Membrane Based Air Conditioning

2016 Building Technologies Office Peer Review

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Brian Johnson, brian.johnson@daisanalytic.com
Dais Analytic Corporation

Project Summary

Timeline:

Start date: October 1, 2015 **NEW PROJECT**

Planned end date: September 30, 2017

Key Milestones

1. System Design Review; March 2016
2. Compressor testing review; September 2016
3. Go/No-Go based on bench testing; September 2016
4. Experimental evaluation of V1 prototype; February 2017

Key Partners:

Oak Ridge National Lab (ORNL) *Building Technologies Research & Integration Center (BTRIC)*
Xergy Inc

Budget:

Total Project $ to Date:

- DOE: $114,087.88
- Cost Share: $39,871.73

Total Project $:

- DOE: $1,200,000.00 (includes $500,000.00 to ORNL)
- Cost Share: $300,000.00

Project Outcome:

This project will develop, fabricate, and test a TRL-6 prototype of a membrane-based, non-vapor-compression HVAC system offering

- Up to 84% energy savings
- Water as a working fluid
- Independent humidity control

Purpose and Objectives

Problem Statement: Development of high performance, cost-effective non-vapor compression air conditioning system for the commercial sector.

Target Market and Audience: The target market is cooling provided by rooftop equipment; roughly half of the current commercial cooling load. We are targeting collaboration with equipment and component manufacturers. The total primary energy consumption for cooling in commercial buildings in 2030 is projected to be 0.57 quad (EIA, AEO)*.

Impact of Project: This project will result in the development of the first packaged, membrane-based air conditioning system with separate sensible and latent cooling.

- Eliminate ~20 lb refrigerants per unit
- 54 – 89% energy savings

* http://www.eia.gov/oiaf/aeo/tablebrowser/#release=AEO2015&subject=0-AEO2015&table=5-AEO2015&region=0-0&cases=ref2015-d021915a

Approach

Approach:

Non-vapor compression cycle transferring water molecules through a selective membrane to independently manipulate temperature and humidity. A 7.5 ton, TRL-6 prototype RTU will be tested at ORNL, demonstrating performance that projects to a primary COP = 2.00 (54 – 89% better than today). RTUs alone consumed 655 Tbtu of primary energy in 2014*, and the technology is broadly applicable to other HVAC sectors.

Key Issues:

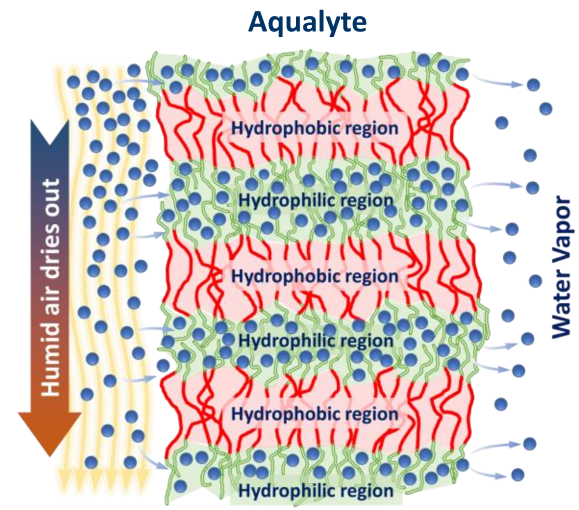
- Techno-economic factors
- Optimal vapor compression
  - Extremely low density water vapor must be compressed efficiently
  - Vapor compressors are by far largest parasitic load

* http://www.eia.gov/forecasts/aeo/

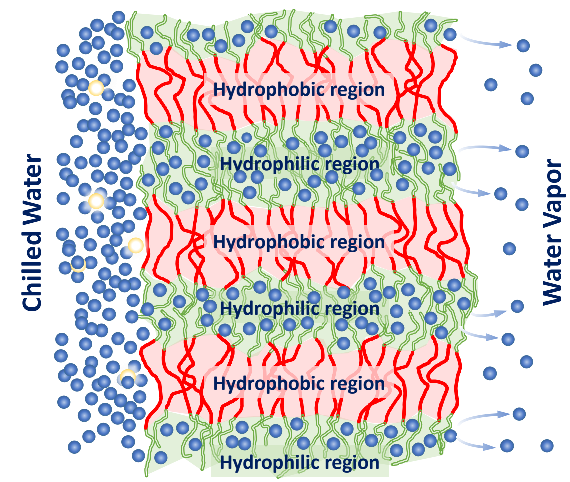
Approach

Distinctive Characteristics:

