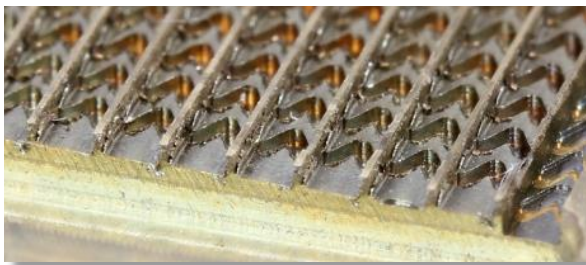
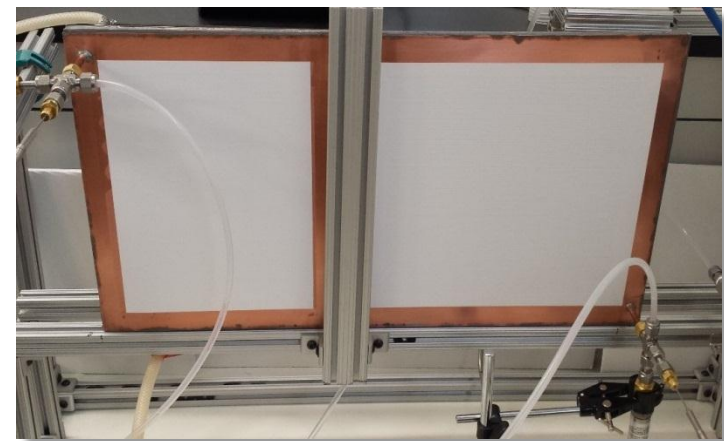


Residential Absorption Water Heater

2014 Building Technologies Office Peer Review



Project Summary

Timeline:

Start date: Oct 1, 2009

Planned end date: Sep 30, 2015

Key Milestones

1. Glycol additive report; Dec 2013
2. Prototype EF>1.0; March 2014

Budget:

Total DOE \$ to date: \$2,429k

Total future DOE \$: \$250k

Target Market/Audience:

Residential gas water heating

Key Partners:

GE	CRADA partner
SRA International	Market assessment
University of Florida	Membrane systems
Purdue University	ABSIM
Ionic Research Technologies, LLC	Ionic liquids
Yankee Scientific	Prototype

Project Goal:

Increase energy factor of gas storage water heater from ~0.65 to >1.0, with zero GWP and zero ODP.

Purpose and Objectives

Problem Statement: Absorption technology could greatly boost water heater efficiency, but faces barriers of high first cost and working fluid challenges.

Target Market and Audience: Residential gas water heating, a 1.29 Quad/year market. Currently, most gas units are the non-condensing storage type, with EF of 0.60 to 0.65.

Impact of Project: By increasing energy factor of gas storage water heating from ~0.65 to >1.0, savings of 0.59 Quads/yr is possible.

Approach

Approach:

- Use validated system modeling tools to develop conceptual designs
- Pursue multiple parallel paths (conventional, membrane, batch)
- Design, build, and test a series of progressively enhanced prototypes to achieve required performance targets
- Conduct market assessment to identify optimal price point for acceptable market penetration

Key Issues:

- Working fluid challenges: corrosion, crystallization, low mass fluxes
- High system cost: novel system configuration

Distinctive Characteristics: Achieving primary energy efficiency exceeding 100% for residential gas fired water heaters

