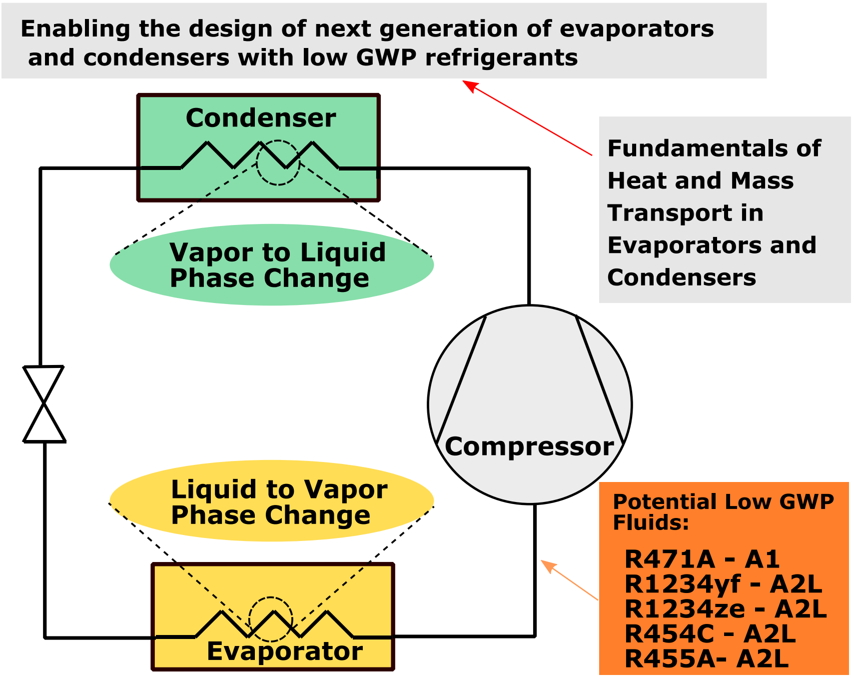
Heat Transfer and Pressure Drop Characterization of Global Warming Potential <150 Refrigerants



Oak Ridge National Laboratory
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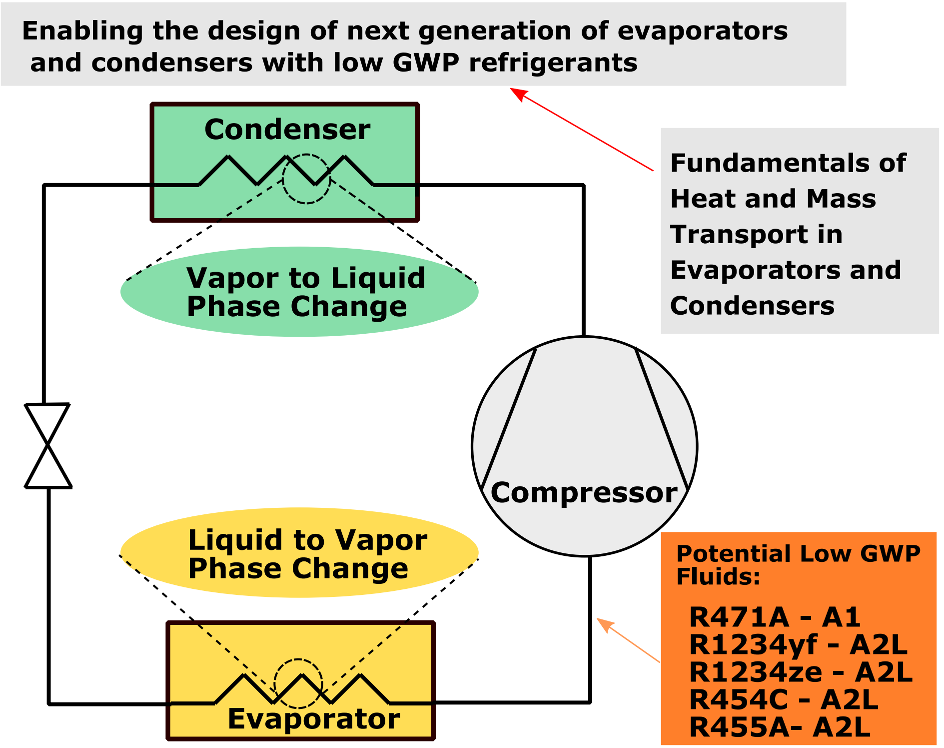
Presenter: Saad Ayub Jajja

