- High humidity areas have an increased cooling load to reduce the indoor humidity below 65% to maintain good IEQ
  - Mechanical methods control humidity through condensation, which further increases the latent cooling load
- An alternative method of latent cooling is sorption which adsorbs water vapor
  - In conventional Liquid Desiccant Air Dehumidifiers (LDADs) make direct contact with wet air to adsorb water – corrosion and contamination risk
  - Membrane ILDADs use noncorrosive Ionic Liquid Desiccants (ILDs) and membranes to prevent the spread of liquid desiccants to the ductworks and reduce the contamination of liquid desiccants

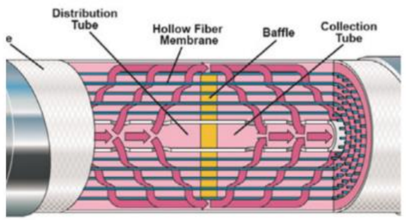
Technology Description: Membrane Contactors

- Membrane Ionic Liquid Desiccant Air Dehumidifiers (MILDADs) separate the liquid desiccant from the air using a membrane semi-permeable to water vapor
- Porous or non-porous membranes can be employed with different water transmission rates and selectivity
  - Non-porous membranes provide better selectivity and eliminate cross-contamination and biologic fouling
  - Membrane tubes do not see the deflection and leakage issues seen in flat sheet modules
- Key technology challenges to using MILDADs are biological fouling on the membrane, low moisture permeation, poor strength and the high cost of membrane

Tubes vs Flat Sheets (Membranes) vs Fibers

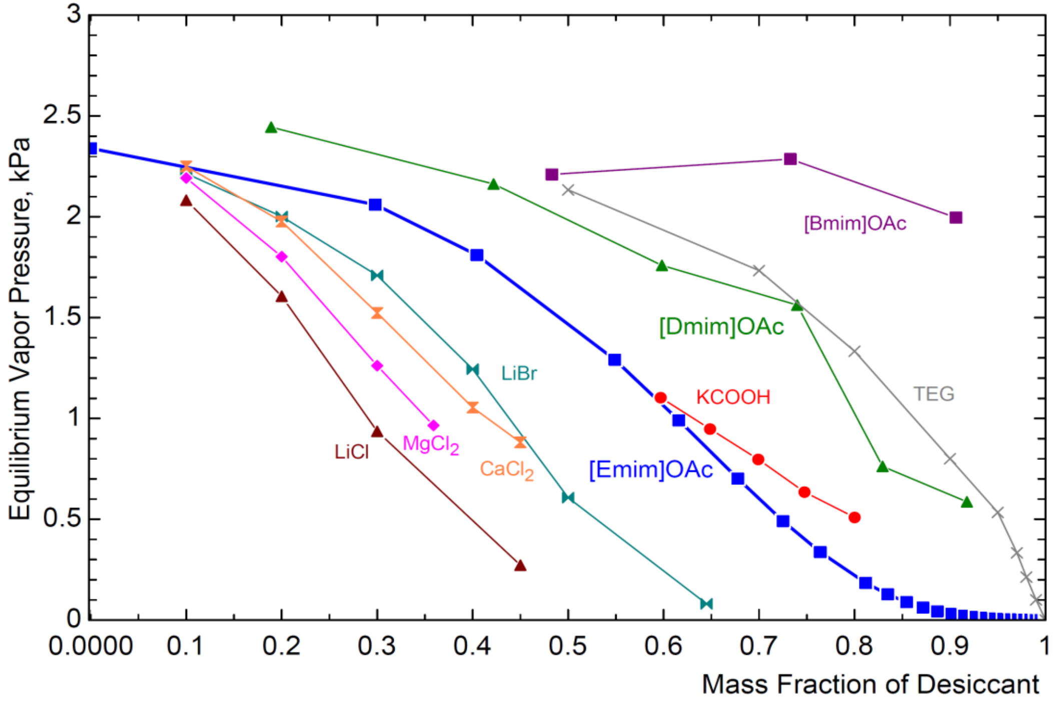
- IONIX's started with Flat Sheet (membranes):
  - Could never 'make' it seal, we had Issues with retrofitting the system
  - Gasketing with flat sheets is a critical issue.
    - Huge amount of gasketing in the unit. compared to the shell and-tube,
      - Several orders of magnitudes longer, and potential for leakage is higher.
- By comparison, a "Removable Bundle Floating Tube-sheet" (RBST) design (employed by IONIX is the most serviceable and leak free system.
  - It offers the greatest flexibility.
  - Most critically, because the tubes are firmly attached (possibly potted) the tube sheet provides excellent sealant, ability to withstand thermal expansion, and reduces the total surface being sealed from literally miles (for plate and frame) to several linear feet for shell and tube.
  - Basically, if the application requires a high probability against leakage, the better choice is a shell-and tube design.
- Hollow fibers are also an option. ORNL/Purdue have investigated
  - IONIX's primary client is concerned about pressure drop – with huge volumes of water they employ