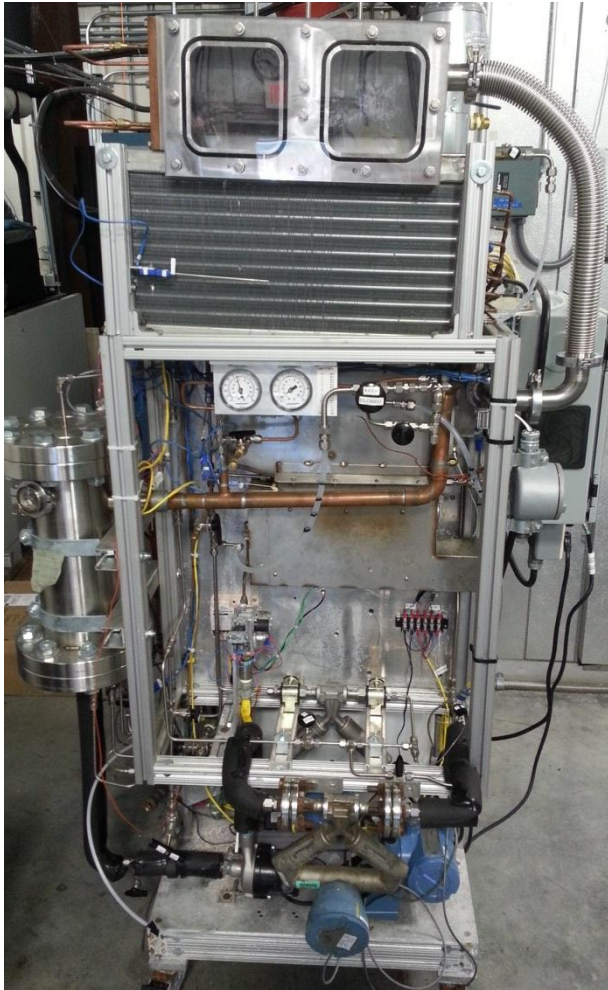
Progress and Accomplishments

Accomplishments:

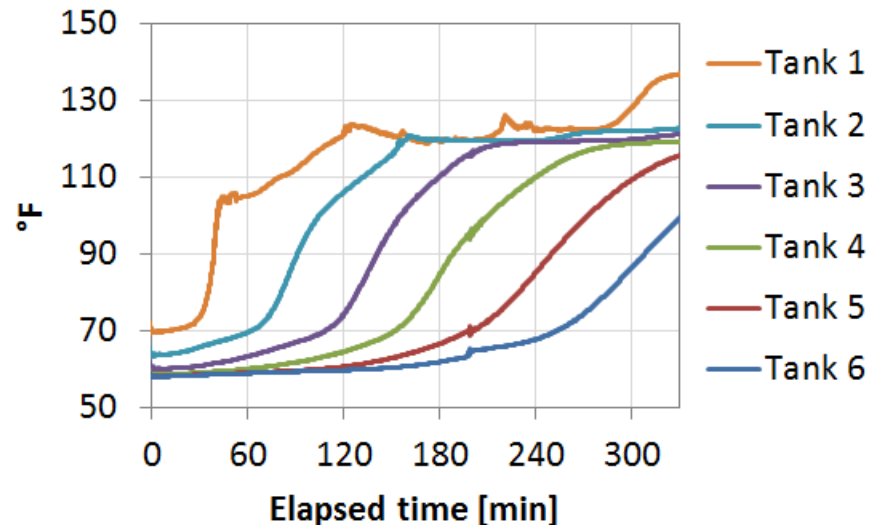
- Membrane-based prototype constructed
- Falling film-based prototype constructed and tested
- Investigated several LiBr water additives (3 publications)
- Developed patent-pending cycle configuration
- Drafted market assessment report
- CRADA partner has also achieved target performance with batch process
- Established subcontracts to investigate alternative paths
- Identified strategies that can be applied to other absorption applications (cycle configurations, additives, membranes)

