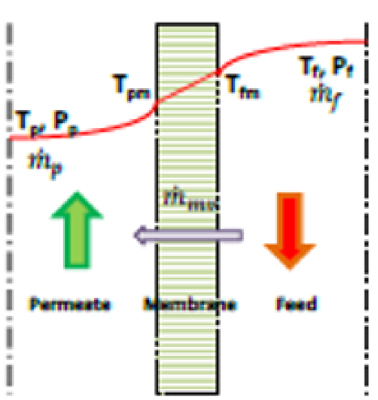
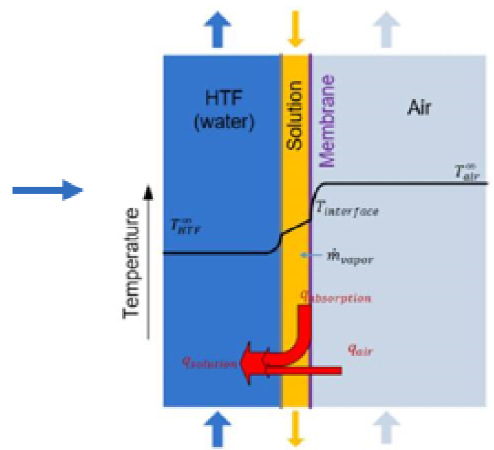
U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

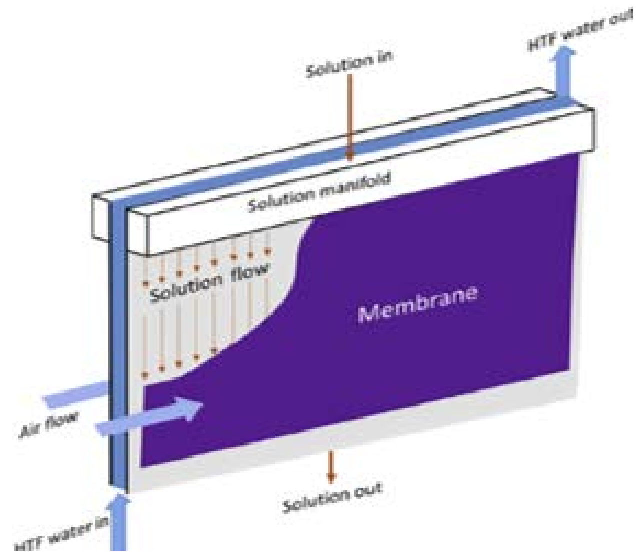
Design/Optimization of Heat/Mass Exchangers (HMX) using Membrane Technologies



Two-fluid model schematic; qualitative temp. profile



Three-fluid model schematic; qualitative temp. profile



Oak Ridge National Laboratory
Van D. Baxter, Distinguished R&D Staff
vdb@ornl.gov

Project Summary

Timeline:

Start date: 10/1/2017

Planned end date: 9/30/2019

Key Milestones

1. Complete extension of ORNL HMX model to three-fluid capability; March 31, 2018
2. Complete draft report on optimization case study of sorption HPWH system using HMX model; August 31, 2018
3. Complete draft report on adaptation of HMX model for condensing membrane HX; June 30, 2019

Budget:

Total Project: $350k thru FY18

- DOE: $350k
- Cost Share: $0

Total Project: $450k

- DOE: $450k
- Cost Share: $0

Key Partners:

Univ. of FL (UFL)	Ionic liquid (IL) desiccant property information & system data for model validation

Project Outcome:

US residential and commercial buildings consumed 1.52 quads and 4.73 quads of natural gas for water heating and space heating, respectively, in 2017. A key goal noted in BTO's 2016-2020 MYPP is development of advanced, heat-pump based gas systems to reduce gas SH and WH consumption. Early stage R&D is underway on several specific system developments. Robust, validated system simulation tools are needed to facilitate system design and optimization, a key step to eventual market entry. The FY18 goals of this supporting project are to develop and validate models of absorber components used in absorption heat pump systems and conduct a system design/optimization case study for one specific system (gas absorption HPWH).