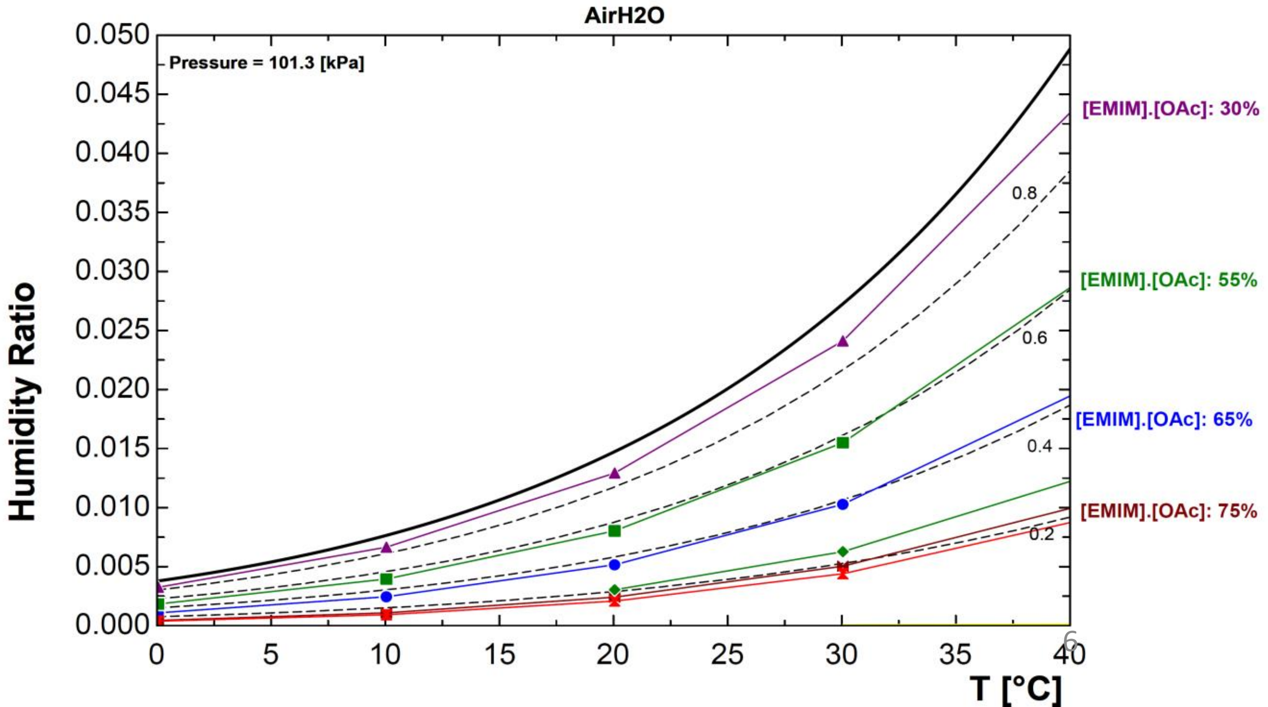




Technology Description: Ionic Liquid Desiccant

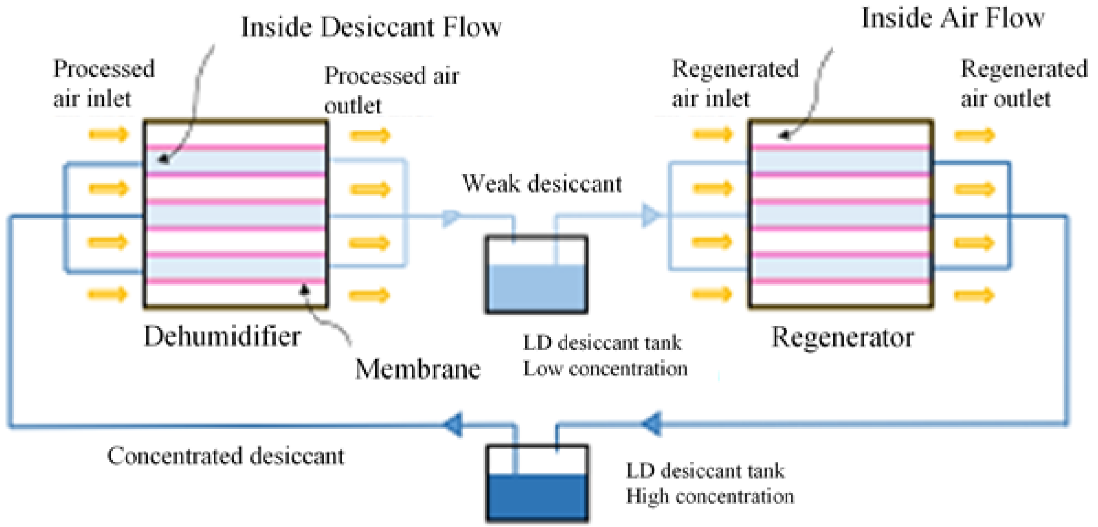
- Most frequently used liquid desiccants are LiCl, triethylene glycol & CaCl
  - Corrosive & high cost
- 1-Ethyl-3-methylimiadazolium acetate ([EMIM][OAc]) selected for high thermal stability, non-corrosivity & very low crystallization
- Concentration of [EMIM][OAc] can be manipulated to adsorb water vapor to drive air to tailored RH equilibrium





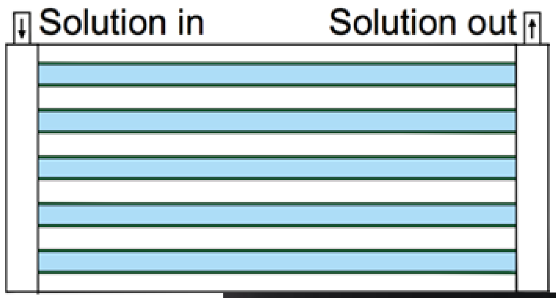
Technology Description: Membrane-based Liquid Desiccant Systems

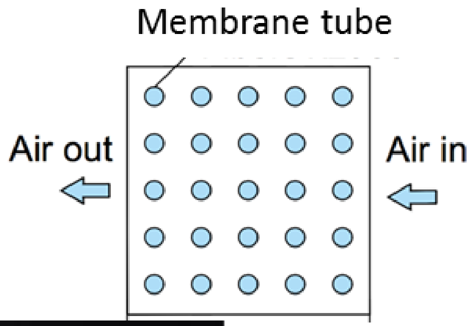
- MILDAD system composed of two supply air streams and two modules