Progress and Accomplishments

Accomplishments: Prototypes tested for Go/No-Go milestone



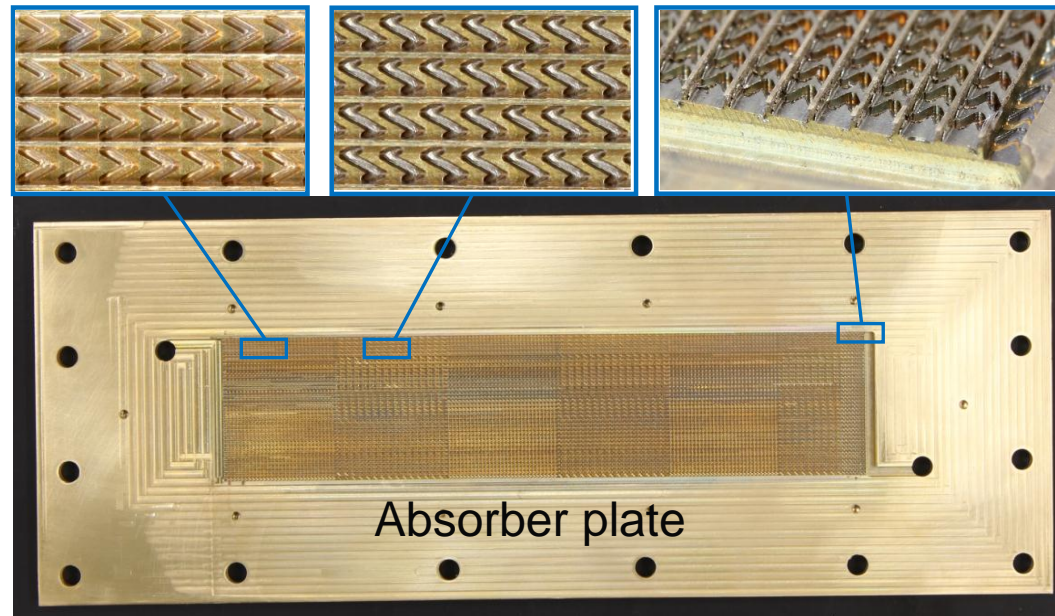
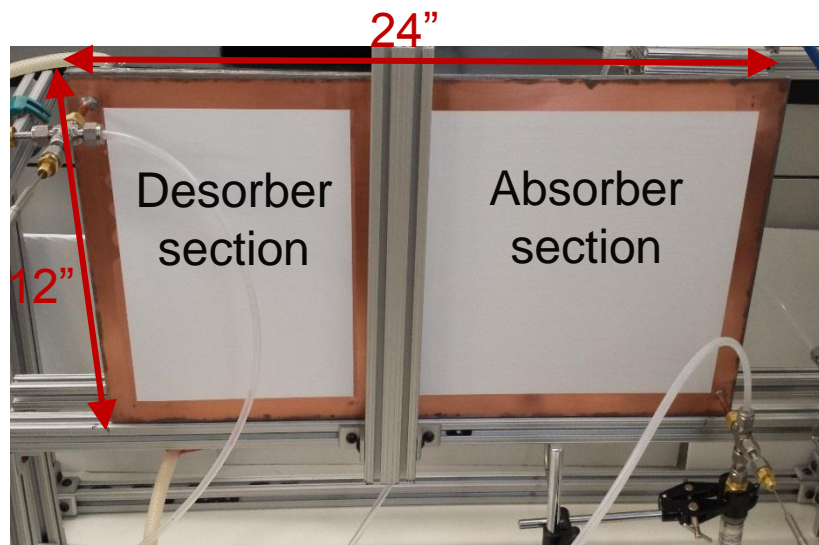
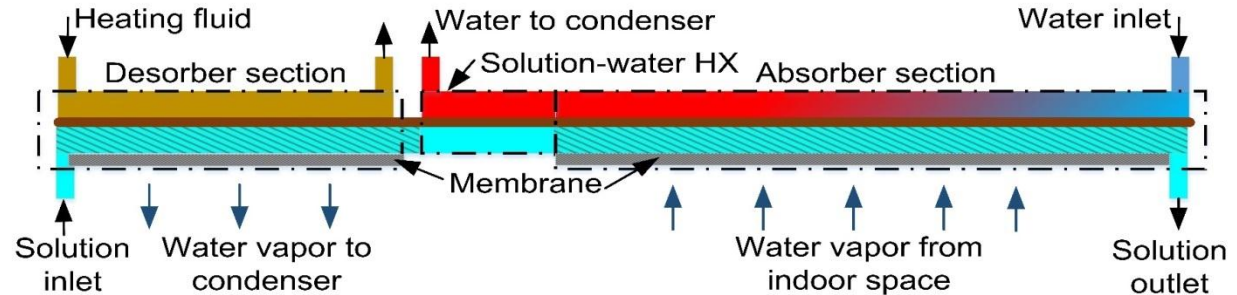
- Target EF achieved by CRADA partner's batch-process prototype
- Membranes yielding excellent preliminary component-level results
- Conventional absorber film given a "no-go"



Progress and Accomplishments

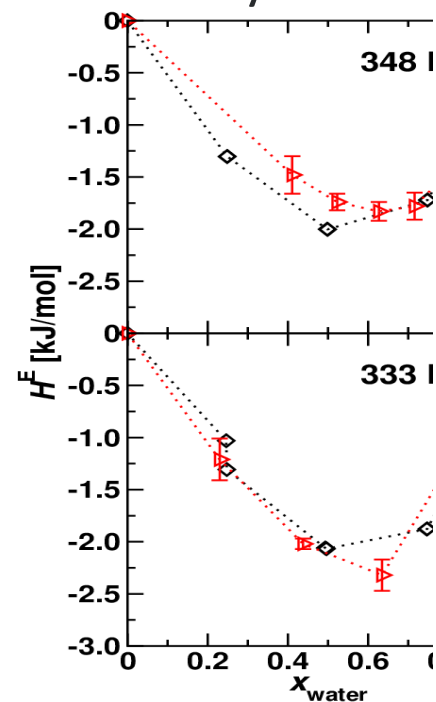
Accomplishments: Membrane-based prototype constructed