- Aqualyte™ = selective pervaporation material
  - Manipulate vapor pressure differentials
  - Low transport rates for N_2, O_2, other gases helps maintain vacuum
- Membrane dehumidifier & humidifier
  - Isothermal transport of water vapor = ***independent control of T and RH***
- Membrane chiller
  - Vacuum evaporation = sub-ambient refrigeration
  - Closed loop heat pump, water as working fluid
- Vapor compressors provide motive force
  - Electrochemical vapor compression (Xergy)
  - Mechanical vapor compression



Membrane Dehumidifier

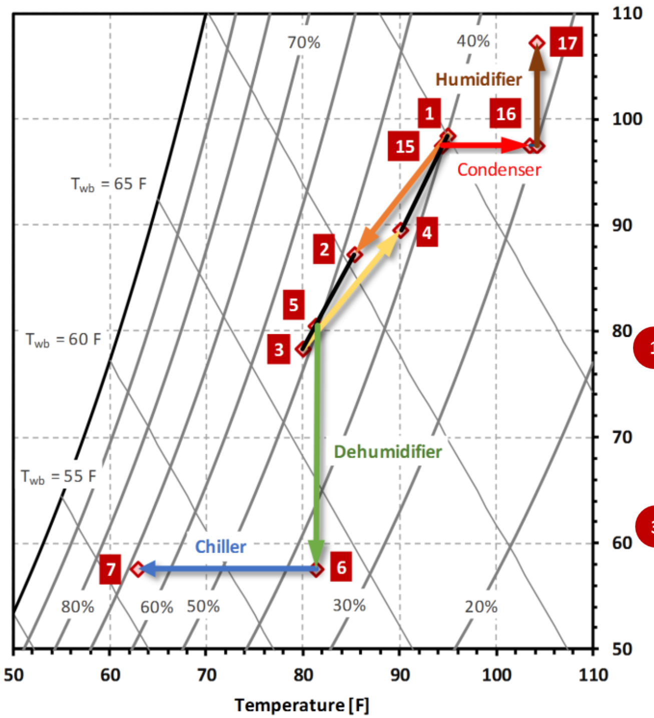


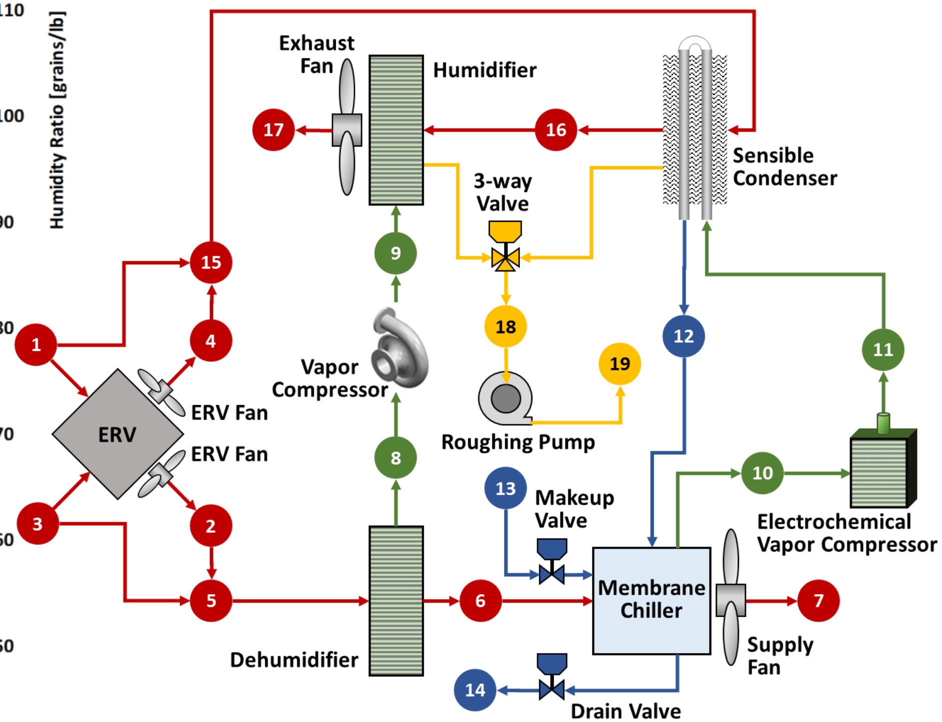
Membrane Chiller

Approach

System Overview:

- Process air is dehumidified, then chilled
  - Compression of water vapor moves excess humidity, heat outside





1	Outside Air
2	ERV Supply Air
3	Return Air
4	ERV Exhaust Air
5	Mixed Return Air
6	Dehumidified Air