- Indoor module supplied with processed (cold) air to act as a dehumidifier
- Outdoor module supplied with regenerated (hot) air regenerate the desiccant

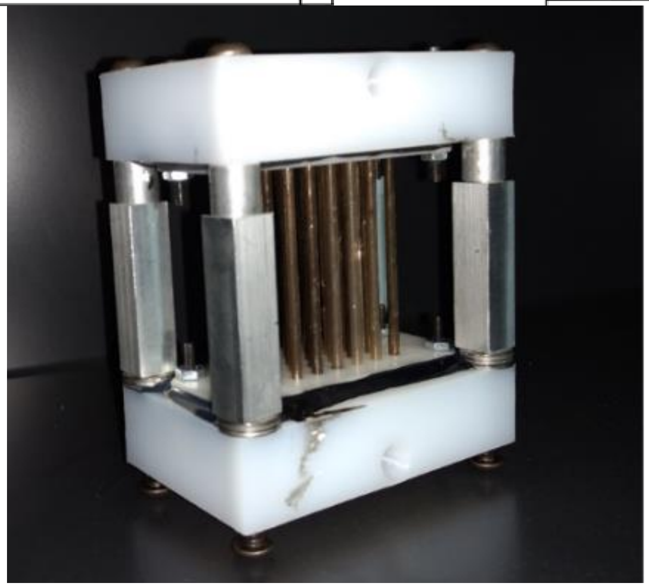


Design of Small-Scale MILDAD Prototype

- Small scale prototype using non-porous membrane tubes
  - 64 mm x 102 mm x 102 mm
- 26 tubes: OD: 3.3 mm, ID: 3.2 mm
  - Tube arrangement (differing from pictured) is staggered to provide better convective heat and mass transfer (akin to a body-centered cubic packing structure)
  - Effective membrane contact area: ~0.017 m^2
- Counter-current flow through the module to improve heat and mass transfer