- Novel system configuration
- Proof of concept prototype constructed
- Very promising compact mass transfer observed

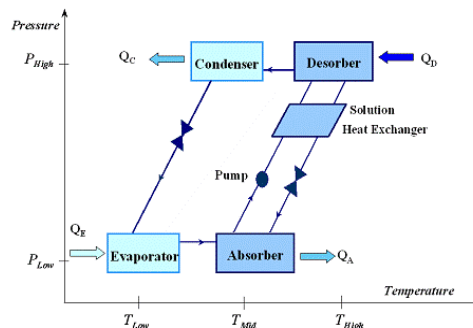
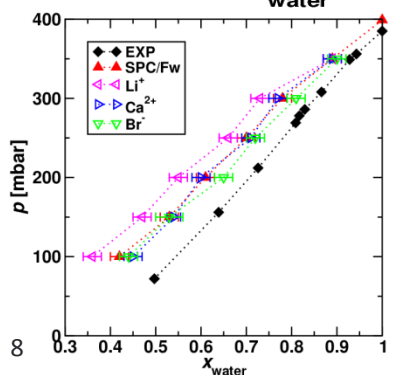


Progress and Accomplishments

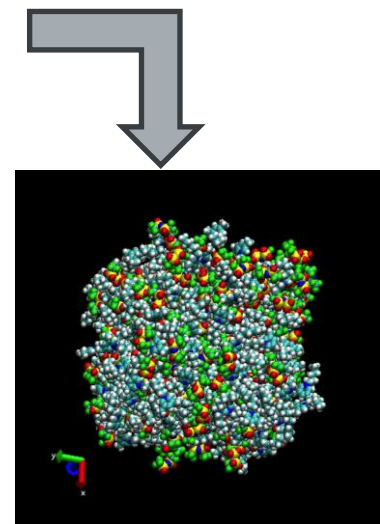
- **Accomplishments:** Worked with Ionic Research Technologies LLC to develop a model based scheme for discovering new ionic liquids
 - ✓ Synthesized sample IL (optimized for AWH) for evaluation at ORNL



Precise Lab
Characterization &
Experimentation



Process Modeling / Life
Cycle Analysis



Computational
Property Predictions



Guided Synthesis

Progress and Accomplishments

Lessons Learned:

- Poor performance of film absorber
- Need to prevent solution mixing with refrigerant (control of solution in desorber is crucial)

Accomplishments:

- Documented the performance of various additives with different ratios to LiBr aqueous solutions; satisfying FY14 Q1 milestone
- Synthesized optimized IL for AWH
- Evaluated different prototype AHWs at different maturity levels (ORNL, GE, and UFL); satisfying FY14 Q2 milestone

Market Impact:

	Relative to Gas Storage WH	Relative to Gas Tankless WH
Levelized Annual Cost Savings*	-\$6 - \$54	\$6 – \$49
Simple Payback Period (yr)	3 and up	N/A
Annual Energy Savings (mmBtu)	2.4 – 8.0	-2.9 – 2.7

Awards/Recognition:

- None yet

Project Integration and Collaboration

Project Integration

- Participated in key conferences and water heating activities
- Participated in the DOE water heating roadmap workshop

Partners, Subcontractors, and Collaborators:

- General Electric Appliances
 - Natarajan Venkatakrishnan, Director Advanced Technologies
 - David Beers, PI
- Subcontractors:
 - Yankee Scientific, Inc. – Breadboard prototype (FY11/12)
 - Ionic Research Technologies, LLC – Ionic liquids (FY12/13)
 - Sentech/SRA International, Inc. – Market assessment (FY13)
 - University of Florida (Prof. Saeed Moghaddam) – Membrane based technology (ongoing)
- Collaborators:
 - Prof. Ming Qu, Purdue University; Visiting Faculty Program at ORNL, planned publication on heat recovery absorption heat pumps



Project Integration and Collaboration

Inventions:

- S. Moghaddam, Thin Film-based Compact Absorption Cooling System, WO Patent 2,013,063,210, 2013.
- S. Moghaddam, D. Chugh, R. Nasr Isfahani, S. Bigham, A. Fazeli, D. Yu, M. Mortazavi, and O. Abdelaziz, Open Absorption Cycle for Combined Dehumidification, Water Heating, and Evaporating Cooling, Patent Application UF-14820, 2013.
- S. Moghaddam and D. Chugh, Novel Architecture for Absorption-based Heaters, Patent Application UF-14697, 2013.