WBS 03.02.02.38

Project Summary

Objective and outcome

- Empirically characterize the heat transfer and pressure drop of GWP < 150 refrigerants
- Assess the predictive capability of existing heat exchanger design correlations and if needed, develop new correlations
- State-of-the art facilities to evaluate flow boiling and condensation for current and future refrigerants
- Empirical data for multi-phase heat transfer and pressure drop for GWP < 150 refrigerant blends
- Design framework for the next generation of heat exchangers employing GWP < 150 refrigerant blends



Team and Partners

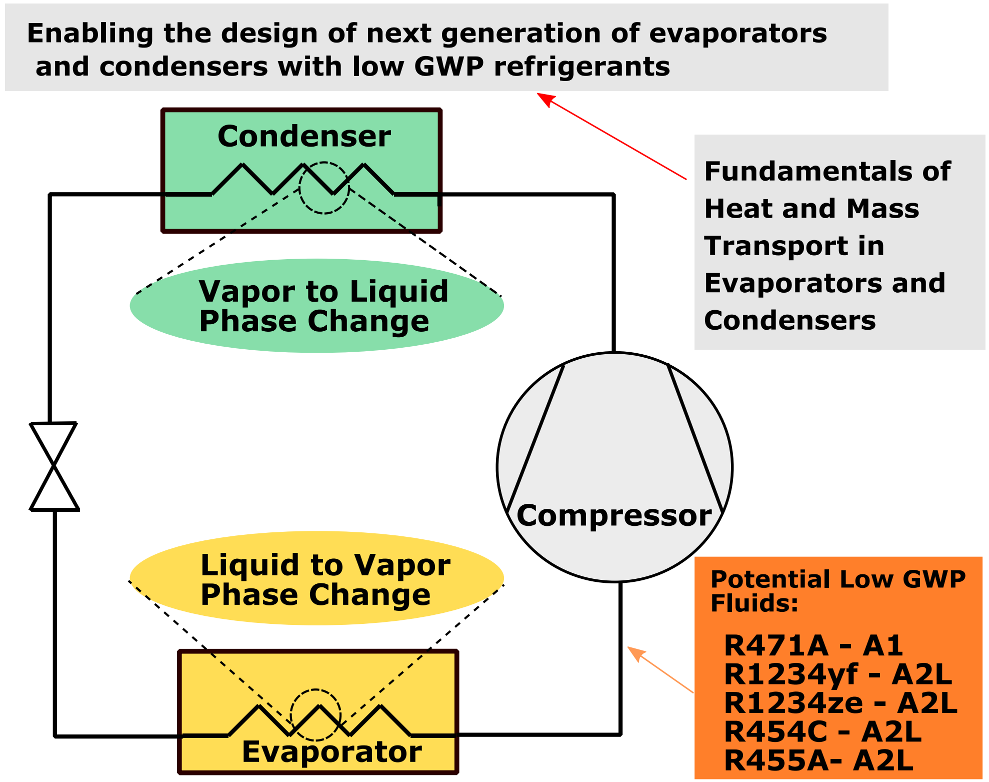
Dr. Samuel Yana Motta (Principal Investigator)
Dr. Saad Ayub Jajja
Dr. Brian Fricke

Stats

Performance Period: FY23-FY24
DOE budget: $700k/year, Cost Share: NA
Milestone 1: Critical literature review Q1 FY23
Milestone 2: Test low GWP fluids in new setup Q4 FY23
Milestone 3: Test other tube materials and geometries Q4 FY24

Problem

- Refrigeration accounts for 7.8% of the total global greenhouse gas emissions, which can be lowered to 3% by switching to refrigerants with substantially low global warming potential [1].
- Additionally, the Kigali Amendment to the Montreal Protocol requires 80% to 85% phase-out of hydrofluorocarbon-based refrigerants in the next two decades[2].
- To meet these requirements and to reduce the emissions associated with refrigerants, the heat exchanger design methods needs to be tailored for the new refrigerants
- **Improperly sized heat exchangers can lead to inefficient system operation which may increase in-direct emissions.**