Experiments

- The mas flow of air and absolute humidity drop across the module was measured to determine the moisture removal rate (m_v)

$$\dot{m}_v = \Delta AH \cdot \dot{m}_{air}$$

- The specific vapor transportation rate (J) was calculated by normalizing the moisture removal rate to the effective contact area

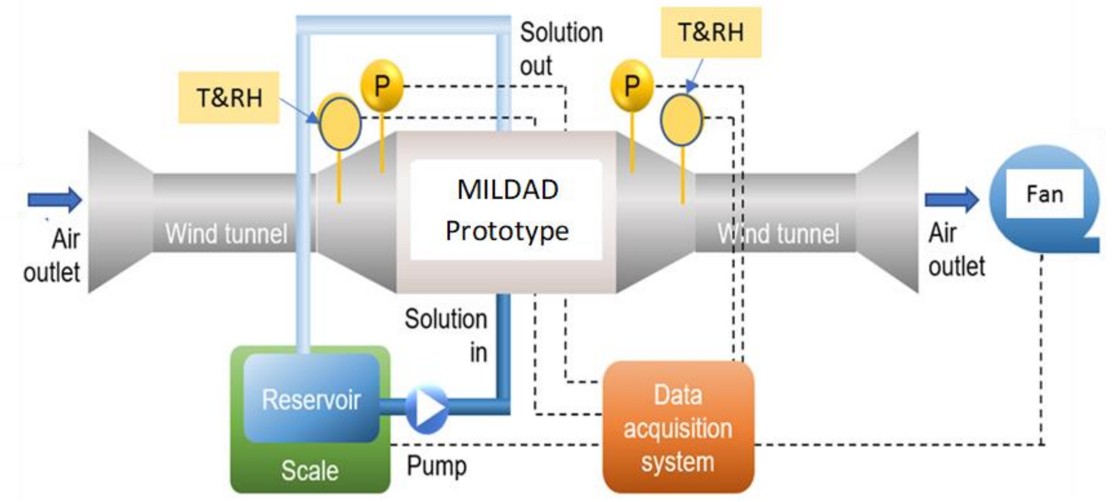
$$J = \frac{\dot{m}_v}{A_{eff}}$$

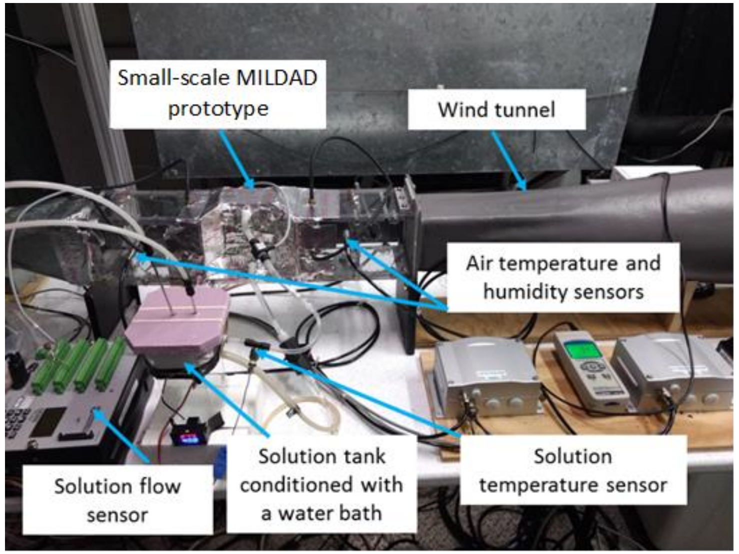
- The effective permeance (P) was calculated by normalizing the specific vapor transportation rate to the vapor pressure difference between the two surfaces of the membrane