Communications (pg. 1 of 2):

- Participation in IEA Annex 43, “Fuel-Driven Heat Pumps”
- Chugh, D., Nasr Isfahani, R., Gluesenkamp, K., Abdelaziz, O., Moghaddam, S. “A novel absorption cycle for combined water heating, dehumidification and evaporative cooling,” *International Sorption Heat Pump Conference*, March 31 – April 3, 2014, College Park, MD.
- Maerzke, K., Mozurkewich, G., Abdelaziz, O., Gluesenkamp, K., Schneider, W., Morrison, D. and Maginn, E. (2014) ‘Ionic liquid development for absorption heat pump applications’, *International Sorption Heat Pump Conference*, March 31-April 3, 2014, College Park, MD.
- Gluesenkamp, K., Abdelaziz, O., Vineyard, E. “Gas-fired absorption heat pump water heater development at Oak Ridge National Laboratory.” Presented to *2013 ACEEE Hot Water Forum*, November 4, 2013, Atlanta, GA.

Project Integration and Collaboration

Communications (pg. 2 of 2):

- Abdelaziz, O., Maginn, E., Morrison, D. (2013). “Ionic fluid design for absorption heat pump applications.” Seminar 58 of 2013 Winter ASHRAE Conference, Dallas, TX, USA.
- Sikes, K., Blackburn, J., Abdelaziz, O. (2012). “Market assessment for high-performance gas absorption water heaters.” November 2012.
- Wang, K., Abdelaziz, O., Kisari, P., Vineyard, E. (2011). “State-of-the-art review on crystallization control technologies for water/LiBr absorption heat pumps.” *International Journal of Refrigeration*, vol. 34, pp. 1325-1337.
- Wang, K., Abdelaziz, O., Vineyard, E. (2011). “The impact of water flow configuration on crystallization in LiBr/H₂O absorption water heater.” *International Journal of Energy Technology and Policy*, vol. 7, pp. 393-404.
- Brownell, D., Stevenson, A., Guyer, E. (2011). “Absorption heat pump water heater prototype, design report B.” Submitted by Yankee Scientific, Inc., under subcontract number 4000101964, May 24, 2011.
- Kisari, P., Wang, K., Abdelaziz, O., Vineyard, E. (2010). “Crystallization temperature of aqueous LiBr solutions at low evaporation temperature.” *Road to Climate Friendly Chillers*, Cairo, Egypt.
- Wang, K., Kisari, P., Abdelaziz, O., Vineyard, E. (2010). “Testing of crystallization temperature of a new working fluid for absorption heat pump systems.” *Road to Climate Friendly Chillers*, Cairo, Egypt.

Next Steps and Future Plans

Next Steps and Future Plans:

- Select most promising design to meet cost and performance targets
- Construct and test final prototype

REFERENCE SLIDES

Project Budget

Project Budget: DOE total \$2,679k FY2010 – 2015

Variiances: None

Cost to Date: \$1,950 through Feb 2014

Additional Funding: None expected

Budget History

FY2010 – FY2013 (past)		FY2014 (current)		FY2015 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
\$2,079k	*	\$350k	*	\$250k	*

* In-kind contribution from CRADA partner – exact total is confidential information

Project Plan and Schedule

Go/No-Go decisions:

- July 2012 – proceed to beta unit; passed
- March 2014 – conventional falling film absorber no-go; membrane and batch-based passed

Project Schedule												
Project Start: Oct 1, 2009	Completed Work											
Projected End: Sep 30, 2015	Active Task (in progress work)											
	◆ Milestone/Deliverable (Originally Planned)											
	◆ Milestone/Deliverable (Actual)											
	FY2013				FY2014				FY2015			
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)
Past Work												
Q1 Milestone: Fabricate beta prototype	◆	◆										
Q3 Milestone: Test prototype			◆			◆						
Q1 Milestone: Draft report of fluid testing					◆							
Q2 Milestone: Go/No-Go						◆						
Current/Future Work												
Q3 Milestone: Identify most promising route							◆					
Q4 Milestone: Design next-gen prototype								◆				