2024 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

BTO Peer Review:

Pool Boiling Heat Transfer for Low-GWP Refrigerants

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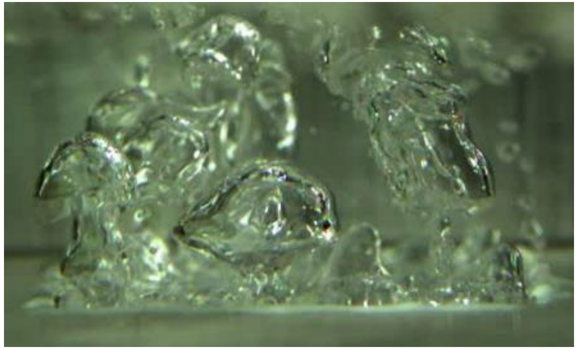
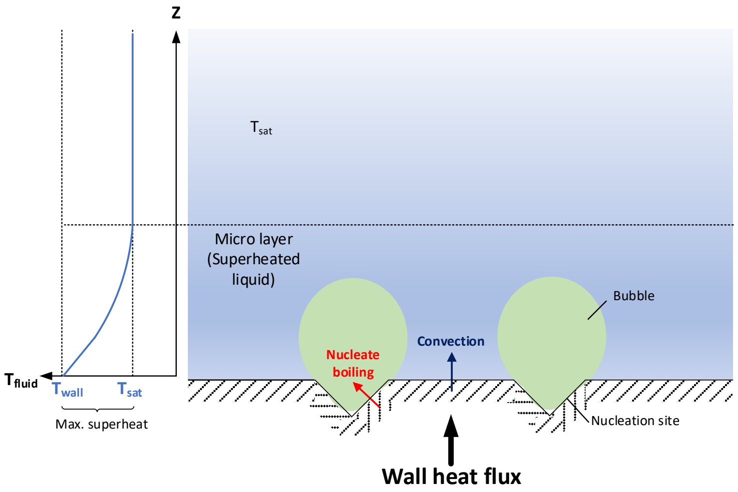
Low-GWP refrigerants





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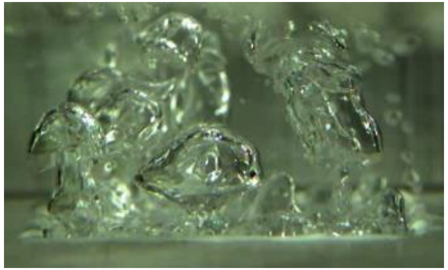
WBS 03.02.02.80.NS04b

Project Summary

OBJECTIVE, OUTCOME, AND IMPACT

The objective of this project is to evaluate the pool boiling heat transfer of new low–global warming potential (GWP) refrigerants, which is critical for designing next-generation heat exchangers with enhanced performance and reduced refrigerant charge. Actional data will be provided, which helps the HVAC and refrigeration industry to transition to ultralow-GWP refrigerants.



Low-GWP refrigerants

TEAM AND PARTNERS

Oak Ridge National Laboratory:

Oak Ridge National Laboratory

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Partners:

Honeywell   Chemours™

STATS

Performance Period: May 2022–September 2025

DOE Budget: $300k/year (FY 2024)

Milestone 1: Development of pool boiling facility for refrigerants (Q2 FY 2023)

Milestone 2: Heat transfer measurement for various low-GWP refrigerants (Q4 FY 2023)

Milestone 3: Evaluation of enhanced surface (Q2 FY 2024)

Problem

- Goal is to support DOE BTO to accelerate the transition to next-generation low-GWP refrigerants
- Widely used nucleate boiling correlations for flat surfaces have been developed for a narrow range of fluids, which is a critical portion of flow boiling correlations and heat exchanger design
- Particularly, no correlation exists to predict the nucleate boiling behavior of low-GWP refrigerants such as R1234yf, R1234ze(E), R1233zd(E), and R1336mzz(Z)

Rohsenow (1952)

$$h_{nb} = 55\left(q''_{nb}\right)^{0.67} P^{*\left(0.12-0.2\log(R_a)\right)}\left(-\log P^*\right)^{-0.55} M^{-0.5}$$

Cooper (1984)

$$h_{nb} = \mu_l h_{fg}\left[\frac{g\left(\rho_l-\rho_v\right)}{\sigma}\right]^{\frac{1}{2}} \mathrm{Pr}_l^{\frac{-s}{r}}\left(\frac{c_{p,l}}{c_{s,f}h_{fg}}\right)\left(\Delta T_{sat}\right)^{\frac{1-r}{r}}$$

Stephan and Abdelsalam (1980)

$$h_{nb} = 0.243\frac{k_l}{D_d}\left(\frac{q''_{nb}D_d}{k_l T_v}\right)^{0.673}\left(\frac{c_p T_v D_d^2}{\alpha^2}\right)^{1.26}\left(\frac{h_{fg}D_d^2}{\alpha^2}\right)^{-1.58}\left(\frac{\rho_l-\rho_v}{\rho_l}\right)^{5.22}$$