$$P = \frac{J}{\Delta P_v}$$

Experimental Set-up

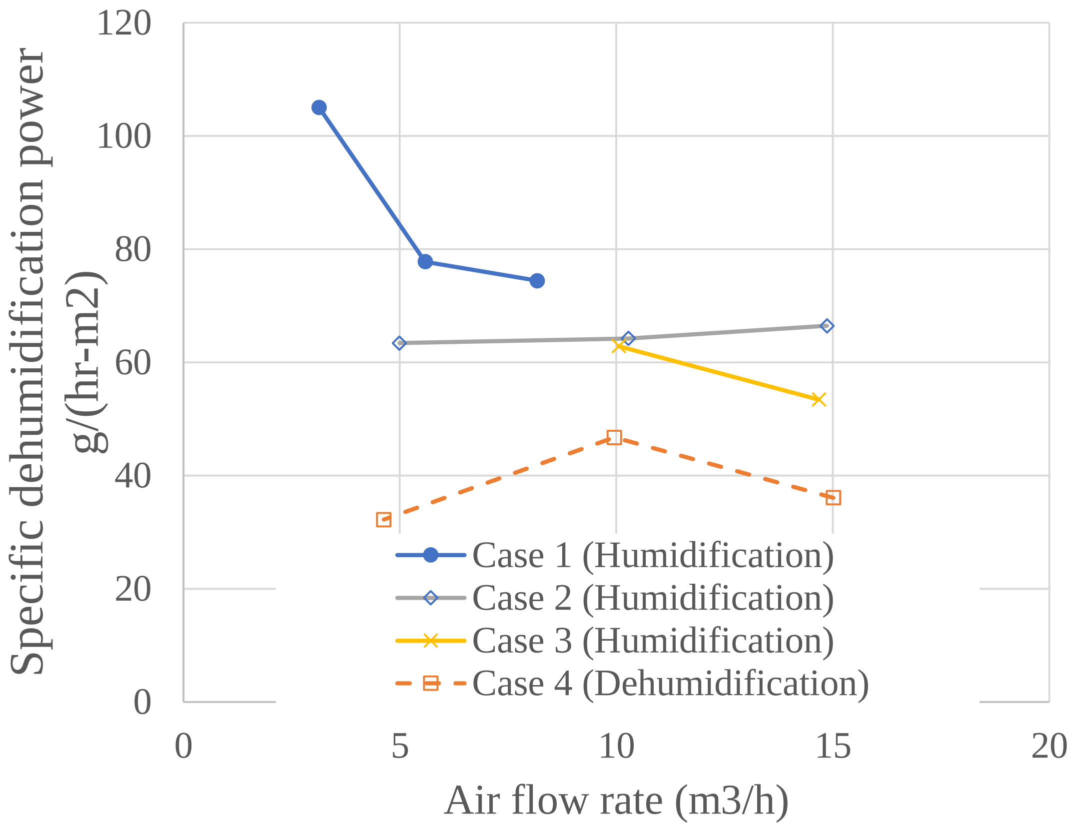
- The prototype device was placed in the center of a wind tunnel
- The air flow rate, inlet & outlet temperature and humidity were measured
- Four cases were explored
    - Humidification using distilled water at 35°C, 20% inlet RH, and 0.49 LPM water flow rate
    - Humidification using distilled water at 25°C, 80% inlet RH, and 0.49 LPM water flow rate
    - Humidification using distilled water at 25°C, 80% inlet RH, and 0.30 LPM water flow rate
    - Dehumidification using 75% [EMIM][OAc] at 25°C, 80% inlet RH, and 0.15 solution flow rate





Results of Small-Scale Prototype

- The small-scale prototype provided a proof of concept for both humidification and dehumidification
- Only case 1 (humidification in dry conditions) was sensitive to flow rate