7	Conditioned Supply Air
8	Water Vapor
9	Compressed Water Vapor
10	Water Vapor
11	Compressed Water Vapor
12	Condensate
13	Makeup Water
14	Drain
15	Mixed Outside Air
16	Heated Outside Air
17	Humid Exhaust Air
18	Non-Condensable Gases
19	Ambient Air

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Progress and Accomplishments

Accomplishments:

- Vendor/partner identification
- High level system design
- Detailed modeling
  - Segment-based computer model of membrane behavior
- Prepared for bench-scale component testing

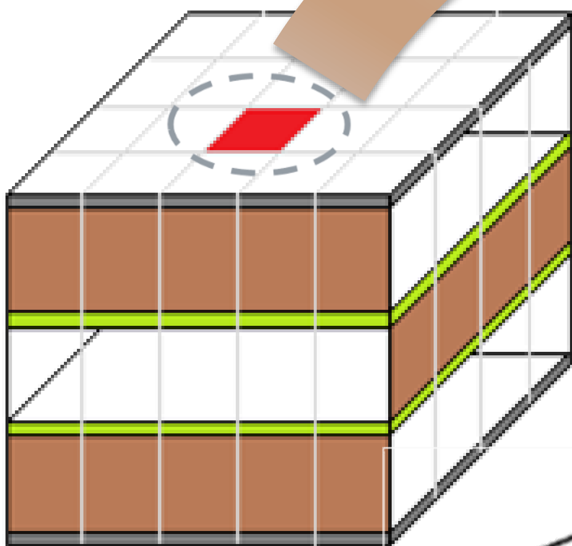
Market Impact: The team is providing information to carefully targeted OEM companies in exchange for market feedback.

Lessons Learned:

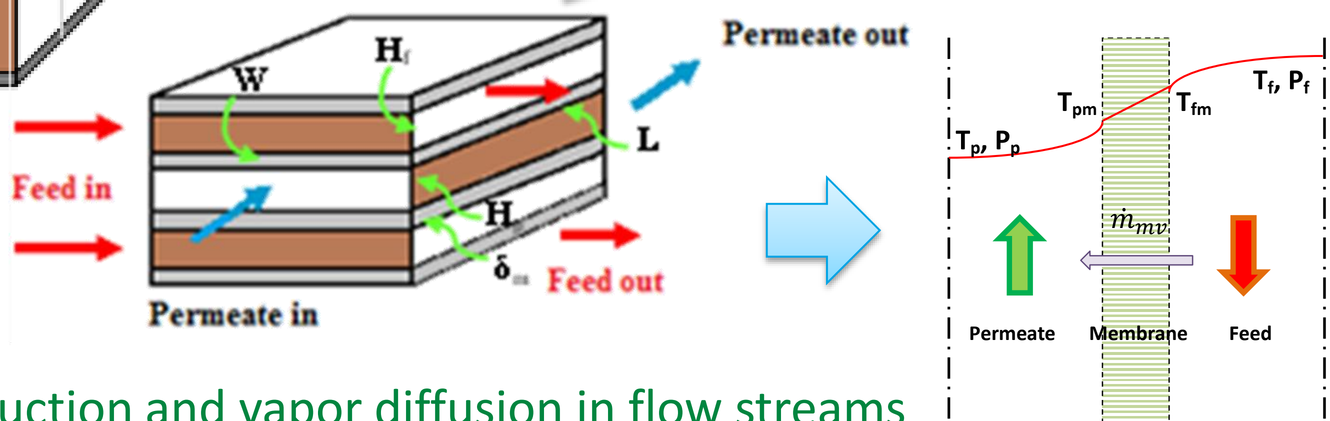
- Mechanical vapor compressor design is not straightforward
  - Efficiency is especially sensitive to inlet conditions, pressure ratio