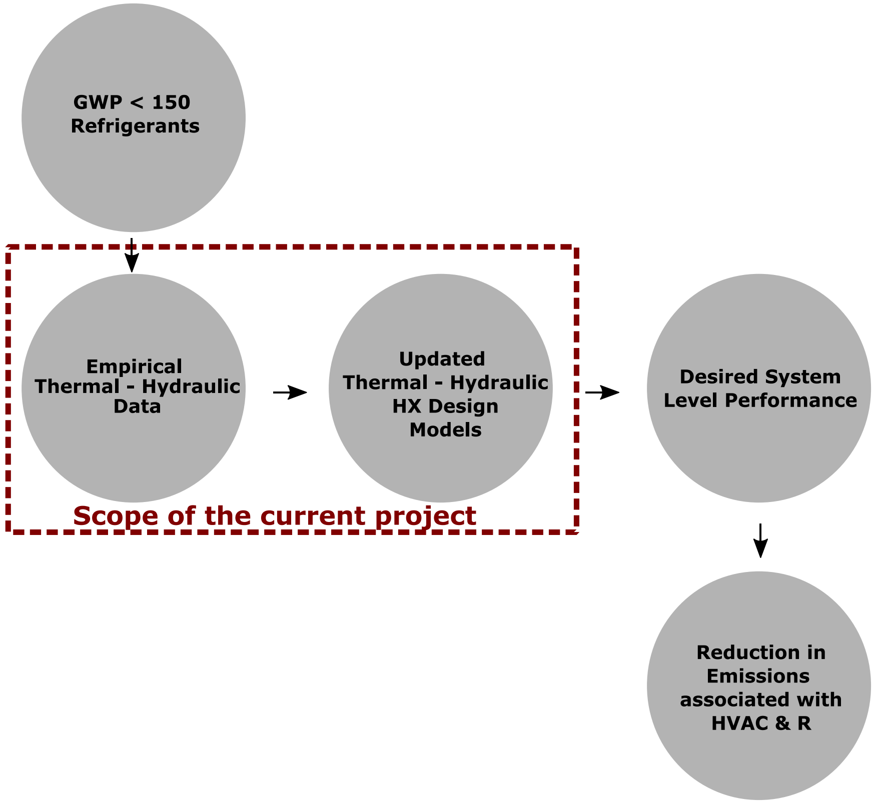


The next generation of vapor compression machines will use low-GWP refrigerants in accordance with the Kigali Amendment to the Montreal Protocol.

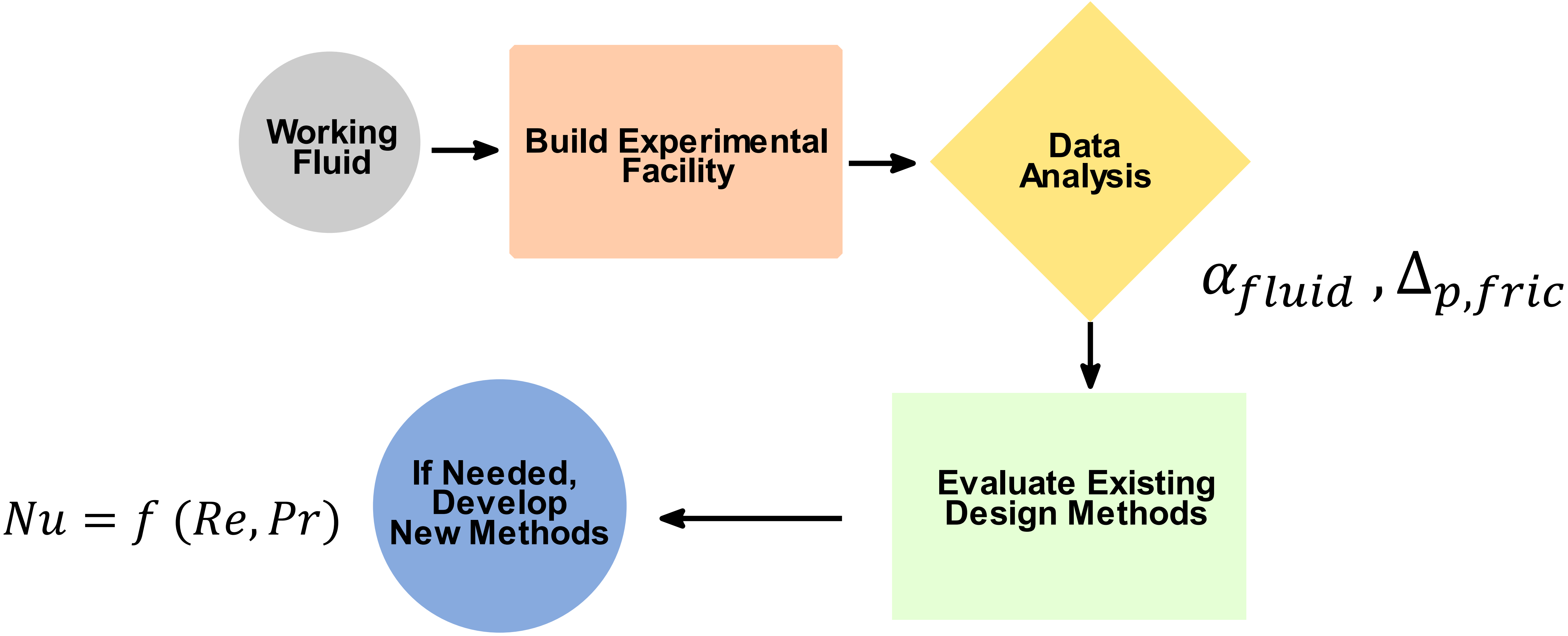
[1] **Mclinden *et al.* (2020)**, 'New Refrigerants and system configurations for vapor-compression refrigeration', ***Science*** 370, 791-796
[2] **Heath, E. A. (2017).** Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer (Kigali Amendment). ***International Legal Materials***, *56*(1), 193–205