Developed based on the following fluids:

- Water
- Hydrocarbons (e.g., benzene, *n*-pentane)
- Cryogenic liquids (e.g., hydrogen, oxygen, nitrogen)
- Refrigerants: R-11, R-12, R-113, R-114, R-21, R-22, RC318, R-744

Alignment and Impact

- Support the nation's ambitious climate mitigation goals by reducing greenhouse gas (GHG) emissions 50%–52% by 2030 vs. 2005 levels
  - ✓ Actionable results for HVAC industry to allow for transitioning from high-GWP refrigerants to low-GWP refrigerants (<150), which help reduce at lease 96% in direct GHG emissions
  - ✓ Ensure US competitiveness in HVAC market
- Support DOE BTO's goal to reduce on-site use intensity in buildings 30% by 2035 and 45% by 2050 compared with 2005 levels
  - ✓ At least 10% energy efficiency improvement and 250 TBtu energy saving in air-conditioning and refrigeration systems
- Support the DOE BTO to decarbonize the US building stock in line with economy-wide net-zero emissions by 2050

Greenhouse gas emissions reductions

50–52% reduction by 2030 vs. 2005 levels

Net-zero emissions economy by 2050

Increase building energy efficiency

Accelerate onsite emissions reductions

Approach

- Evaluate various refrigerants with GWP < 150
- Measure the heat transfer coefficient (HTC) and generate pool boiling curve
- Develop an empirical model or correlation that will be suitable for new low-GWP refrigerants

Refrigerant	Composition (blends)[1]	Regulatory GWP[2]	ASHRAE Class[1]
R1234yf	Pure fluid	1	A2L
R1234ze(E)	Pure fluid	1	A2L
R1233zd(E)	Pure fluid	4	A1
R1336mzz(Z)	Pure fluid	2	A1
R1336mzz(E)	Pure fluid	26	A1
R514A	R1336mzz(Z)/R1130(E) (74.7%/25.3%)	7	B1
R516A	R1234yf/R134a/R152a (77.5%/8.5%/14.0%)	142	A2L

(1. ANSI/ASHRAE Standard 34-2022; 2. EPA, https://www.epa.gov/climate-hfcs-reduction/technology-transitions-gwp-reference-table)

Approach

Phase I

Facility development

- Review state-of-the-art test facility in literature
- Develop pool boiling setups for evaluating medium- and low-pressure refrigerants
- Validate the facility by comparing with open literature
- Study heat transfer measurement techniques

Phase II

Evaluation of low-GWP refrigerants

- Evaluate pool boiling heat transfer for various low-GWP refrigerants
- Study heat transfer mechanisms for pool boiling
- Fabricate and characterize the surface structure of the enhanced surfaces
- Evaluate the pool boiling heat transfer of the enhanced surfaces