Progress and Accomplishments

Membrane Dehumidification Modeling



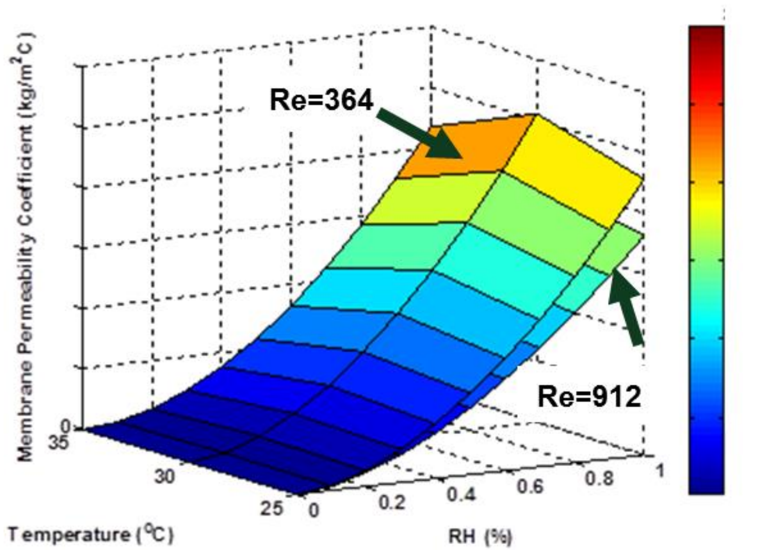
- Current model capability
  - C++ CODE setup
  - 1D heat and mass balance
  - Segment-by-segment solution method
  - Multiple membrane layers
  - Parallel and cross flows
  - Membrane deflection correction



- Assumptions:
  - Steady state
  - Negligible conduction and vapor diffusion in flow streams
  - Conduction and diffusion thru the membrane