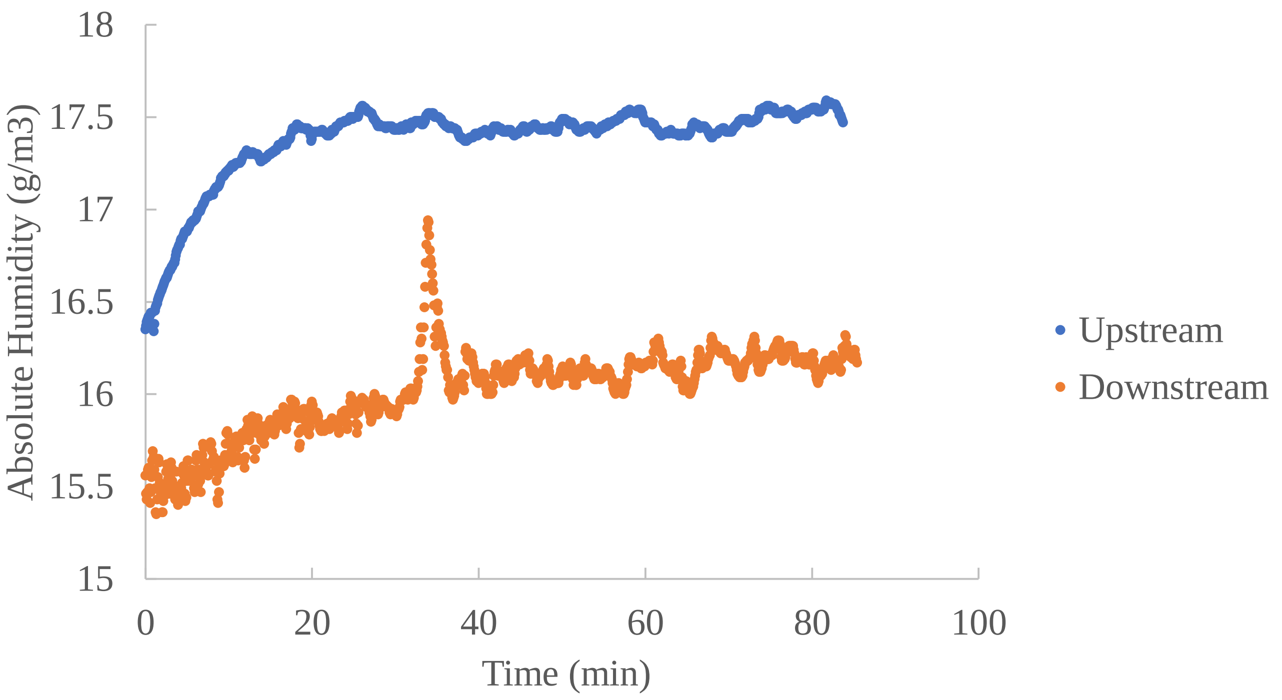


Medium-Scale Prototype Set-up

- A medium scale prototype was developed with and effective contact area of 0.2 m^2
- The air circulation was maintained at 0.28 m^3/min
- The temperature, relative humidity and flow rate was measured throughout the experiment

Medium Scale Prototype Results

Total testing time*	79.33	minutes
Air Flow Rate	0.28	m^3/min
Total Volume of Air Processed	22.5	m^3
Average ΔAH	1.3	g/m^3
Total Moisture Removed*	29.68	g
Specific Water Removal Rate	0.03	$g/m^2/s$
Cumulative latent cooling	72,843	J
Latent cooling power	15.3	W
Power consumption of fan and pump	14.4	W
Estimated COP of latent cooling	1.06	W/W



Design and Predicted Performance of Full-Sized MILDAD

To meet the latent cooling capacity of a conventional 1.5 kW (5,000 BTU) air-conditioner, a full-sized MILDAD would need to provide 0.3 kW of latent cooling

Overall permeance	0.000027	g/(m^2-s-Pa)
Vapor pressure difference	700	Pa
Water removal rate	0.0189	g/(m^2-s)
Total membrane surface area	6.5	m^2
Tube diameter	0.003	m
Tube length	0.457	m
Surface area per tube	0.005	m^2
Total number of tubes	1371	[-]
Tube length	0.457	m
Tube spacing (2× dia.)	0.007	m
MILDAD width	0.762	m
MILDAD height	0.076	m

Commercial “Breakthrough”

- Tube Functional Media:
  - Fluorinated
    - Used Initially for prototypes
  - Non-Fluorinated
    - Now proven for this application
    - Significant cost reduction in raw material cost

- Functional Media Tube Production:
  - Tube form provides substantial for reduction in cost
    - Lends itself to Mass Production

Commercial Applications

- Dehumidifying Underwater Submersible:
  - Dramatic “ Revolution” Moisture Management
    - Improved comfort
    - Reduced Energy Requirements (For Comfort)

- Evaporative Cooling:
  - Dramatic “Revolution” in Evaporative Cooling
    - Reduced Water Usage
    - Improved Hygiene - No Bacterial/Viral Carryover
    - Currently Under Test – indications 2-3x improved performance

Conclusions

- The small-scale prototype showed a MILDAD’s ability to provide both humidification and dehumidification
- The medium-scale prototype shows that the technology scales well, providing a specific vapor transportation rate about 3 times that of the small-scale prototype
    - High flow rate and longer tube length increases the contact time for better heat and mass exchange between the ILD and air
- Coordinating with industrial partners to scale up the technology
    - Currently in “commercial” scale up mode

Acknowledgements

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- Our partners in this project included ORNL, and NREL
- Several F500 companies have also been intimately involved with FFI IONIX Inc. in helping drive this innovation forward