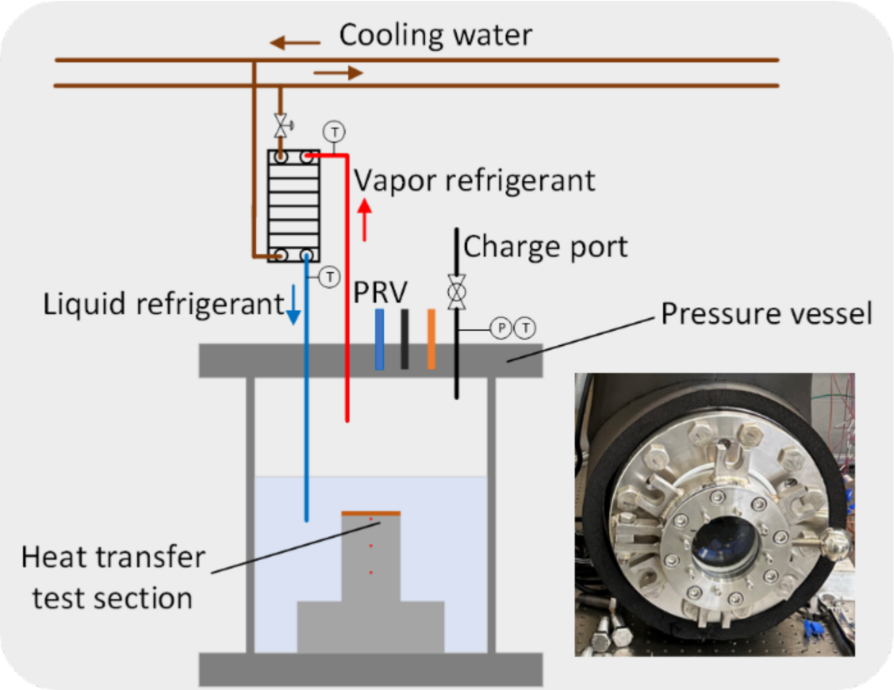
Phase III

Empirical model development

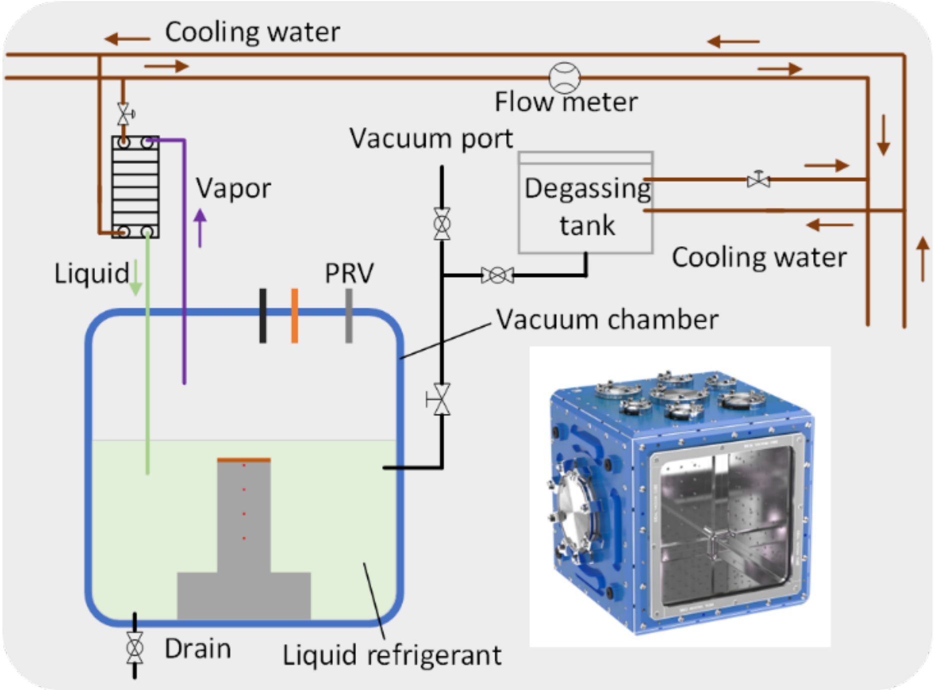
- Evaluate the existing correlations by comparing the experimental results
- Identify relevant variables involved in the heat transfer
- Perform dimensional analysis and determine dimensionless group
- Develop a physics-based model to predict the performance of new refrigerants

Approach Closed-loop pool boiling heat transfer test apparatus

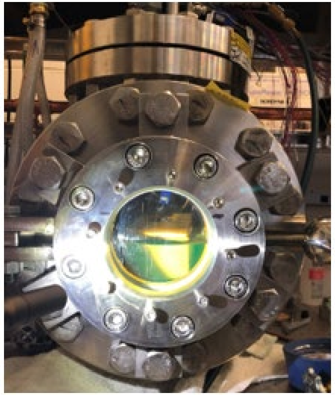
Pool boiling for medium-pressure refrigerants



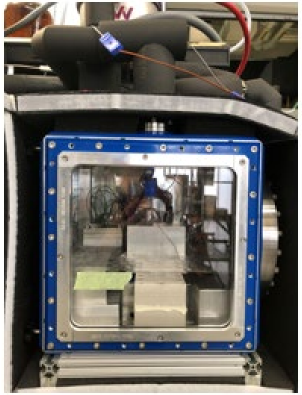
Pool boiling for low-pressure refrigerants



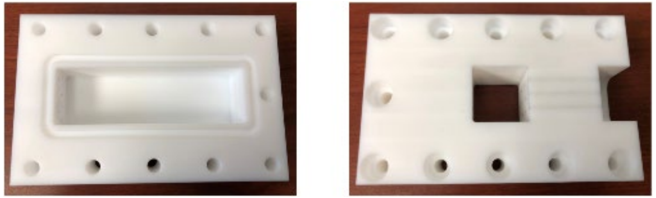
Approach Closed-loop pool boiling heat transfer test apparatus



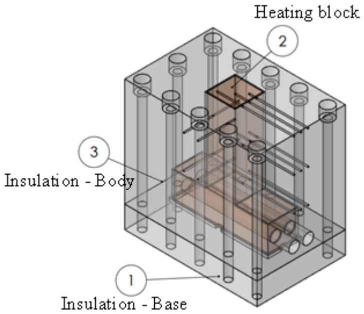
Pressure vessel



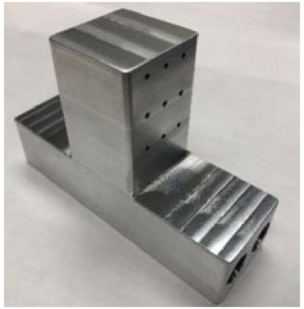
Vacuum chamber



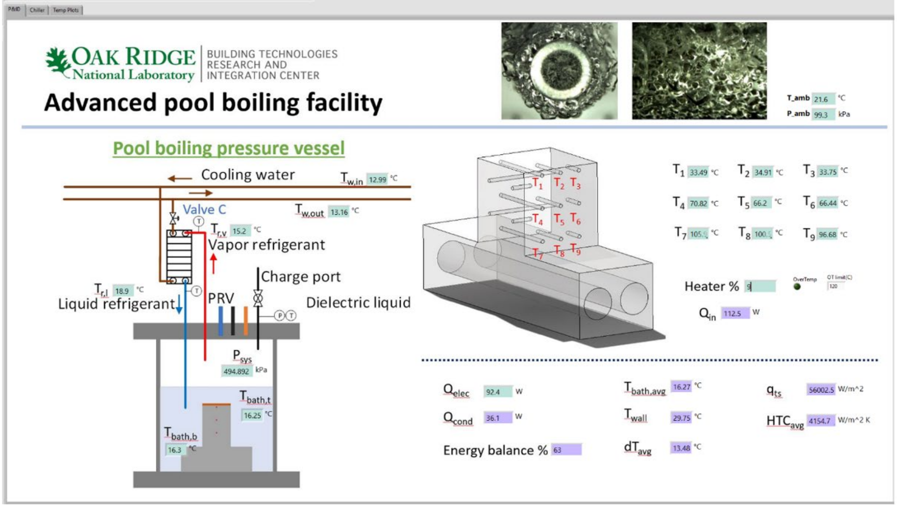
PTFE insulation (base plate and top cover)



Test section



Heating block



LabVIEW program for pool boiling facility

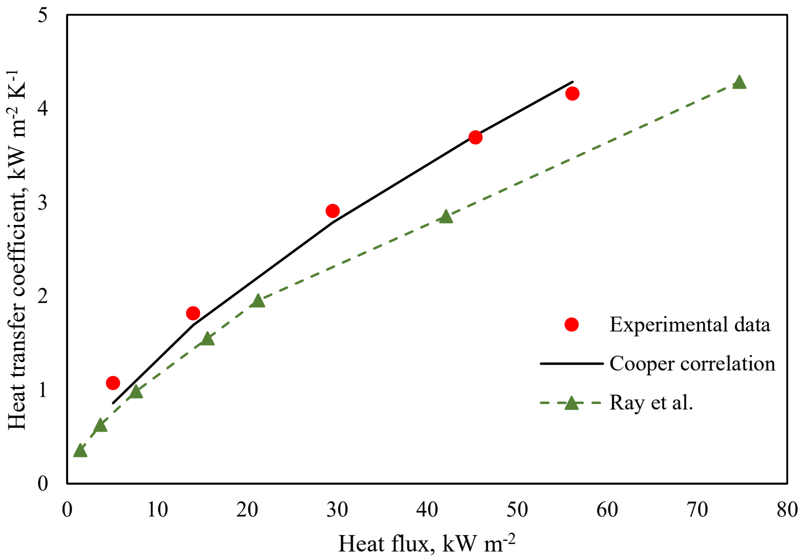
Approach Validation of test apparatus using R134a

- Experiments for facility validation:
  - Bare copper surface
  - R134a
  - Saturation pressure: 5 bar (P_r = 0.123)
  - Heat flux: 5–56 kW/m^2
- Comparison with literature:
  - Experimental data of R134a pool boiling data from Ray et al.
  - Pool boiling correlation developed by Cooper

$$h_{nb} = 55\left(q''_{nb}\right)^{0.67} P^{*(0.12-0.2\log(R_a))}\left(-\log P^*\right)^{-0.55} M^{-0.5}$$

- Results:
  - A maximum deviation of 7% with Cooper correlation
  - About 23% with Ray et al.'s experimental data
  - P_r of the current study is slightly different from Ray et al.'s conditions
- *The test setup has been validated, and the results of HTC showed a reasonable agreement with Cooper correlation.*

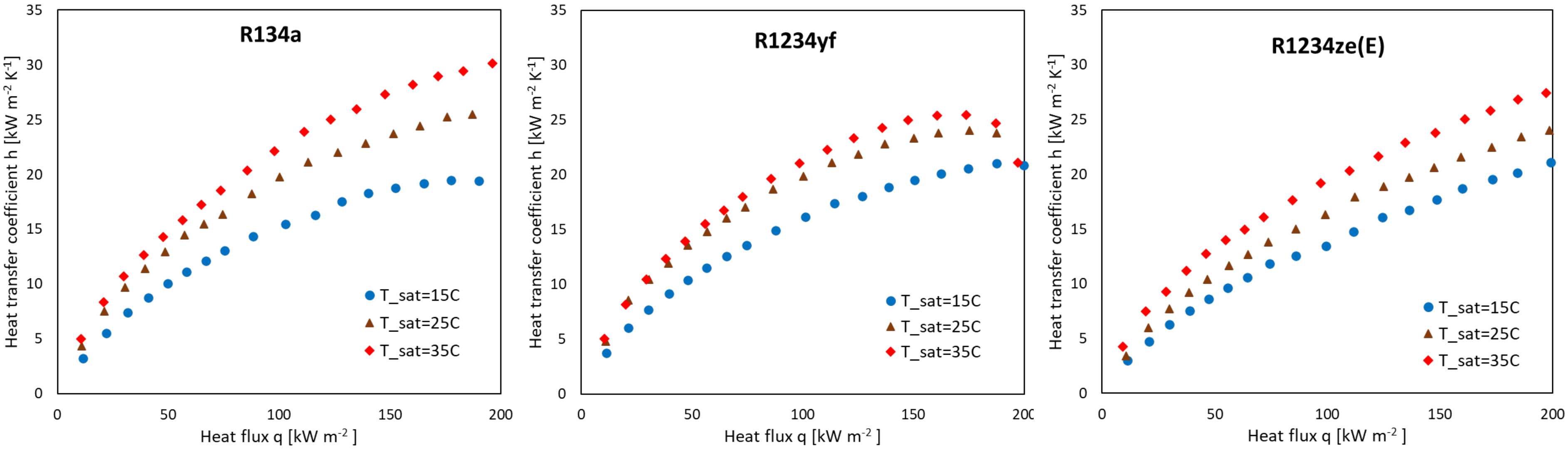
Comparison of measured HTC with Cooper correlation and Ray et al.'s experimental data



Sources:
M. Cooper, "Saturation Nucleate Pool Boiling: A Simple Correlation," Department of Engineering Science, Oxford University, England, vol. 86, pp. 785–793, 1984.
M. Ray, S. Deb, and S. Bhaumik, "Pool boiling heat transfer of refrigerant R-134a on TiO2 nano wire arrays surface," Applied Thermal Engineering, *vol. 107, pp. 1294–1303, 2016.*

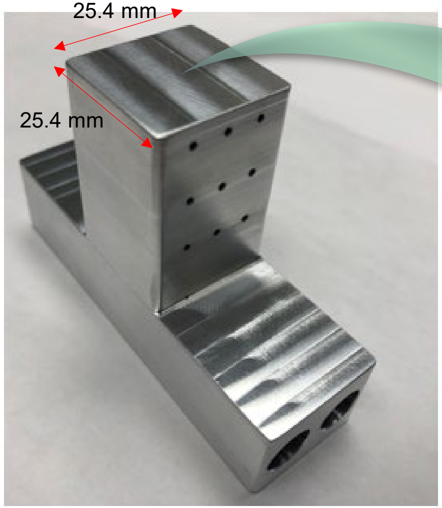
Progress Pool boiling heat transfer of refrigerants on a plain surface

HTCs under various heat fluxes and saturation temperatures

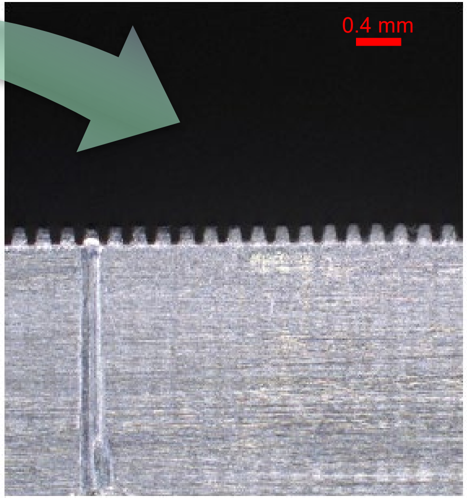


- R1234yf ≈ R134a at saturation temperatures of 15°C and 25°C
- R1234ze(E) <R134a and R1234yf

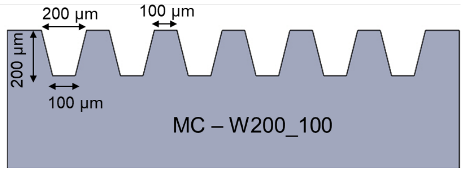
Progress Fabrication and characterization of enhanced surfaces

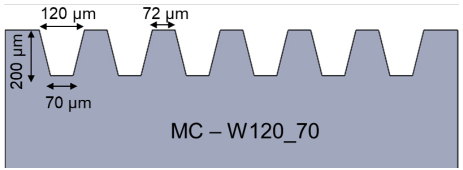


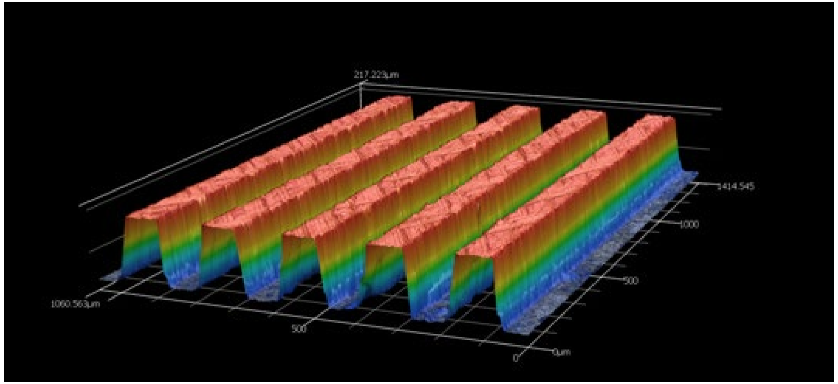
Heating block



Enhanced surface



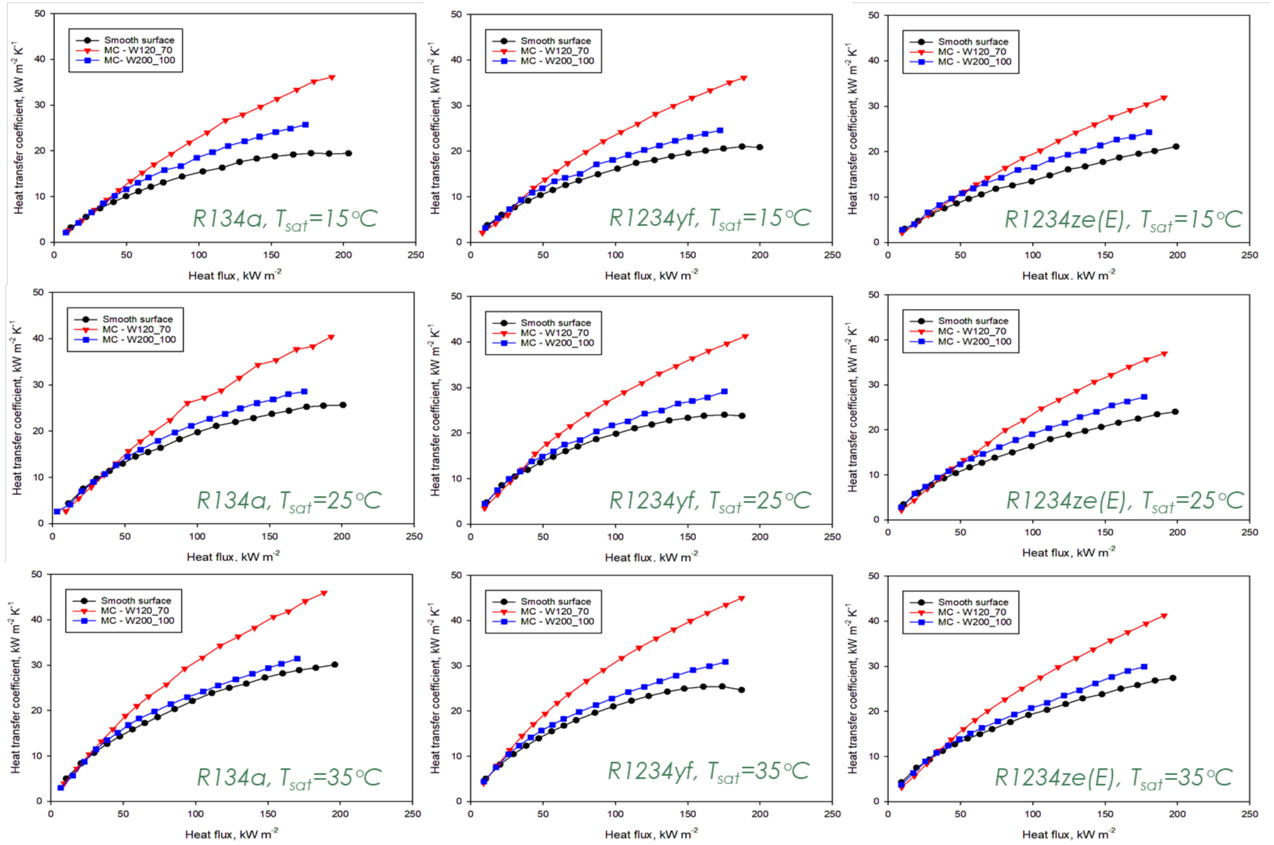




Topography of the microgrooves through a profilometer

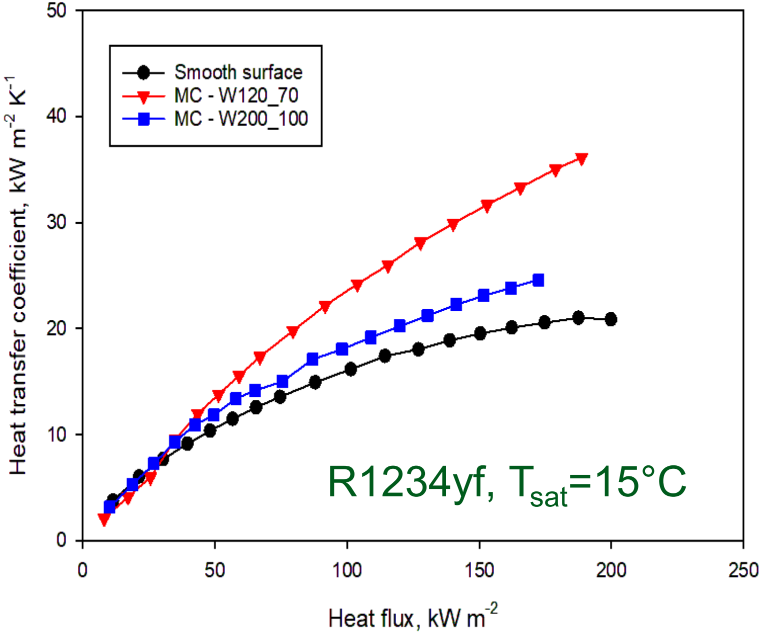
- Two enhanced surfaces were directly fabricated on top of the heating block through end-milling process in a CNC machine
- The surface topography information was acquired through a 3D noncontact surface profilometer

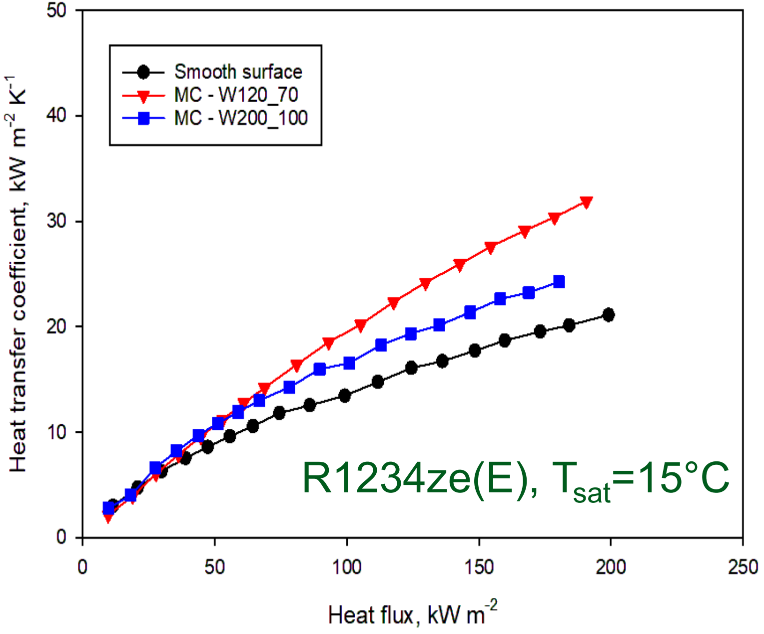
Progress Pool boiling heat transfer for enhanced surfaces



- Three refrigerants: R134a, R1234yf, and R1234ze(E)
- Three surfaces: plain, MC–W200_100, and MC–W120_70
- Three saturation temperatures: 15°C, 25°C, and 35°C
- Heat fluxes: 5–200 kW/m^2

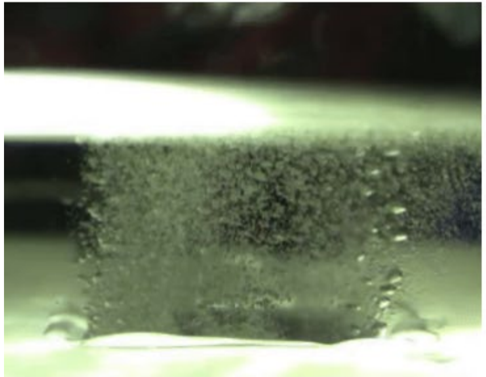
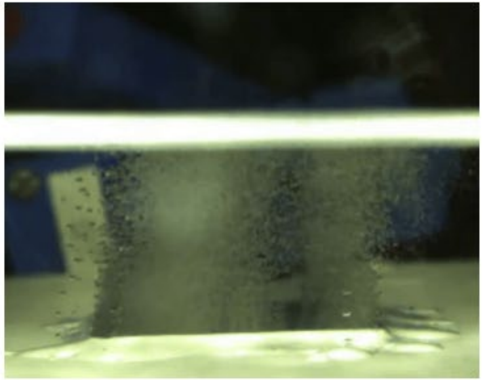
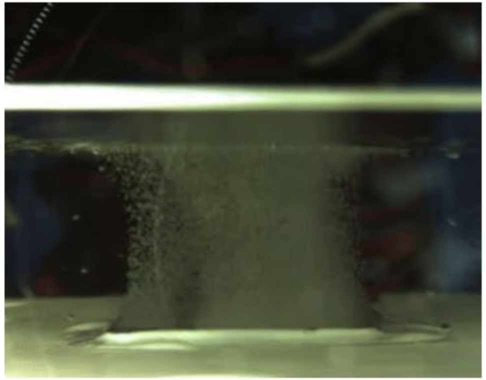
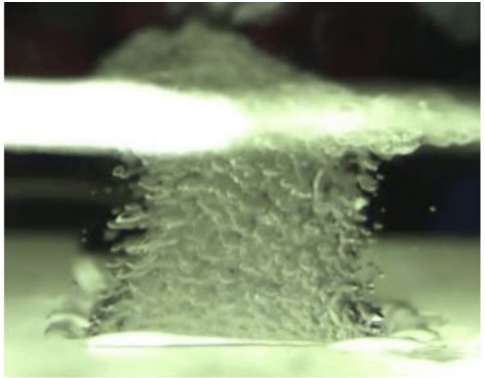
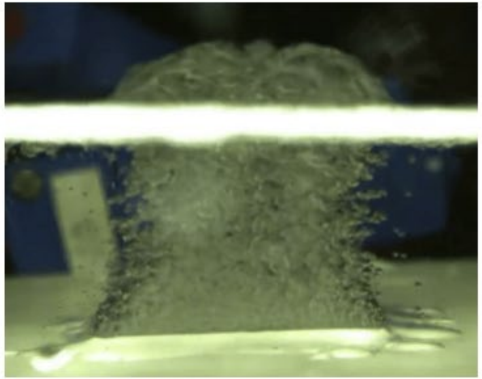
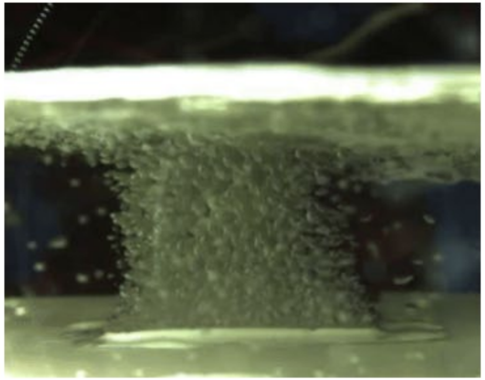
Progress Pool boiling heat transfer for enhanced surfaces





- Performance of all three surfaces are similar up to a heat flux of 25 kW/m²
- MC–W120_70 showed a maximum HTC improvement of 86%, followed by MC–W200_100 with 30%

Progress Pool boiling on various surfaces (R134a, T_{sat} = 35°C)

	Plain surface	***Enhanced surface 1 (MC –W120_70)***	***Enhanced surface 2 (MC – W200_100)***
q = 5 kW/m^2			
q = 49 kW/m^2			

Future Work

- Conduct the pool boiling experiments using low-GWP, low-pressure refrigerants
- Investigate the pool boiling heat transfer of low-GWP mixture refrigerants
- Develop a model to predict the performance of new refrigerants
- Modify the test apparatus to evaluate the effect of orientation on pool boiling heat transfer
- Investigate the bubble dynamics and heat transfer mechanisms of the low-GWP refrigerants on the enhanced surface

Thank you

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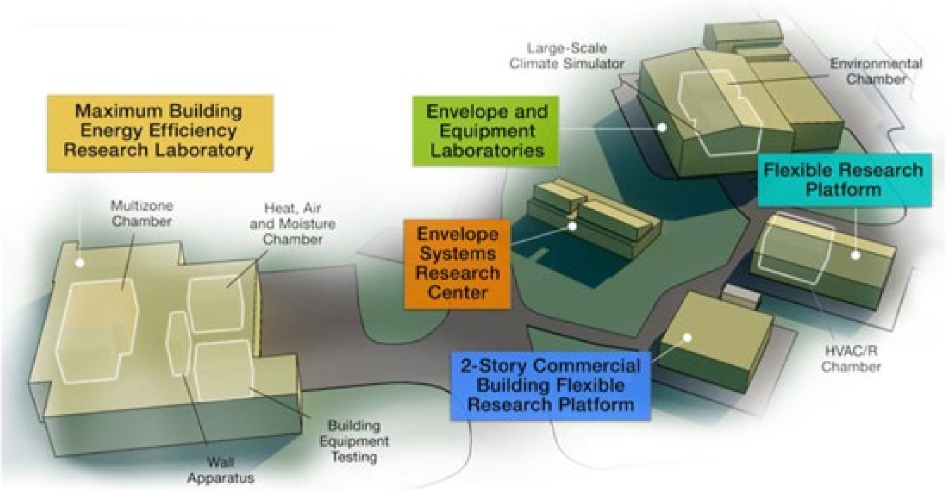

The **Building Technologies Research and Integration Center** (**BTRIC**) at ORNL has supported DOE BTO since 1993. BTRIC is composed of more than 60,000 ft^2 of lab facilities conducting R&D and development to develop affordable, efficient, and resilient buildings and also reducing their greenhouse gas emissions 65% by 2035 and 90% by 2050.

Scientific and Economic Results
139 publications in FY 2024
140+ industry partners
60+ university partners
16 R&D 100 Awards
64 active Cooperative Research and Development Agreements

BTRIC is a DOE-designated National User Facility

Reference Slides

Project Execution

	FY2023				FY2024				FY2025			
Planned budget	$750k				$300k							
Spent budget												
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q1 Milestone: Validate pool boiling facility using R134a												
Q2 Milestone: Modeling strategy for pool boiling HTC												
Q4 Milestone: Test low GWP refrigerants (plain surface)												
Q1 Milestone: Infrastructure of low-pressure refrigerants												
Q2 Milestone: Fabricate and evaluate enhanced surfaces												
Go/No-Go: Demonstrate at least 10% HTC enhancement												
Current/Future Work												
Q4 Milestone: Summarize findings of pool boiling HTC												
Q2 Milestone: Pool boiling of low-pressure refrigerants												
Q4 Milestone: Empirical correlation (model development)												

Team

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