Team

Within DOE, ORNL is the Center of Excellence in Commercial and Residential building equipment R&D along with supporting analysis tool development.

Team members for this project include:

- **Dr. Zhiming Gao** – Developer 2-fluid HMX model, leads development of 3-fluid model & adaptation to condensing membrane HXs
- **Dr. Moonis Ally** – Consultant for HMX model
- **Dr. Bo Shen** – Heat Pump Design model (HPDM) developer, lead incorporation of HMX model into HPDM; co-lead system simulation & optimization
- **Dr. Kyle Gluesenkamp and Dr. Ahmad Abu-Heiba** – Sorption HPWH experts, coordinating with UFL for system test data and liquid desiccant properties data; co-lead system simulation & optimization
- **Dr. Patrick Geoghegan** – Sorption HPWH expert; model review; co-lead system simulation & optimization
- **Van Baxter** – Project manager, PI







Challenge

Problem Definition:

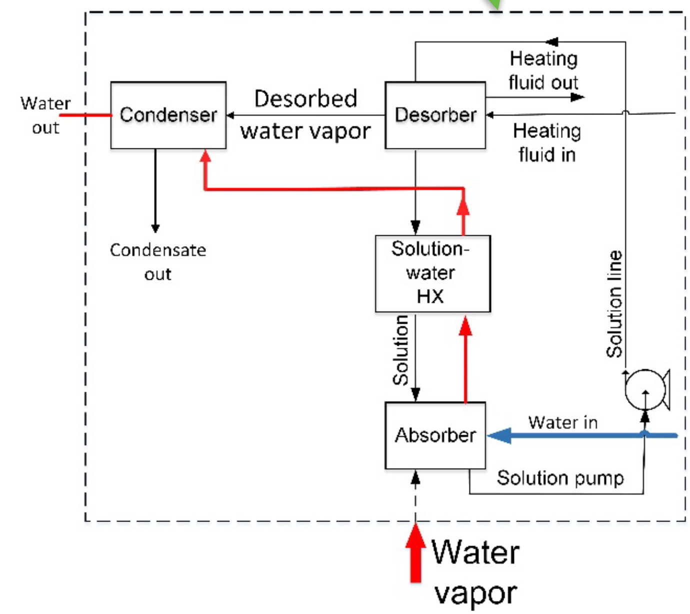
- US buildings consume 1.52 quads natural gas for water heating (WH) and 4.73 for space heating (SH).
- BTO's 2016-2020 MYPP --- early stage R&D efforts underway on gas heat pump based technologies.
  - 2020 targets: 1.38 SCOP for SH and 1.2 UEF for sorption-based gas HPWHs (primary energy basis).
  - ~45% savings vs. 95% AFUE gas furnaces and Energy Star gas storage WHs, respectively.
- Membrane-based HPWH project (Moghaddam, 2017)
  - Lab-measured 1.23 COP by prototype at UEF conditions.

Key need:

- Validated, robust analytical tools for simulation and design optimization of advanced systems.
  - Facilitate advancement to market readiness.
- FY18 goals of this early-stage supporting project
  - Develop/validate models of absorber & desorber.
  - Add to system model & conduct optimization case study.

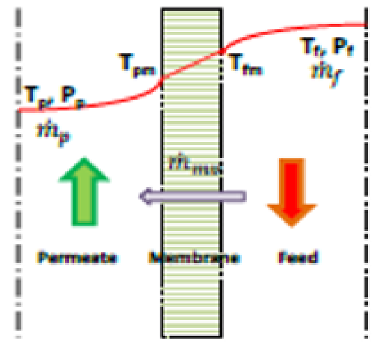
Membrane HPWH Product concept

Semi-open absorption heat pump cycle diagram

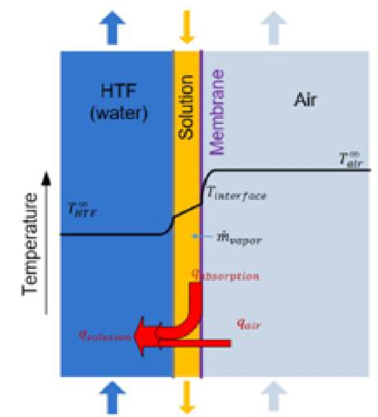


Approach

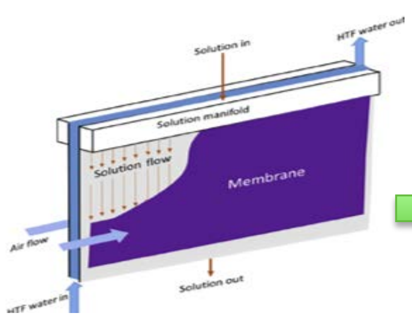
- In prior FY, the ORNL team developed a membrane-based heat and mass exchanger (HMX) model for simulation of membrane dehumidification (DH) processes.
- In FY18, the project plan is to:
  - Extend 2-fluid DH model to enable simulation of membrane-based HMX with 3-fluid streams (e.g., the absorber configuration for the Membrane-Based HPWH).
  - Validate and refine the HMX component model vs. data from the current lab prototype membrane HPWH.
  - Add HMX model to the ORNL Heat Pump Design Model (HPDM) for a case study membrane HPWH system design and optimization analysis.



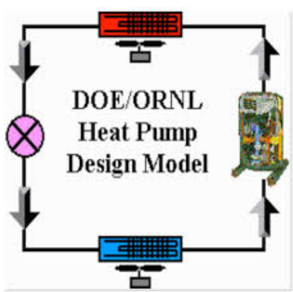
Two-fluid model schematic; qualitative temp. profile



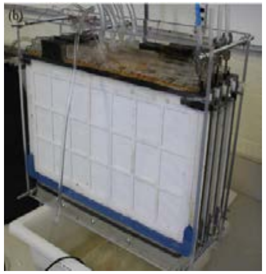
Three-fluid model schematic; qualitative temp. profile



Membrane-based 3-Fluid HMX modeling



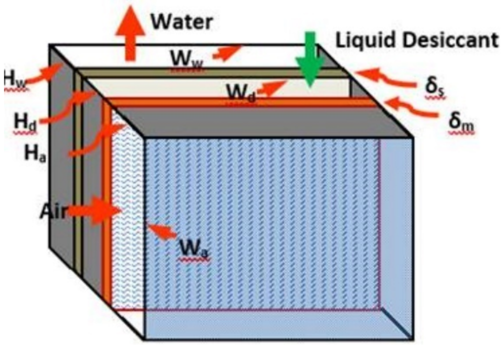
Component-based system modeling platform

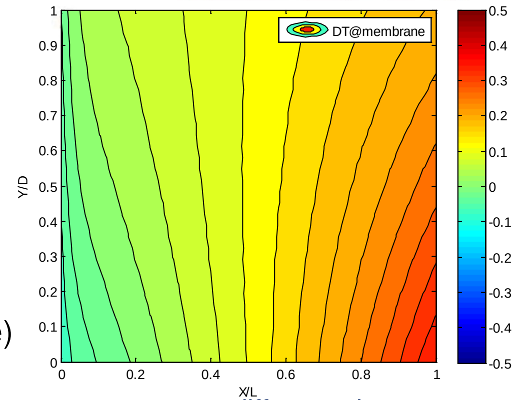


Membrane-based HPWH prototype absorber/HX component (multiple, parallel absorber panels)

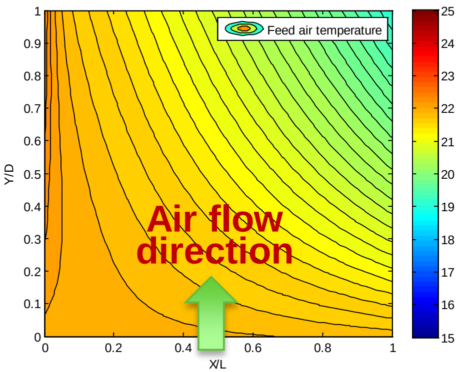
Progress

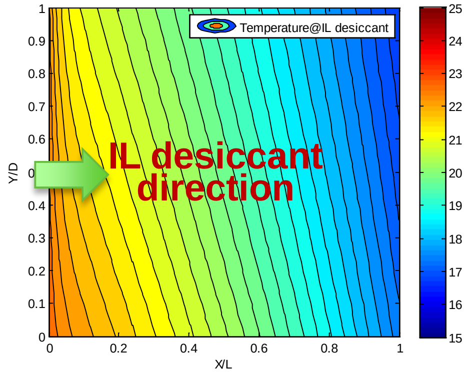
- This supporting project began in FY18 but builds upon earlier development of the initial two-fluid absorber HMX model.
- The project is on track: The first milestone to complete extension of the two-fluid model to three-fluid capability has been completed on schedule.
  - Basic geometry schematic shown; source air stream is in crossflow, liquid desiccant and water can be in parallel or counter flow.
  - Segment-by-segment simulation approach.
    - Each HX panel divided into small parallel segments; 2176 segments used in sample case illustrated here (5x6 mm each).
  - Model tested with sample data; achieved good mass & energy balances between the three fluid streams.
    - Right: temperature difference across membrane (Tair-side – Tdes-side)
    - Below: air, desiccant, and water stream temperature profiles

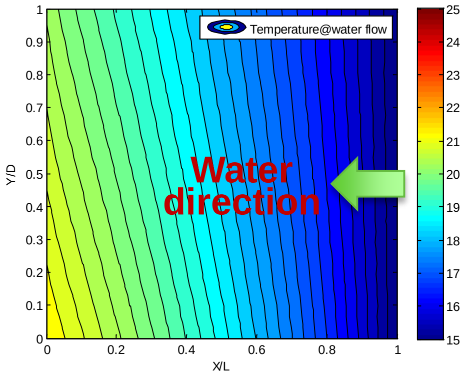




Temperature difference between the membrane interface







Sample study:
- 6 panels, each 0.34m*0.195m.
- Inlet air: 22°C, 0.037kg/s and 50% RH;
- Inlet ionic liquid (IL) desiccant: 23°C, 0.002 kg/s and 95% IL concentration;
- Inlet water: 15°C, 0.0075kg/s

Impact – Sorption HPWH and SH heat pumps

Most of the 6.25 quads of natural gas for buildings SH and WH (4.73+1.52) are presently consumed by gas-combustion furnaces and water heaters, respectively.

If advanced gas-based heat pump technologies with 45% energy savings replaced existing SH and WH stock overnight, the total potential source energy savings would be 2.8 quads/y. Even if the advanced technology captured only 10% of the market, savings would be 0.28 quads/yr.

- *The availability of proven, robust gas heat pump analyses tools for system design and optimization is a key to facilitating development of market-ready gas heat pump products and progressing toward achieving this savings potential.*
- *This project is designed to advance gas heat pump system analyses tool development.*

Stakeholder Engagement

Since this is a supporting model development project within the HVAC&R, WH, and Appliances subprogram intended to facilitate future industry collaborative activities for several gas heat pump based projects, the principal stakeholders are the BTO sponsor and PIs for those activities along with the HPDM developer. All are actively engaged in reviewing the HMX model development progress.

Remaining Project Work

Remaining FY18 work:

- Test/validate HMX model vs. data from lab prototype membrane HPWH.
- Incorporate HMX model into HPDM and conduct HPWH system optimization case study analysis.

FY19 planned work:

- Adapt HMX model to simulate condensing membrane HX.
  - Support to membrane HX development under companion Furnace/Membrane project.
- **Motivation:**
  - Currently high efficiency (condensing) gas furnaces only account for ~25% of total US furnace shipments (Energy Star 2016 shipment data).
  - Condensing membrane HX concept shows promise to reduce furnace costs with same high AFUEs (≥90%).
- **Impact:**
  - If cost reduction can enable condensing furnaces to capture an additional 25% of shipments, energy savings impact would be about 0.17 quads/yr.
  - Proven, robust system simulation tools a key need to facilitate advanced development in concert with manufacturer partners.

Thank You

Oak Ridge National Laboratory
Van D. Baxter, Distinguished R&D Staff
vdb@ornl.gov

Reference: S. Moghaddam, *"A Combined Water Heater Dehumidifier and Cooler,"* presented at 2017 BTO Peer Review meeting: https://www.energy.gov/eere/buildings/downloads/combined-water-heater-dehumidifier-and-cooler-whdc

REFERENCE SLIDES

Project Budget

Project Budget: $450k total FY18019.
Variances: None to date.
Cost to Date: ~$116k through March 2018.
Additional Funding: None.

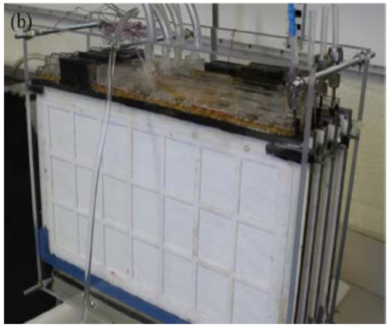
Budget History			
FY2018		FY2019 (planned)	
DOE	Cost-share	DOE	Cost-share
$350k	$0	$100k	$0

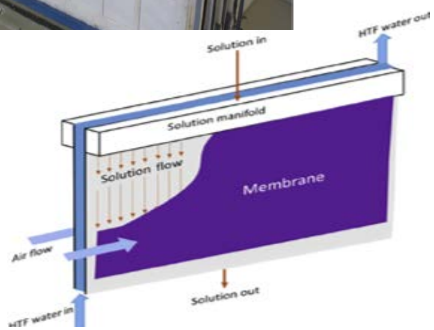
Project Plan and Schedule

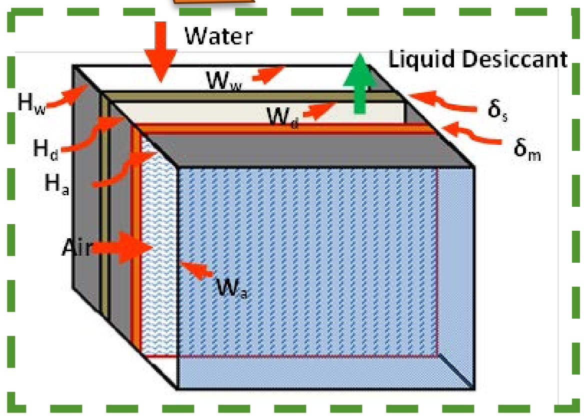
- Project start: 10/1/2018
- Project planned completion date: 9/30/2019
- Schedule and Milestones: see below

Project Schedule												
Project Start: October 1, 2017		Completed Work										
Projected End: September 30, 2019		Active Task (in progress work)										
		Milestone/Deliverable (Originally Planned) use for missed										
		Milestone/Deliverable (Actual) use when met on time										
	FY2018				FY2019				FY2020			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Current/Future Work												
Q2: complete 3- fluid HMX model extension												
Q4: complete system design/opt case study												
Q3: complete condensing membrane HX model												

Membrane-based 3-Fluid HMX Methodology

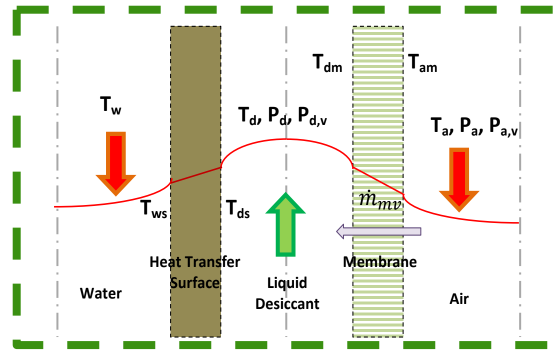






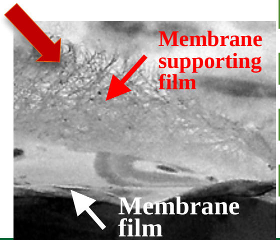
Current Model capability:

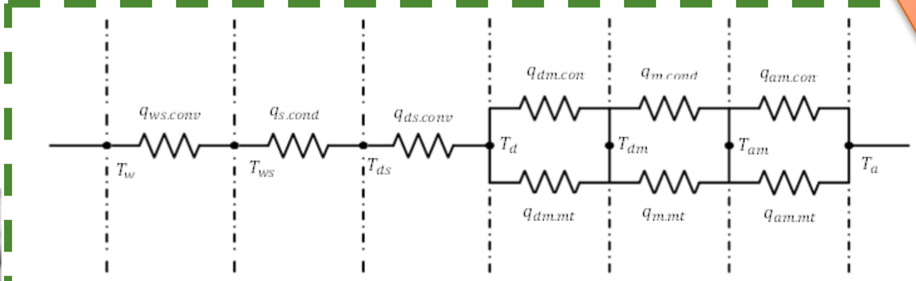
- C++ CODE setup
- Segment-by-segment solution
- Multi-membrane panels
- Water & desiccant streams can be parallel or counter flow
- Surface deflection correction (account for non-uniform spacing between membrane panels)



Key assumptions:

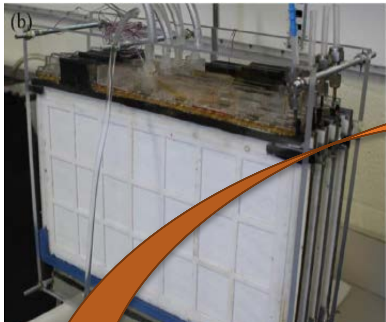
● steady state ● heat conduction and vapor diffusion thru the membrane ● negligible conduction and vapor diffusion in flow stream direction ● two-layer membrane structure
● vapor condensation within liquid desiccant

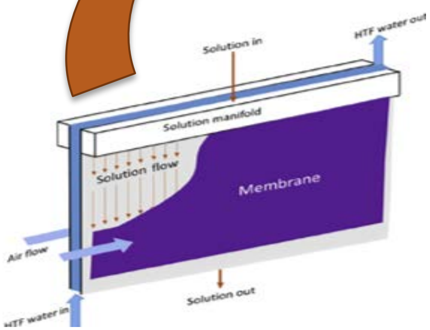




Electrical analog of HT resistance across the 3-Fluid HMX

Heat Pump Design Model (HPDM)





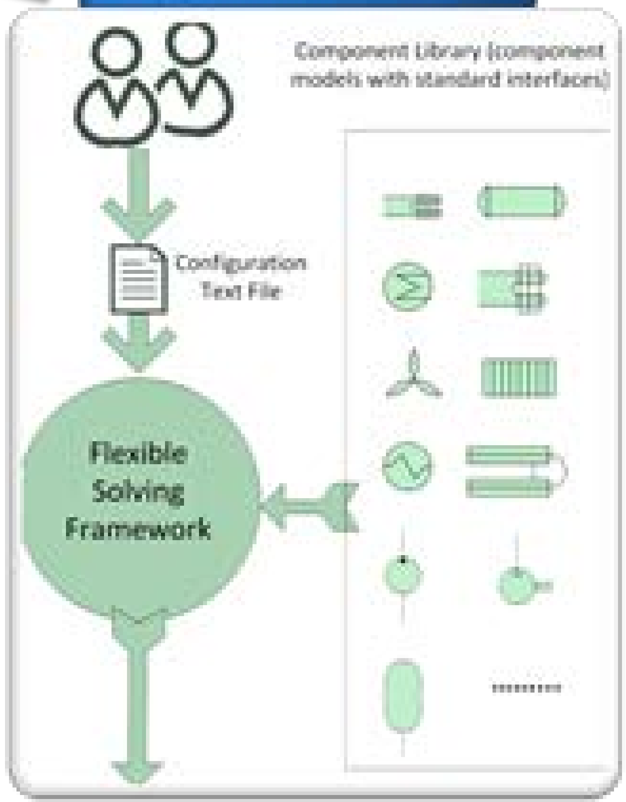
Semi-open absorber component for membrane HPWH: Membrane-based 3-Fluid HMX component model

Plug-&-Play

HPDM:

Component-based system modeling platform

Component-Based



Component models have standard interfaces to the solving framework, and generic connections to each other.

Automatically connect components into required system configuration by user input file.