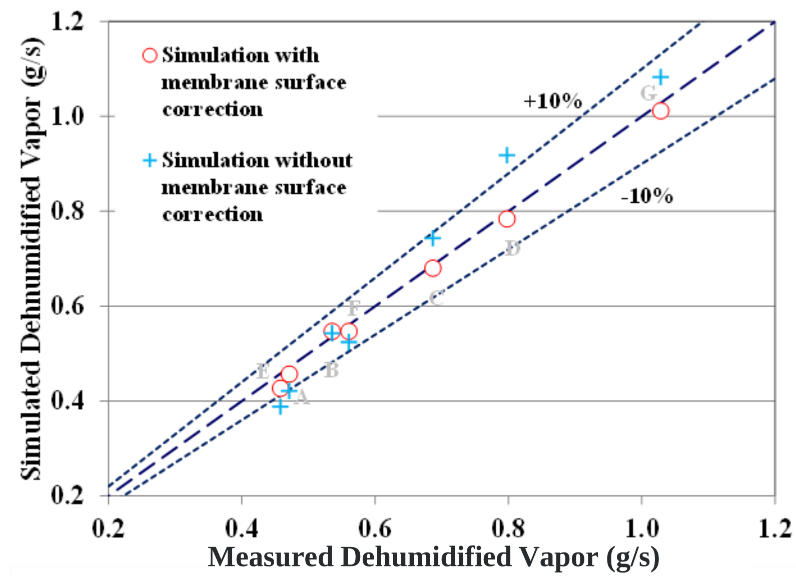
Progress and Accomplishments

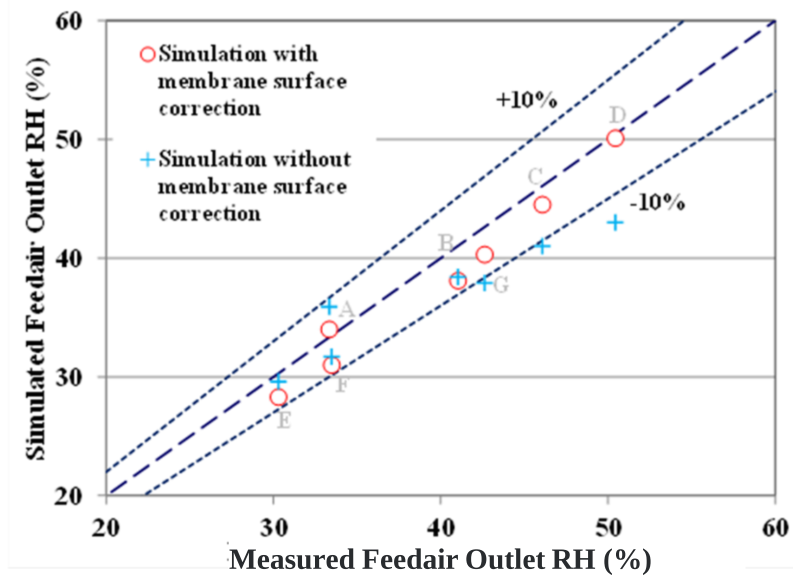
Membrane Dehumidification Modeling



Empirical membrane performance data

- Performance Map:
  - Data matched to empirical testing
  - Significantly outperforms diffusion models commonly used with membrane analysis





Project Integration and Collaboration

Project Integration: Both Dais and ORNL maintain industry contacts, ORNL through R&D projects and symposia, Dais thru 14 years as an HVAC OEM.

Partners, Subcontractors, and Collaborators:

- ORNL Building Technologies Research & Integration Center (BTRIC)
  - Full scale testing, performance modeling, rapid prototyping
- Xergy Inc. [Seaford, DE]
  - Electrochemical vapor compressor design & production
- SoftInWay Inc. [Burlington, MA]
  - Mechanical vapor compressor design
- ROBRADY Design [Sarasota, FL]
  - Mechanical design of components and systems

Communications: None applicable.

Next Steps and Future Plans

Next Steps:

- Fabrication and testing of bench scale prototypes
  - Membrane dehumidifier
  - Membrane chiller
  - Mechanical vapor compressor
  - Electrochemical vapor compressor
- Fabrication and testing of 7.5 ton V1 prototype system
  - Carried out by BTRIC
- Optimization based on lessons learned with V1
- Fabrication and testing of V2 prototype system

Future Plans:

- Evaluate commercial markets and select initial target for entry

REFERENCE SLIDES

Project Budget

Project Budget: $1,500,000.00 total, including $300,000.00 cost share.
Variances: None
Cost to Date: Thru February 2016 (Month 5 of 24), Dais has spent $153,959.61 of $1,000,000.00. $500,000.00 to ORNL is being accounted for separately.
Additional Funding: None

Budget History					
FY 2015 (past)		FY 2016 (current)		FY 2017 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
N/A	**N/A**	**$543,120**	**$187,824**	**$156,880**	**$112,176**

Project Plan and Schedule

Project Start: 10/1/2015
Project End: 9/30/2017
Project Length: 24 months

Plan | Actual | % Complete | Actual (beyond plan) | % Complete (beyond plan)

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
System and component design review	1	2	1		80%
Final design review based on bench testing results	3	2			0%
T2M strategy/commercialization plan	1	3	1		25%
Listing of potential manufacturers	1	3	1		25%
Mechanical compressor design & evaluation	1	3	1		50%
Electrochemical compressor design review	1	2	1		60%
Compressor testing review	3	2			0%
Go/No-Go: Performance ≥ vapor compression	4	1			0%
Fully operational V1 prototype RTU	5	1			0%
Experimental evaluation of V1 prototype RTU	6	1			0%
Redesign and optimization of V1 prototype	6	1			0%
Review optimized component designs for the V2	7	1			0%
Experimental evaluation of V2 prototype RTU	8	1			0%

FY2016 FY2017
1 2 3 4 5 6 7 8

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy