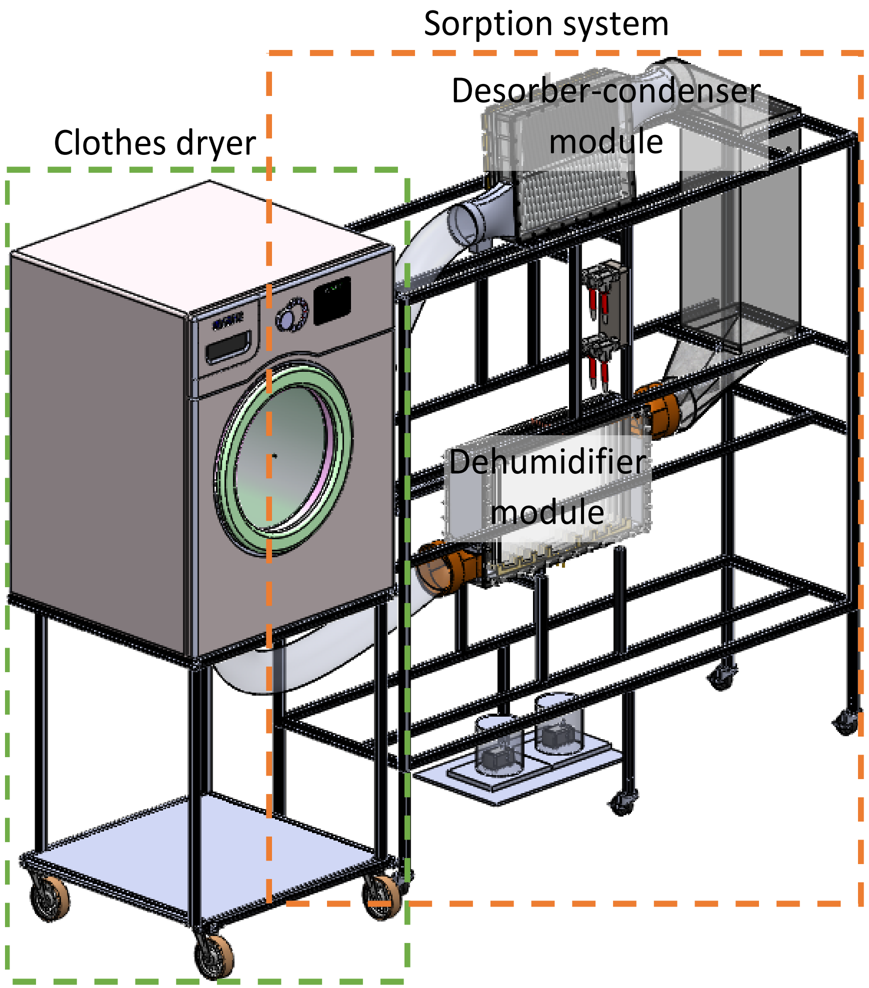
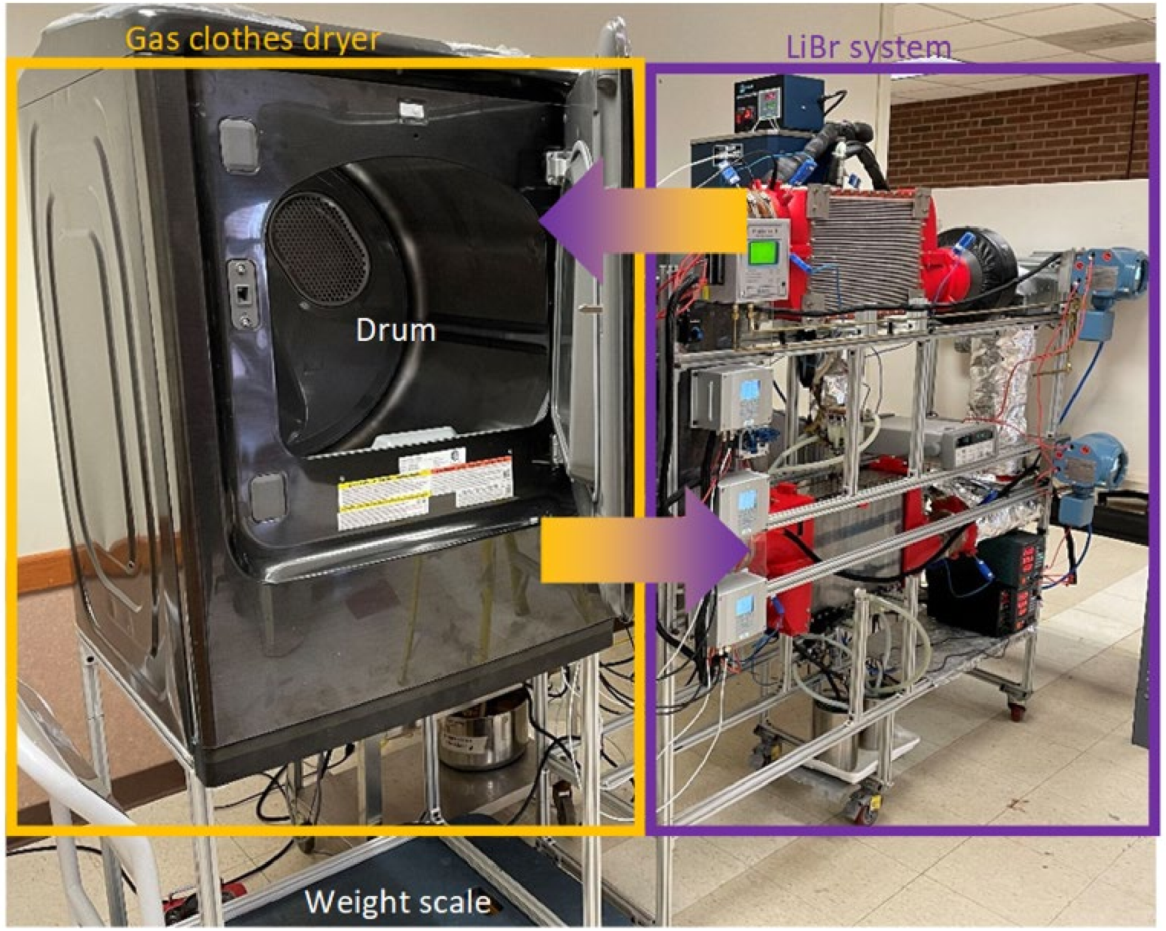
Next-generation Desiccant-based Gas Clothes Dryer Systems

2021 Building Technologies Office Peer Review





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Project Summary

Timeline:

Start date: 7/1/2019

Planned end date: 6/30/2022

Key Milestones

1. Demonstrate a dehumidification rate of 0.5 g/m^2-s at relevant drum conditions; 6/30/2020
2. Demonstrate a CEF of 5.7 $lbm_{dry\ clothes}$/kWh; 6/30/2021

Budget:

Total Project $ to Date:

- DOE: $373,938
- Cost Share: $119,175

Total Project $:

- DOE: $734,565
- Cost Share: $183,723

Key Partners:

ORNL
Samsung Electronics America

Project Outcome:

1. Develop an advanced non-vapor compression heat pump clothes dryer solution
2. Experimentally demonstrate technical viability of the desiccant-based gas clothes dryer concept
3. Improve combined energy factor while reducing drying time of the new dryer system
   - Demonstrate an energy factor (EF) of 5.7 $lbm_{dry\ clothes}$/kWh, a 73% energy improvement compared to state-of-the-art gas clothes dryers exhibiting an EF of 3.3 $lbm_{dry\ clothes}$/kWh

Team

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Assistant Professor
Michigan Tech

Masoud Ahmadi
Ph.D. Student
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Behnam Ahmadi
Ph.D. Student
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Sunil Pinnu
M.Sc. Student
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Gracie Brownlow
Undergrad student
Michigan Tech

- Thermodynamic/CFD modeling
- Component design and fabrication
- System development and testing
- Performance evaluation

Kyle R. Gluesenkamp
R&D Staff
ORNL

Kashif Nawaz
R&D Staff
ORNL

Ayyoub M. Momen
R&D Staff
ORNL (now on a leave)

- Performance evaluation
- Technology transformation partner

Guolian Wu
Senior Engineering Manager
Samsung Electronics America

Alexander Minkin
Senior Engineering Manager
Samsung Electronics America

Raveendran Vaidhyanathan
Director Engineering
Samsung Electronics America

- Clothes dryer design guidelines
- Consumer insights
- Commercialization partner

Challenge

Problem Statement:

The majority (more than 90%) of commercial dryers and approximately 20% of residential dryers are gas-fired models. The annual U.S. shipments are 0.18 and 1.43 million gas dryer units in the commercial and residential sectors, respectively. The commercial and residential dryers represent a primary energy market size of ~1000 TBtu/yr [1,2].

Particularly, the commercial dryers typically remain in service 24 hours per day [3]. Dryers in hotels and resorts can be responsible for as much as 90% of overall energy bill [4].

The core technology of gas dryer systems has not changed much over the last several decades. Existing gas dryer systems simply burn a fuel to heat the ambient air. They reject 50-60% of total input energy as waste heat.

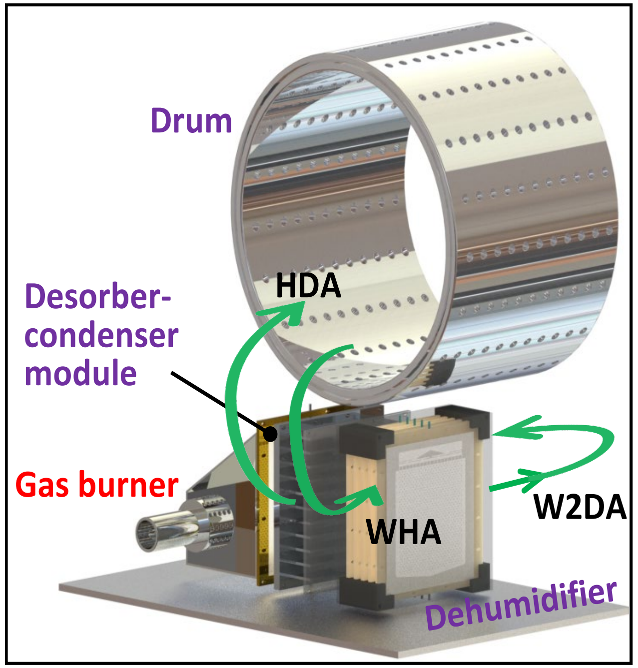
New gas clothes dryer technologies could significantly reduce energy consumption of hotels, resorts, hospitals, laundromats, and many others.

Approach: Dehumidify, heat, and recirculate vented air at high-T

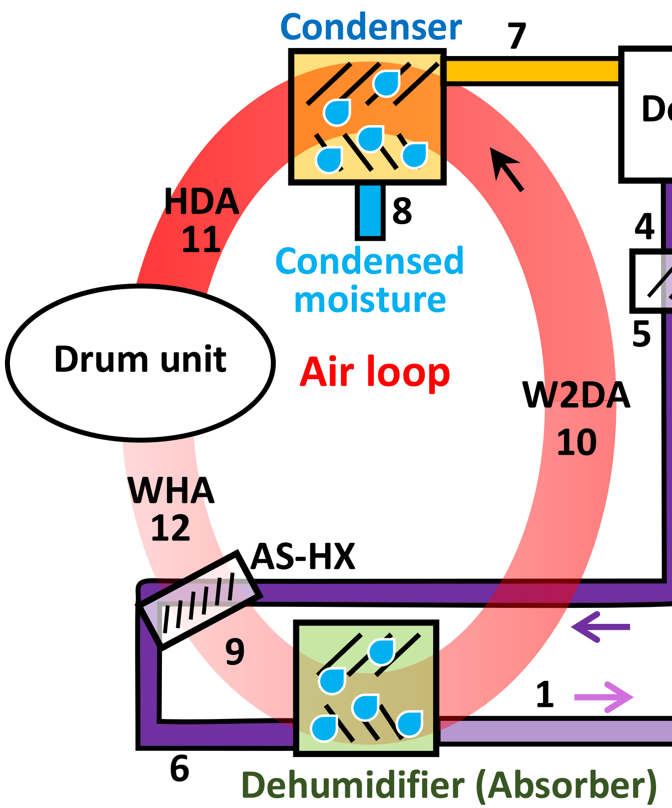
Technical challenge: State-of-the-art gas CDs are incapable of using high temperatures/enthalpies associated with the vented drum air (reject 50-60% of total input energy).

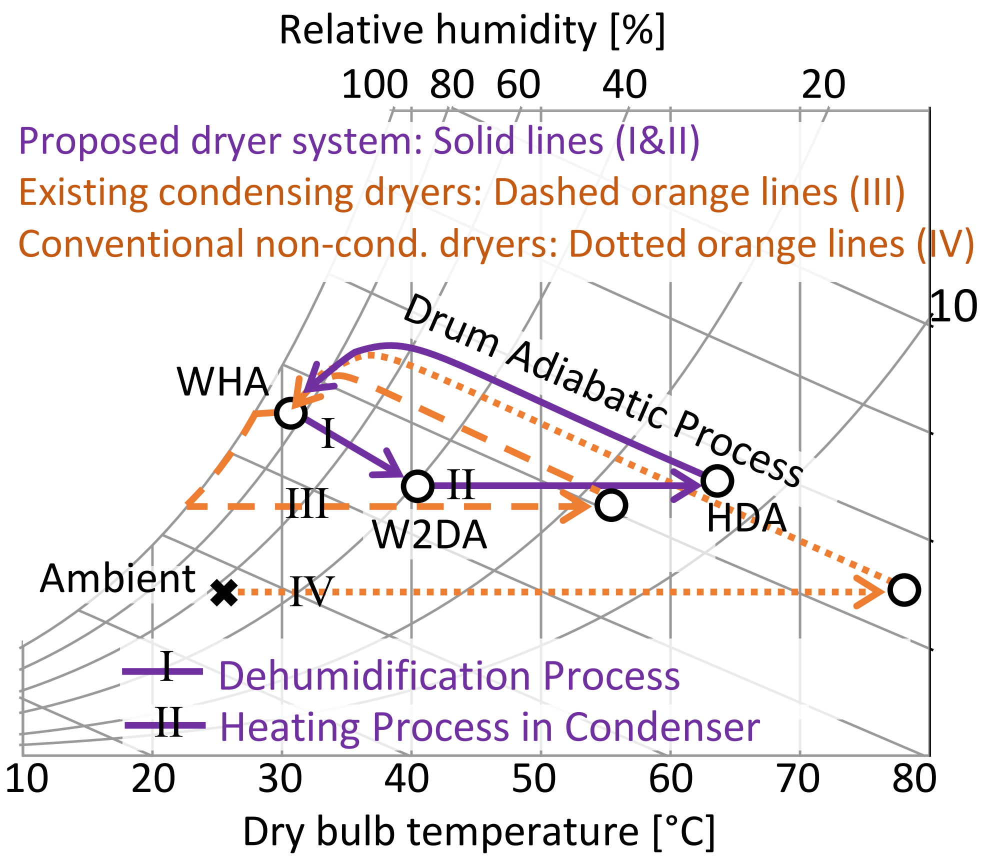
Approach: The proposed system uses natural gas to drive a desiccant-based thermodynamic cycle leveraging waste latent heat from highly humid air leaving the drum. In other words, the technology separates sensible and latent loads enabling to simultaneously dehumidify, heat, and recirculated the vented drum air at elevated temperatures.

This functionality, currently unavailable in existing CD systems, significantly reduces drying energy consumption.



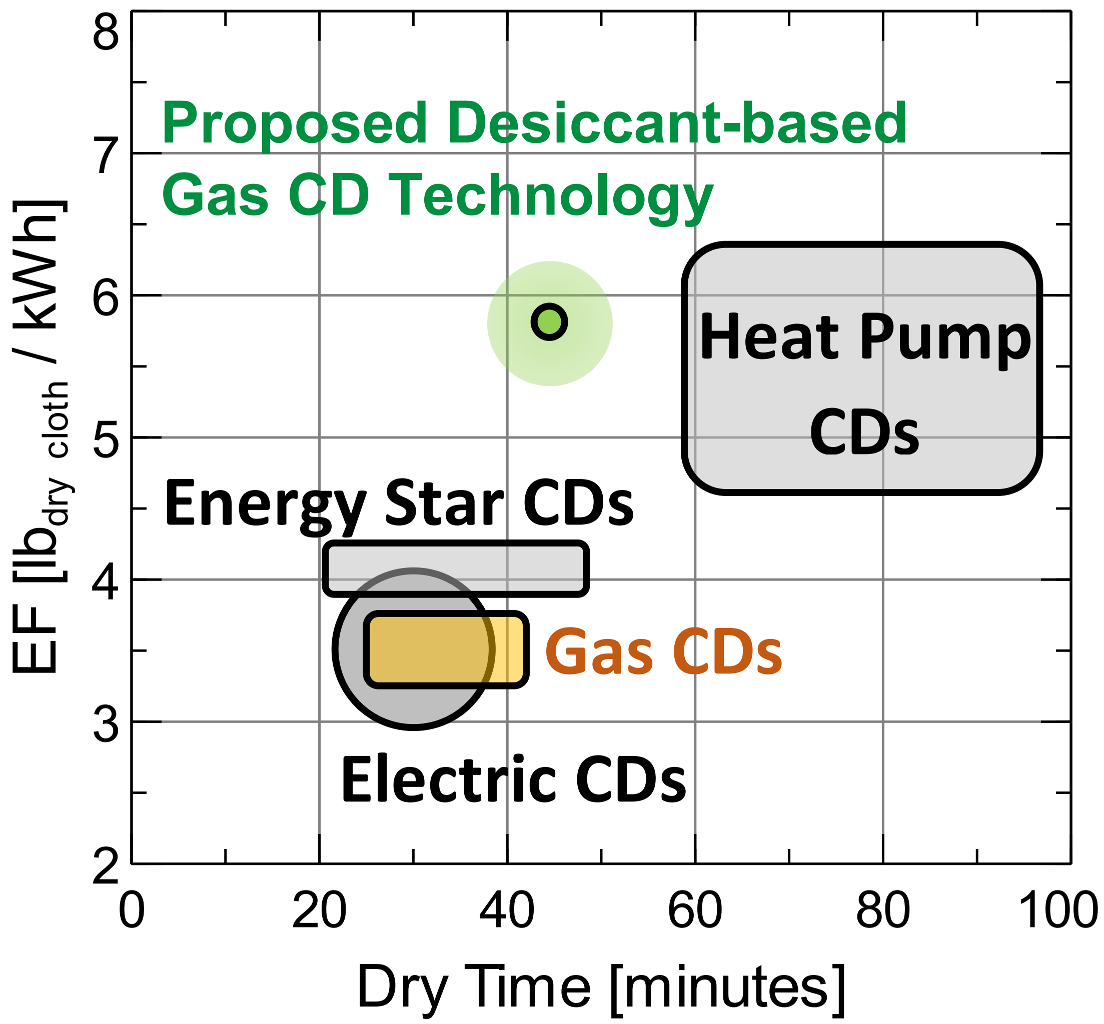
Approach: Novel desiccant-based drying cycle





- The proposed technology effectively utilizes the latent heat associated with the laundry moisture twice; once during dehumidification and again during subsequent condensation.
- Dehumidification at high-T contrasts the proposed technology with current systems that vent (in std. CDs) or cool (in condensing CDs) the drum air, either of which spoils the available enthalpy of drum outlet air.

Impact



Introduce an advanced high-performance gas clothes dryer system leveraging latent heat of drum humid air

Increase EF of gas dryers from 3.3 to 5.7 $lbm_{dry\ cloth}$/kWh

Total primary energy saving: 340 TBtu/yr

Simple payback: 2.5 years

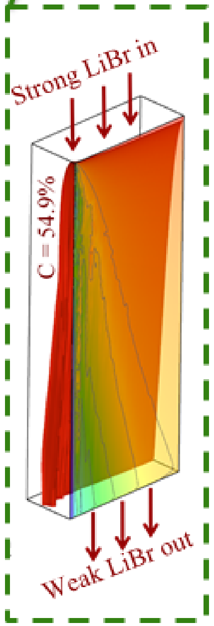
The proposed concept will be validated through both modeling and extensive experimental testing.

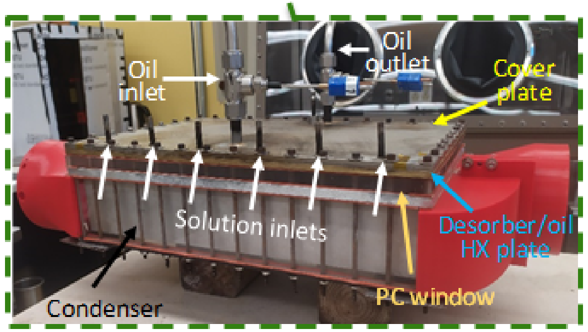
Progress: (current stage of the project: mid stage)

Completed | In progress | Not started

Year 1 (Fall 2019 – Summer 2020)

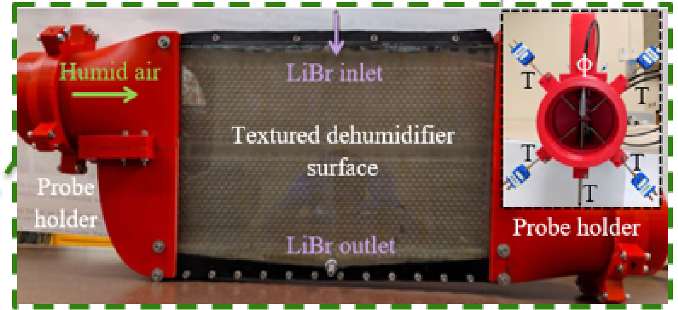
- Thermodynamic modeling (Completed)
- CFD simulations (Completed)
- Design & fabrication of desorber/cond. module (Completed)
- Performance eval. of desorber/cond. module (Completed)



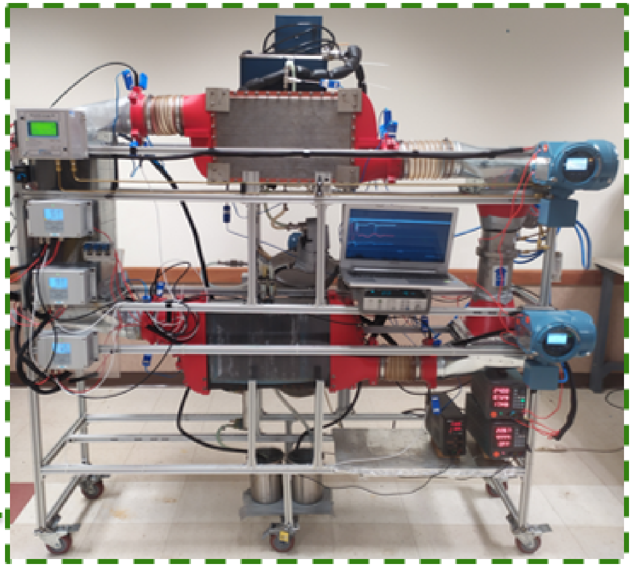


Year 2 (Fall 2020 – Summer 2021)

- Design & fabrication of dehumidifier module (Completed)
- Performance evaluation of dehumidifier module (Completed)
- Design & fabrication of liquid-desiccant loop (Completed)
- Performance eval. of liquid-desiccant loop at simulated dryer conditions (Completed)



Year 3 (Fall 2021 – Summer 2022)

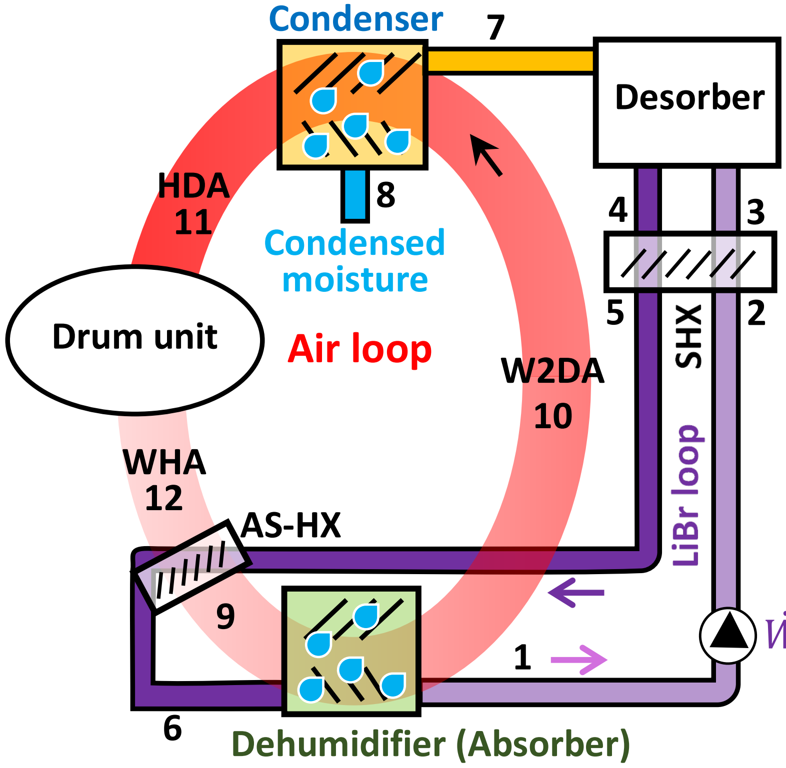


- Performance eval. with standard cloth under DOE-D1 standard conditions (In progress)
- Performance eval. with actual cloth under non-standard conditions (Not started)

Progress: Thermodynamic modeling

$$CEF = \frac{8.45\ (lbm_{dry\ clothes})}{(\dot{Q}_{des} + \dot{W}_{blower} + \dot{W}_{drum})Drying\ time}$$

$$\dot{Q}_{cond} = \dot{m}_{vapor}(h_7 - h_8)$$
$$\dot{m}_{dry-air}(h_{11} - h_{10}) = (U\ A)_{cond} LMTD_{cond}$$

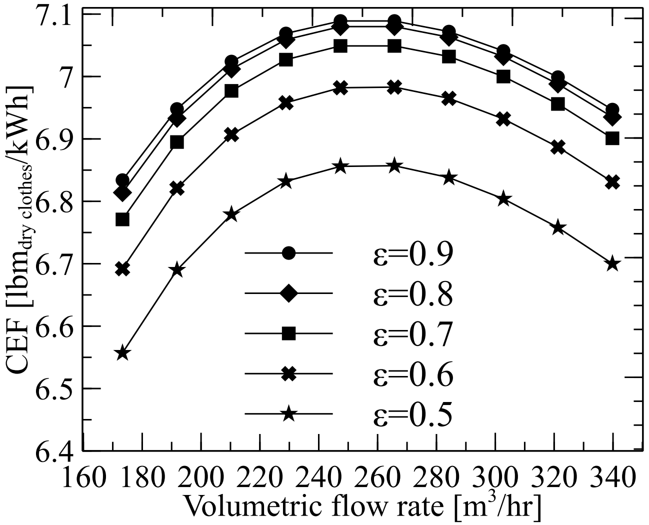


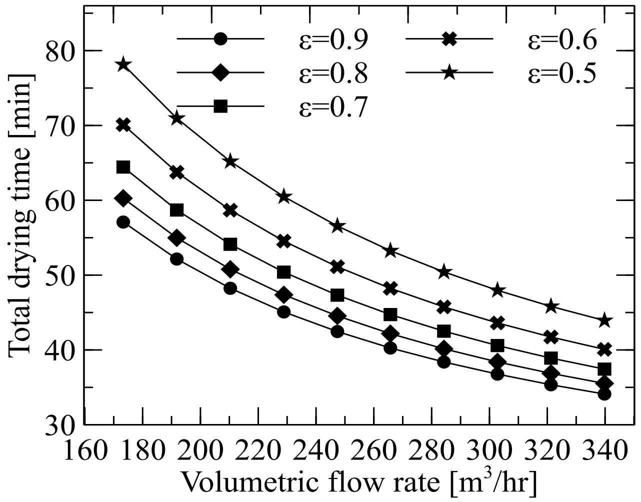
$$\dot{Q}_{des} = (U\ A)_{des} LMTD_{des}$$
$$= \dot{m}_4 h_4 + \dot{m}_7 h_7 - \dot{m}_3 h_3$$

$$\eta_{hx1} = \frac{T_4 - T_5}{T_4 - T_2}$$

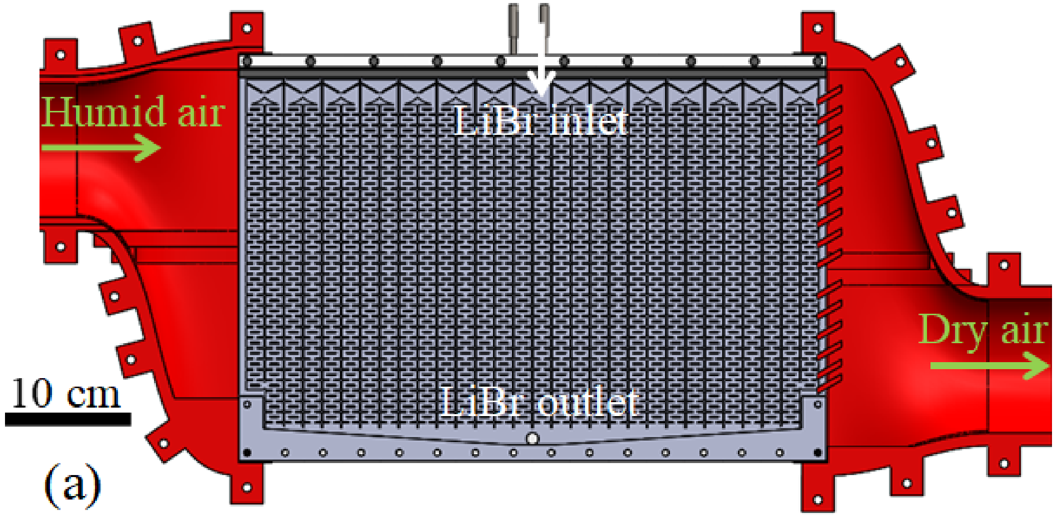
$$\dot{W}_{pump} = \dot{m}_2 h_2 - \dot{m}_1 h_1$$

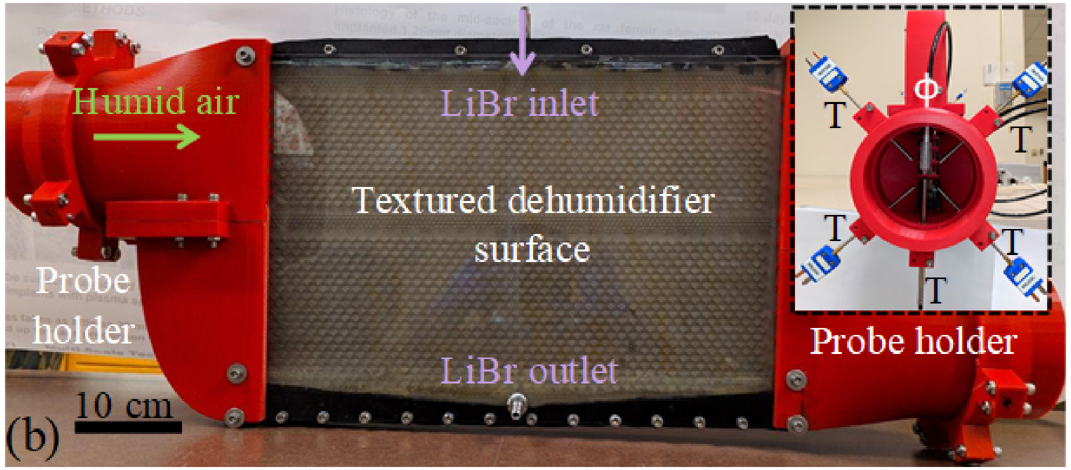
$$\dot{Q}_{abs} = \dot{m}_6 h_6 + \dot{m}_{vapor} h_{vapor} - \dot{m}_1 h_1$$
$$\dot{m}_{dry-air}(h_{10} - h_9) = (U\ A)_{abs} LMTD_{abs}$$

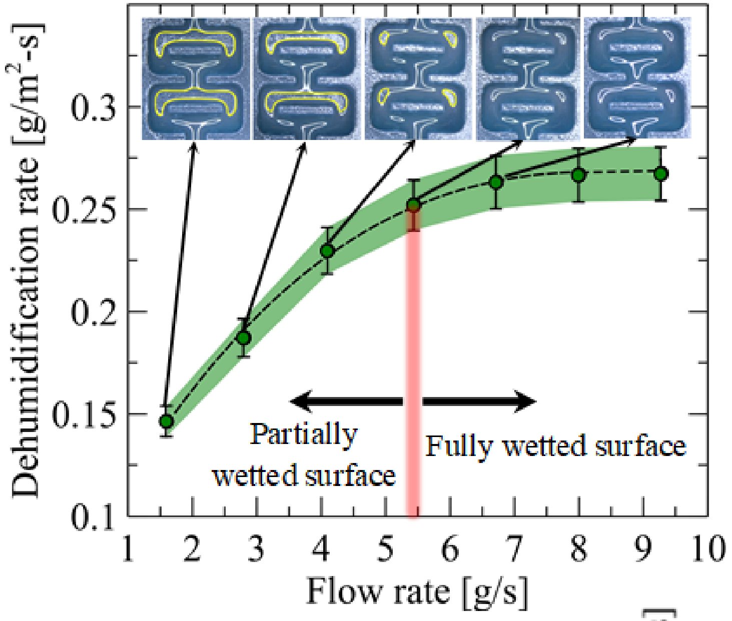


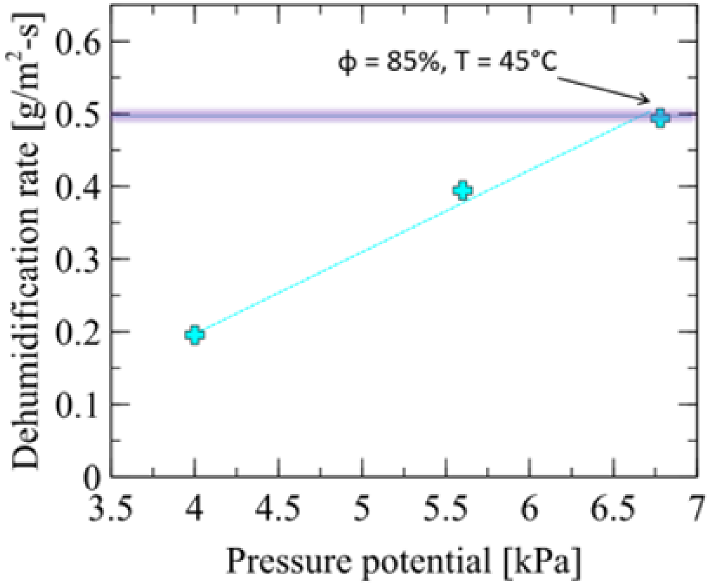


Progress: Dehumidifier module development and testing

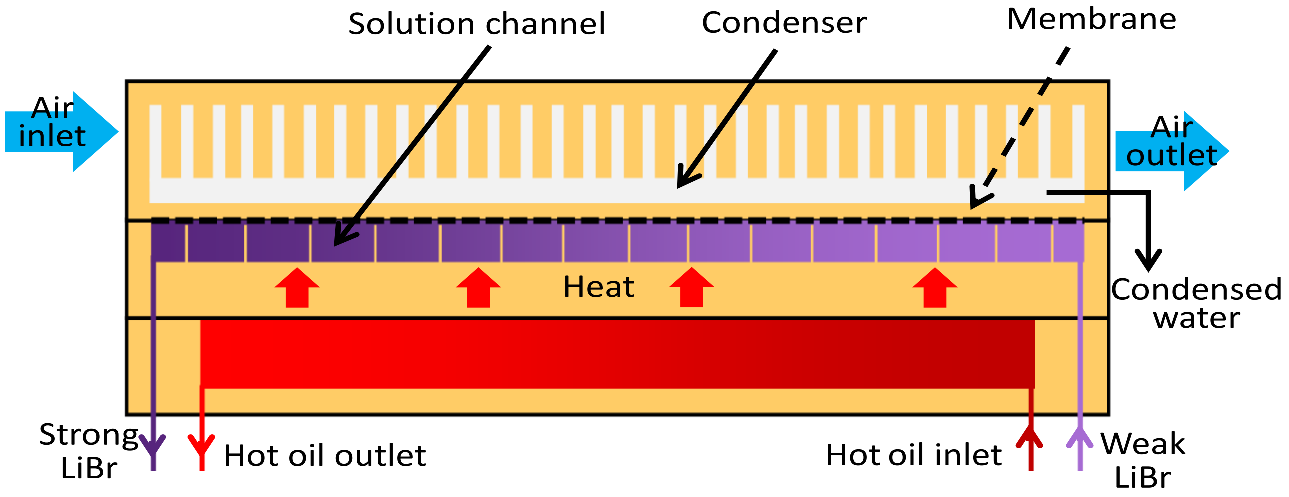


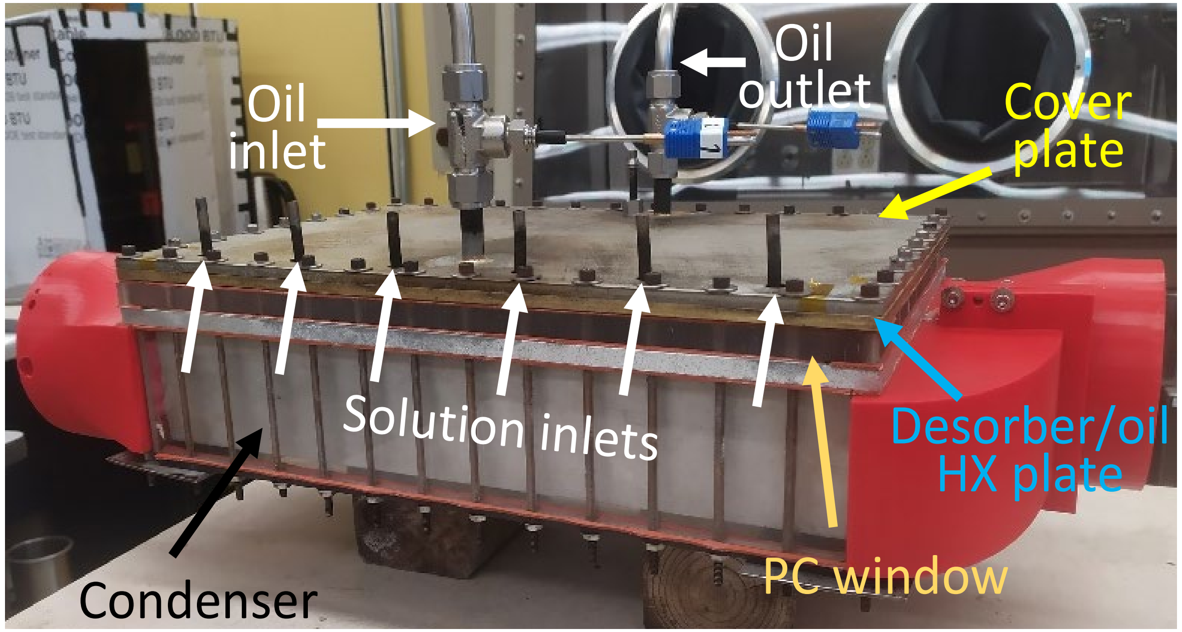


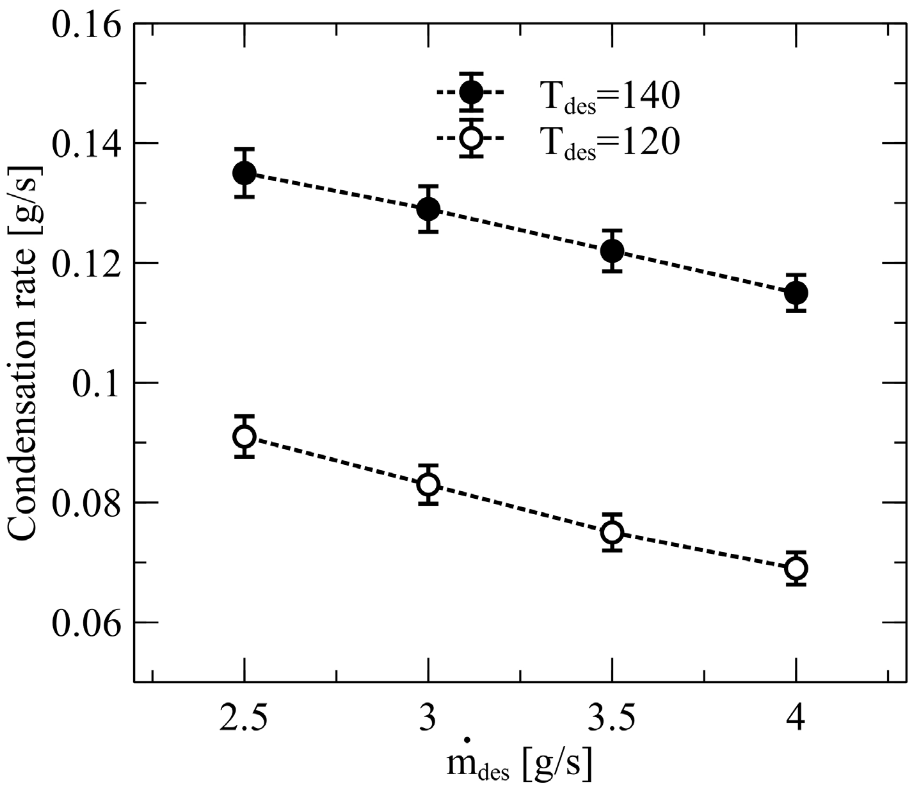




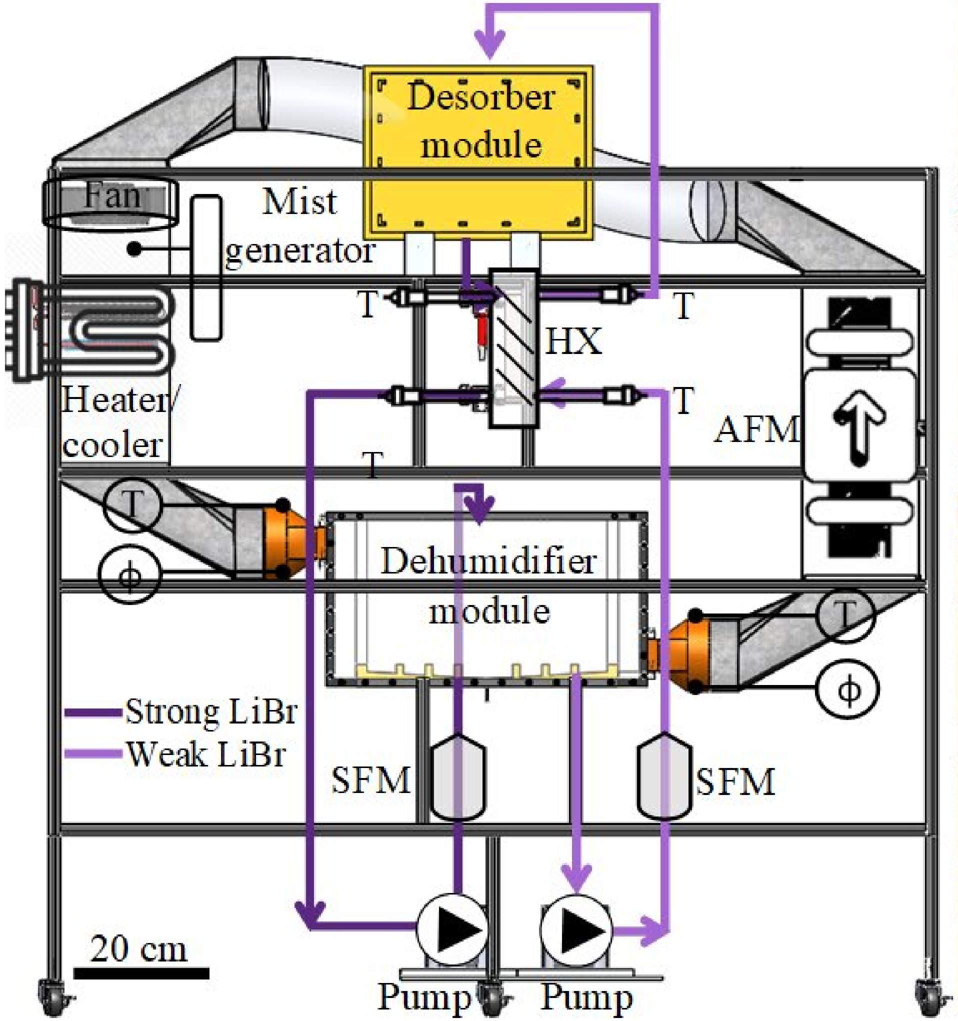
Progress: Desorber/cond. module development and testing

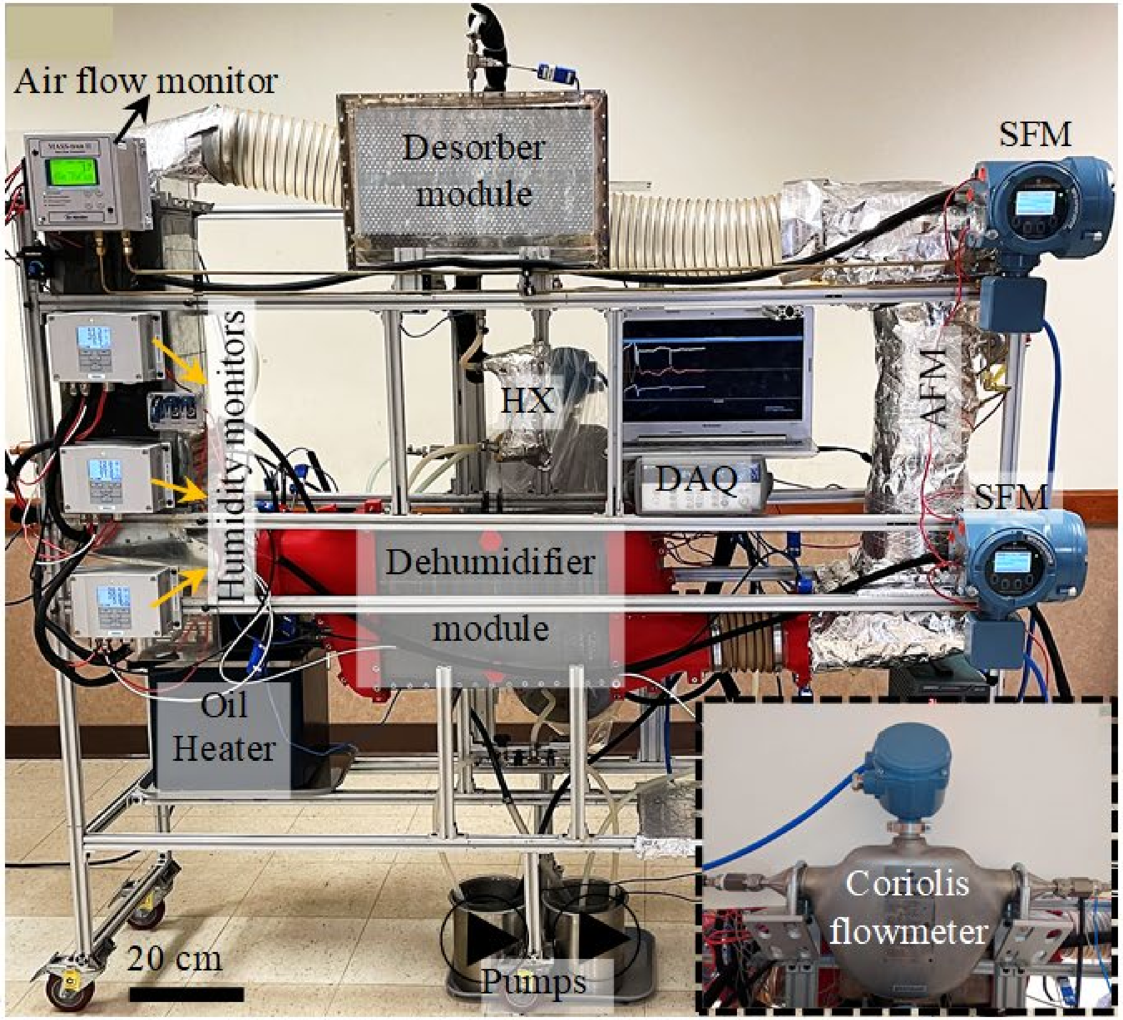




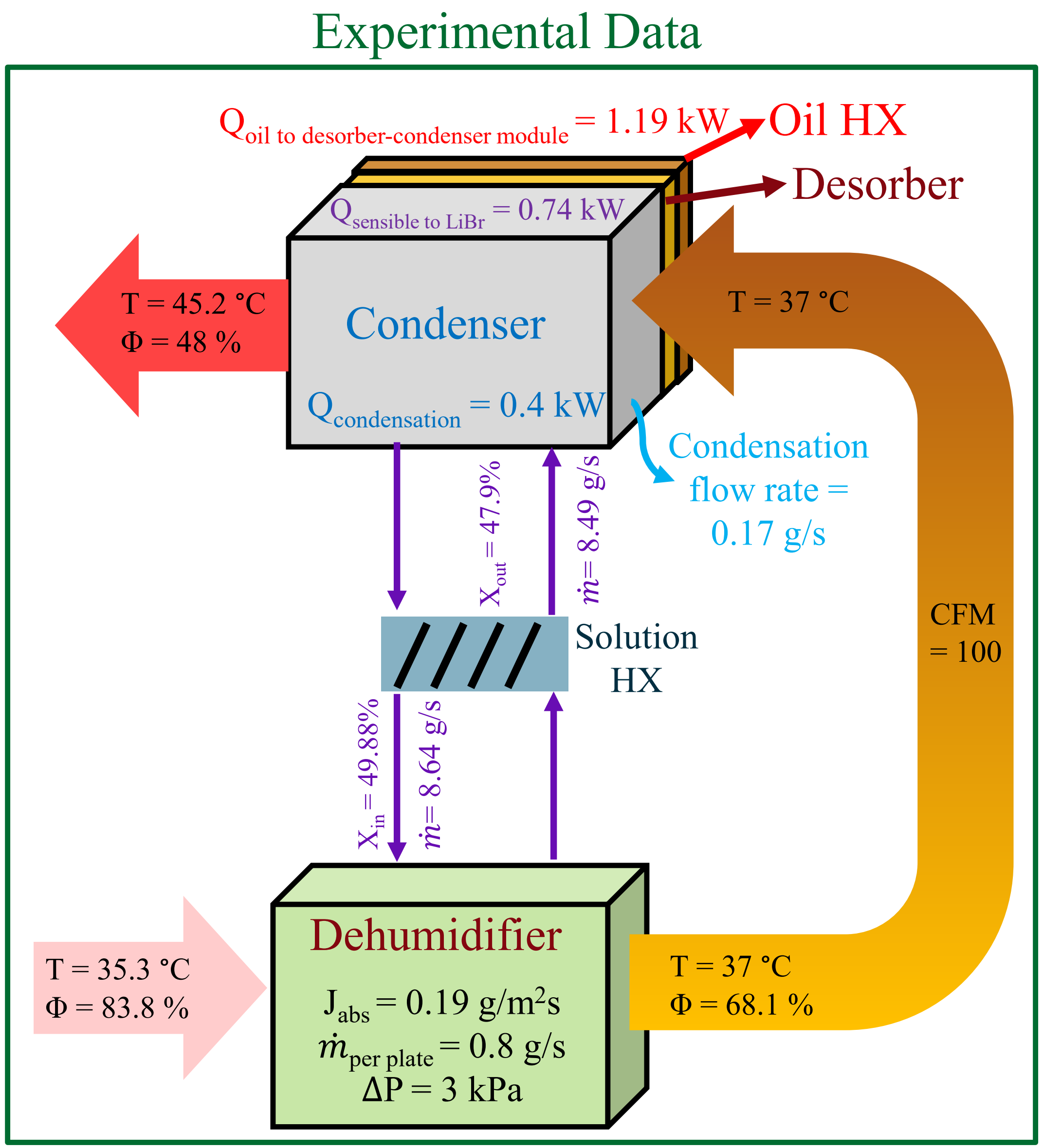


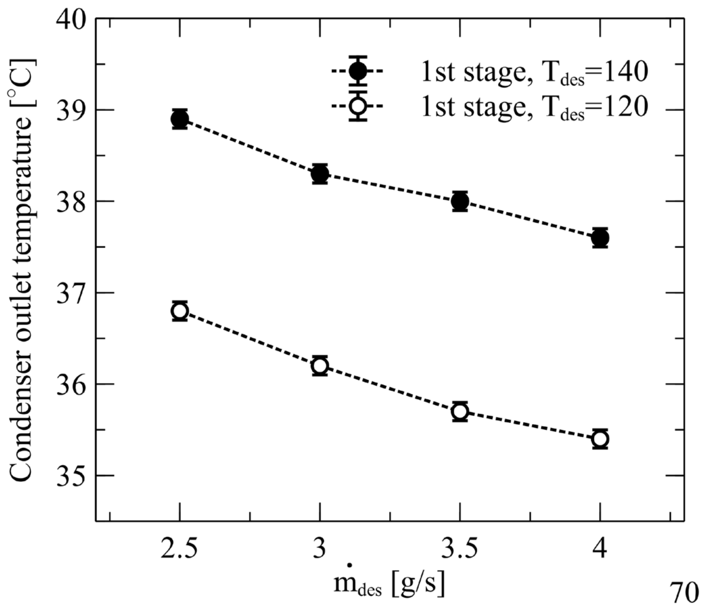
Progress: Desiccant system development

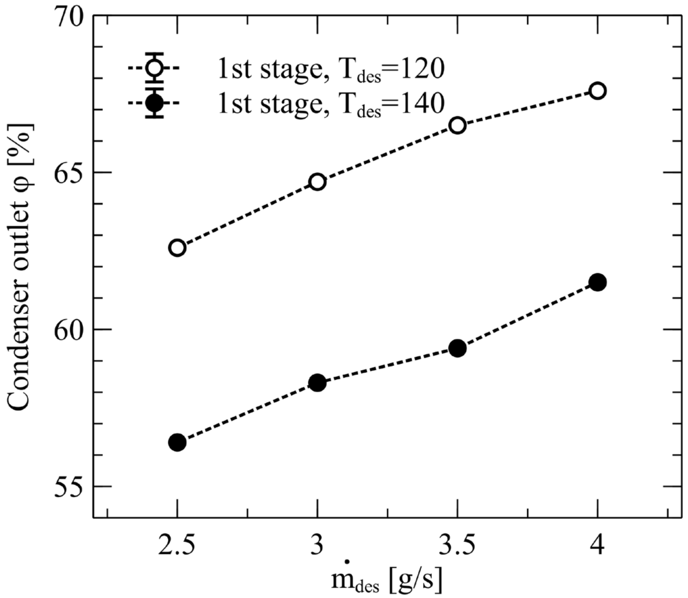




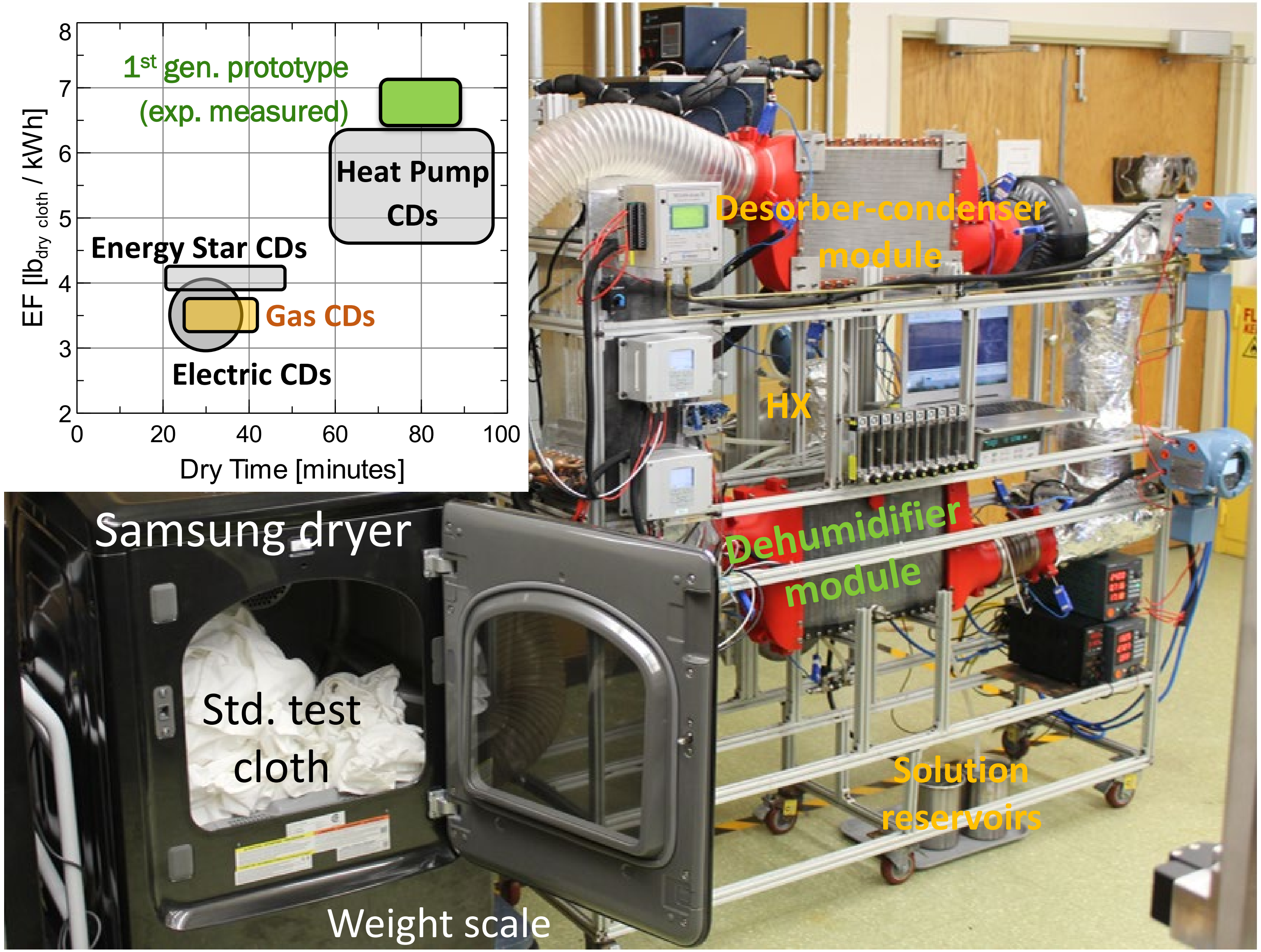
Progress: Desiccant system testing







Progress: Integrated desiccant-clothes dryer testing



<u>Preliminary</u> **integrated testing with standard cloth under DOE-D1 standard test conditions:**

Weight of dry-bone cloth: 8.45 lb

Initial RMC: 57.5

Final RMC: 3.5

Desorber temperature: 120-140°C

Experimentally measured CEF:

6.5-7.05 $\text{lbm}_{\text{dry-bone}}$/kWh (considering all waste heat)

Drying time: 70-90 minutes

Stakeholder Engagement

- Our industry partner, Samsung, is a key player in the gas clothes dryer market.
- They are actively involved with all stages of the project.
- They provide design guidelines and customer insights as the proposed concept is developed.
- Samsung is currently considering commercialization prospects. The first step is to have a prototype system and facilitate field demonstration.

Remaining Project Work

- **Testing under standard loading:** conduct testing with standard cloth under the DOE-D1 standard conditions to experimentally evaluate drying performance of the proposed concept (50% cotton and 50% polyester fabrics)
- **Testing under non-standard loading:** conduct testing with actual cloth under non-standard conditions to evaluate drying performance of the proposed concept (Actual clothes, towels, and sheets are more likely to be 100% cotton than a 50/50 blend. Clothes made of 100% cotton tend to absorb and retain more water than 50/50 blends, requiring longer drying times and/or higher temperatures.)
- **Performance improvement:** fabricate a 2nd generation prototype considering lessens learned and improvement in dehumidifier and desorber modules
- **Samsung testing:** ship a prototype system to Samsung for further validation and field demonstration

Thank You

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REFERENCE SLIDES

Project Budget

Project Budget: Federal: $734,565, Cost Share: $183,723
Variances: None
Cost to Date: $493,113 ($273,938 MTU, $100,000 ORNL, $119,175 Cost Share)
Additional Funding: None

Budget History					
FY 2019 – FY 2020 (past)		FY 2021 (current)		FY 2022 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$244,890	$100,010	207,458	$50,202	$282,217	$33,511

Project Plan and Schedule

Project Schedule												
Project Start: 07/01/2019		Completed Work										
Projected End: 06/30/2022		Active Task (in progress work)										
		Milestone/Deliverable (Originally Planned)										
		Milestone/Deliverable (Actual)										
	FY19	FY2020				FY2021				FY2022		
Task	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)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)
Past Work												
Conduct thermodynamic/CFD modeling												
Design, fabricate, and evaluate a full-scale desorber/cond. module												
Design, fabricate, and evalaute a full-scale dehumidifier module												
G/NG 1: Dehumidification rate established												
Design and fabricate the desiccant loop system												
Integerate the desiccant loop with a clothes dryer drum												
G/NG 2: Design goals demonstrated												
Current/Future Work												
Performance evaluation under DOE-D1 standard conditions												
Performance evaluation under non-standard conditions												