Alignment and Impact

- The residential and light commercial A/C installed base use approximately 321,728 tons of R-410A, *which represents direct emissions of 33,000,000 tons of CO_2.* This estimate is based on leak rates of 4% per year, and an end-of-life loss of 15%.
- The database developed in this project *can reduce the direct emissions by 96.4% (32,500,000 t of CO_2).* This supports the EERE/BTO goal of 50-52% reduction in greenhouse gas emissions by 2030.
- Additionally, optimized heat exchangers, enabled by the data generated in this project, will help to lower indirect emissions. These emissions include both refrigeration and air-conditioning applications.

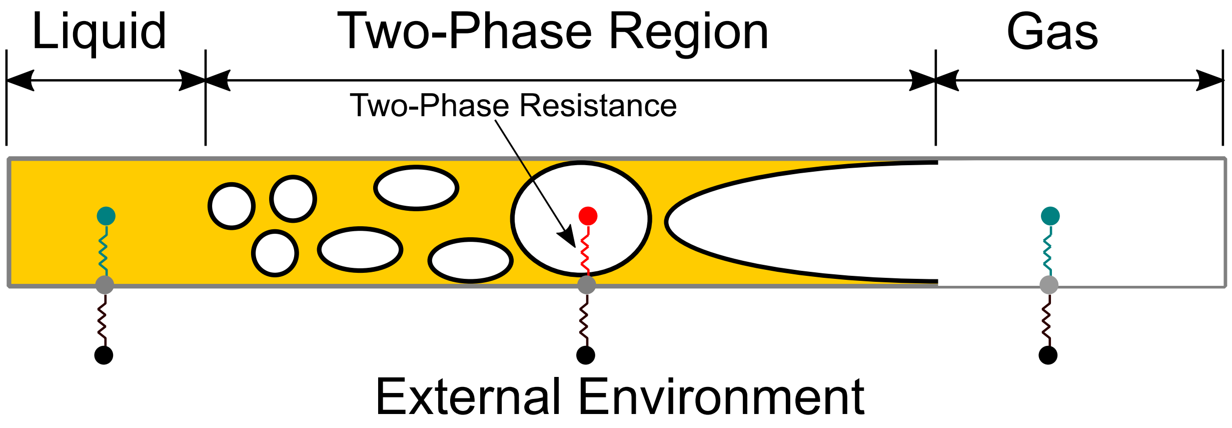


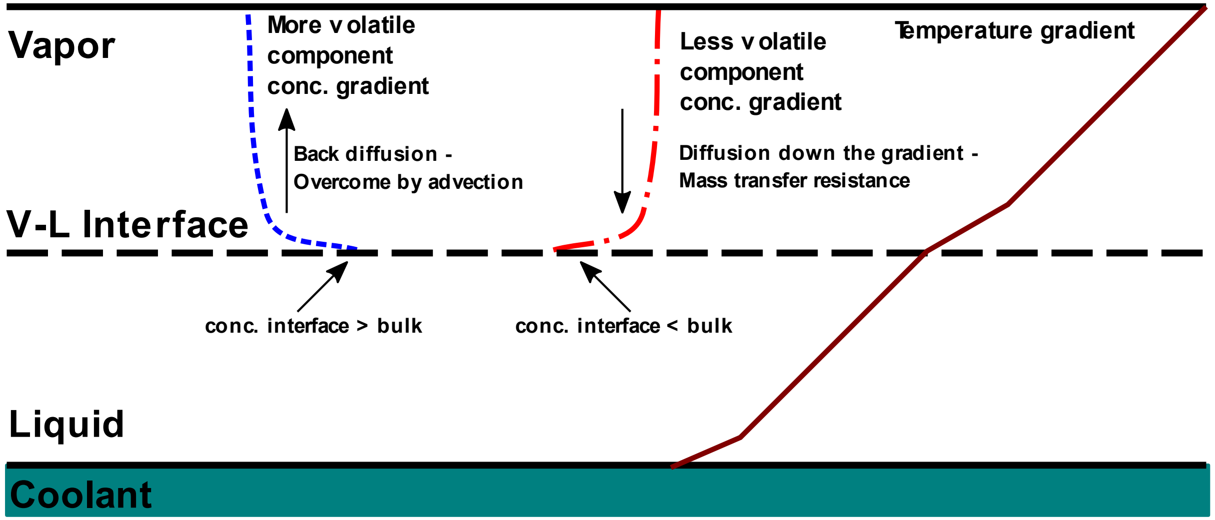
Approach


Working Fluid
Build Experimental Facility
Data Analysis
$\alpha_{fluid}, \Delta_{p,fric}$
Evaluate Existing Design Methods
If Needed, Develop New Methods
$Nu = f\ (Re, Pr)$

Why empirically test new refrigerants?

- The thermophysical properties of new refrigerants differ from the old ones –this may change the underlying flow patterns
- Mixture effects will be more pronounced in refrigerants such as R-454C when compared to R-454B
- Both of these facts require empirical heat transfer and pressure drop data to validate and update the existing design models.

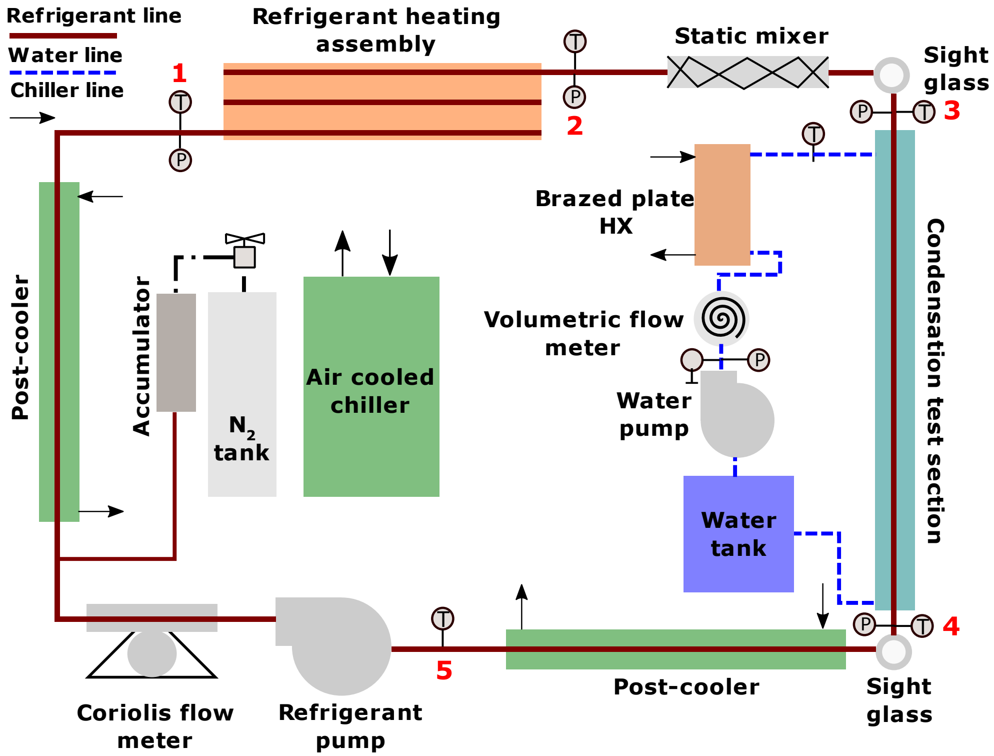


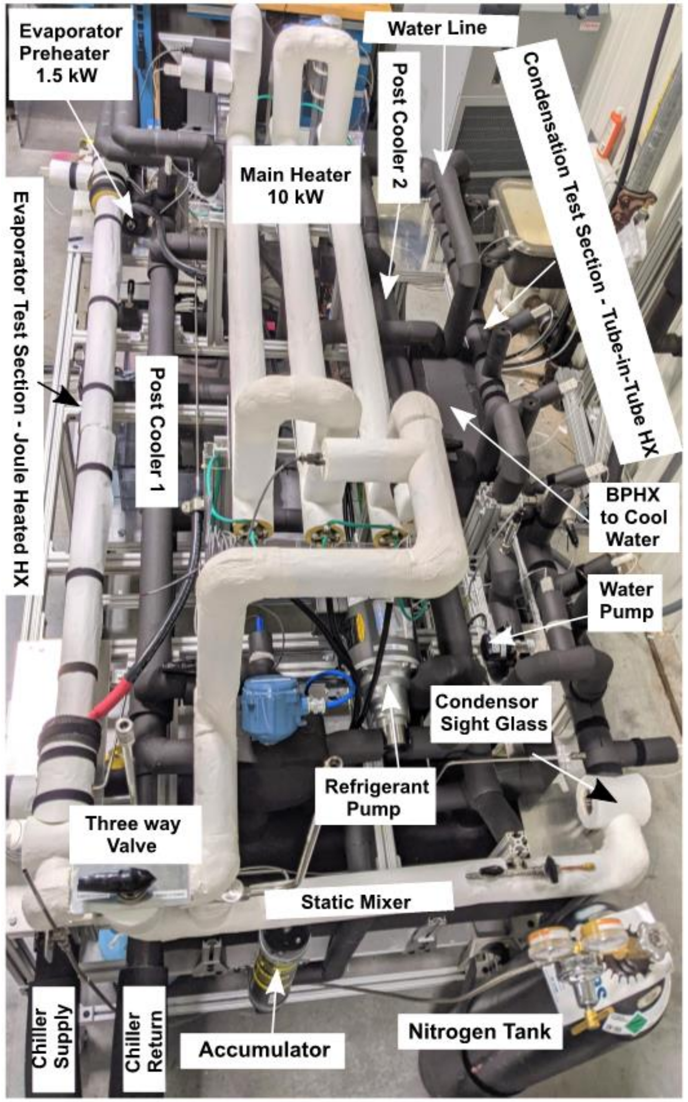


Refrigerant	$\Delta\,\rho_{lv}$ $(kg\,m^{-3})$	$\Delta\,\mu_{lv}$ $(kg\,m^{-1}s^{-1})$ $\times\;10^{-6}$	σ $(N\,m^{-1})$ $\times\;10^{-3}$
R-134a	1097	148.5	6.112
R-1234yf	976.1	114.9	4.403
R-454C	907.6	93.6	4.12

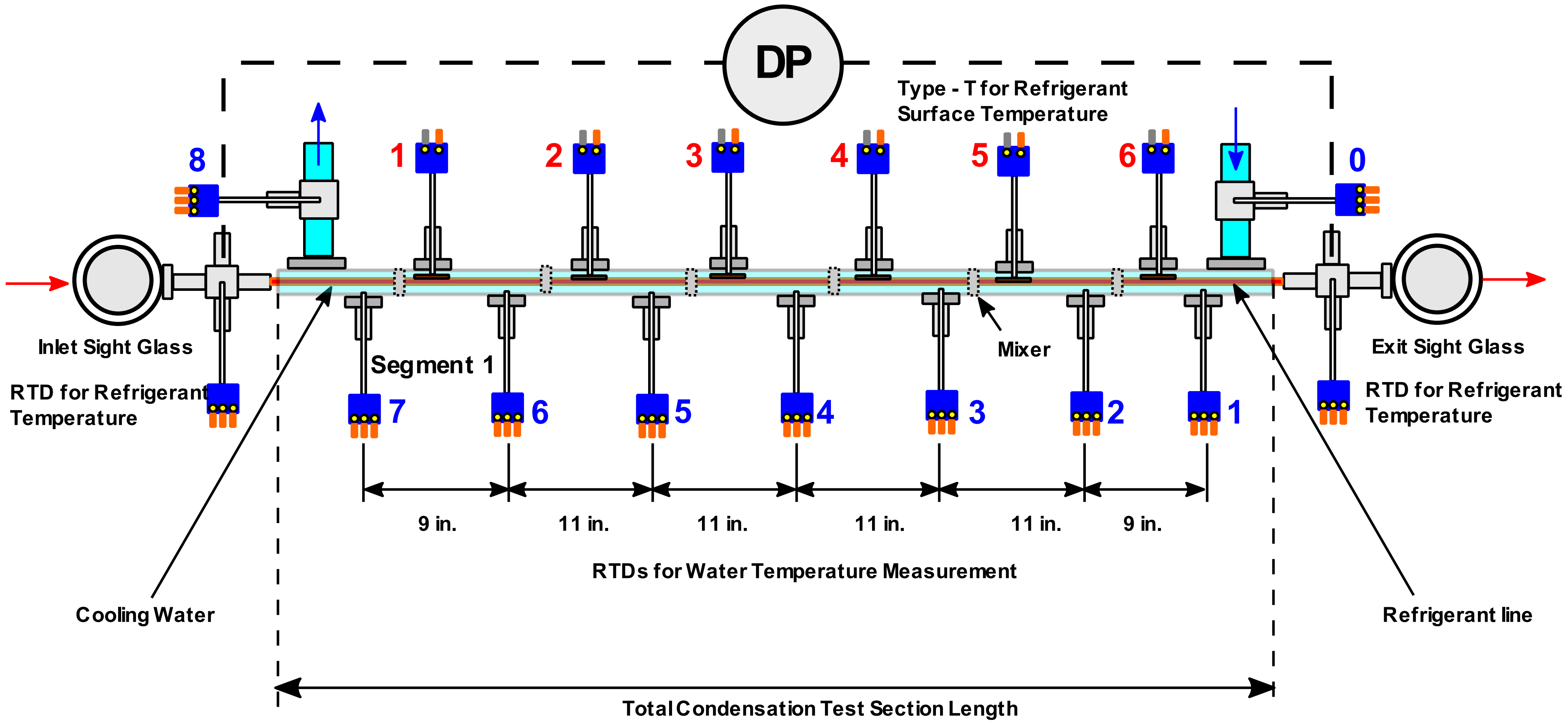
Progress – Refining of Scope

- To refine the scope of the project and to identify unique research avenues, we did some initial exploratory condensation experiments using existing capabilities at ORNL.
- Experiments were done in 9.5 mm OD smooth copper tubes and 7.2 mm OD smooth aluminum tubes using R-410A and R-454B.





Progress – Refining of Scope



Progress – Initial Testing Details

- **Aluminum tube test matrix:**
- $35\,(°C) \leq T_{cond} \leq 50\,(°C)$
- $152.7\,(kg\,m^{-2}\,s^{-1}) \leq G \leq 346\,(kg\,m^{-2}\,s^{-1})$

} R-454B

- $35\,(°C) \leq T_{cond} \leq 50\,(°C)$
- $156\,(kg\,m^{-2}\,s^{-1}) \leq G \leq 354.5\,(kg\,m^{-2}\,s^{-1})$

} R-410A

- **Copper tube test matrix:**
- $35\,(°C) \leq T_{cond} \leq 50\,(°C)$
- $95\,(kg\,m^{-2}\,s^{-1}) \leq G \leq 198\,(kg\,m^{-2}\,s^{-1})$

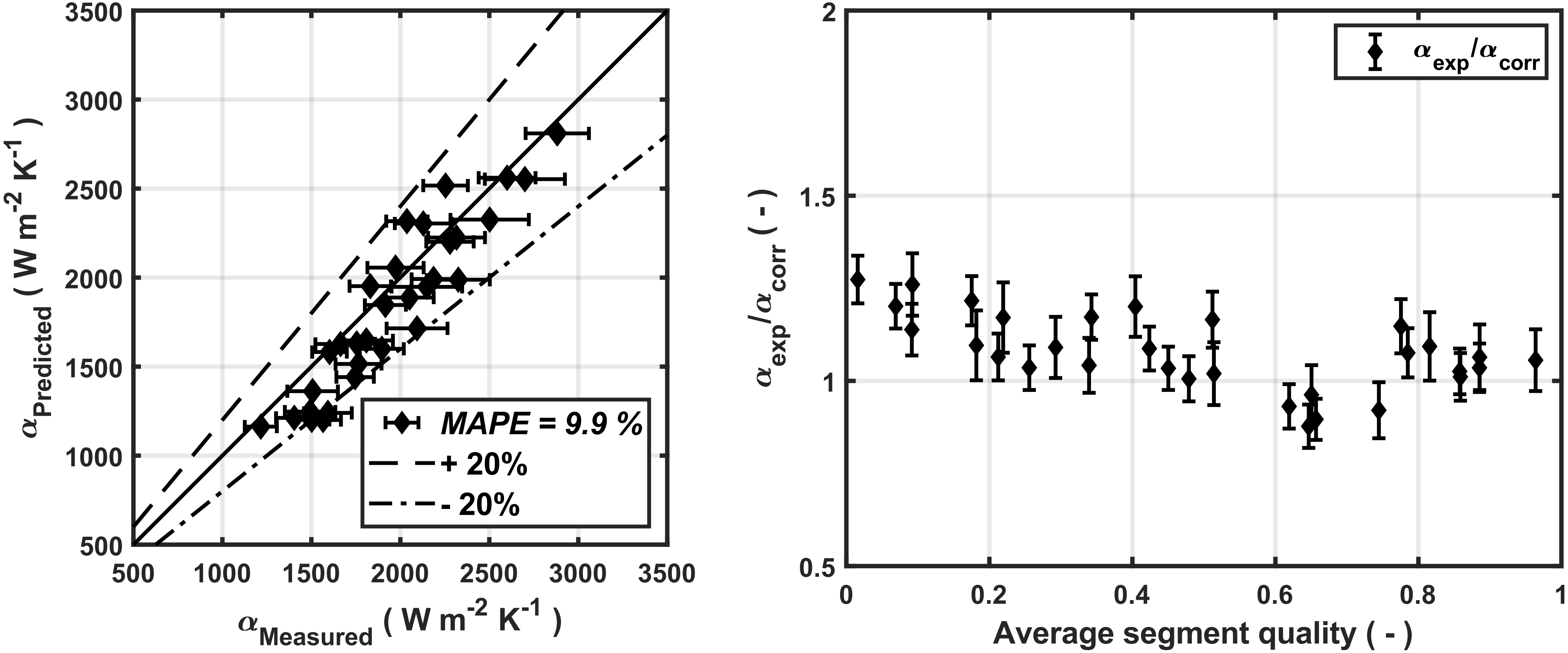
} R-454B

- $40\,(°C) \leq T_{cond} \leq 50\,(°C)$
- $111\,(kg\,m^{-2}\,s^{-1}) \leq G \leq 199.4\,(kg\,m^{-2}\,s^{-1})$

} R-410A

Progress – Initial Results

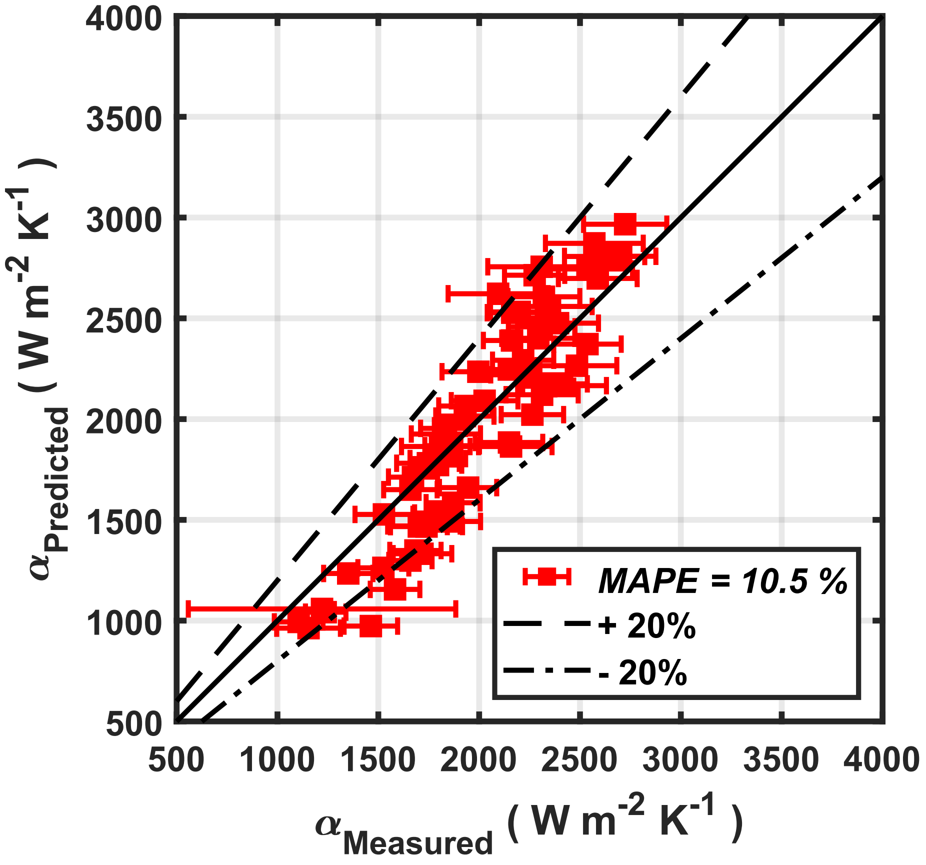
Smooth 9.5 mm OD Copper tube with **R410A** compared against Cavallini's correlation [3]

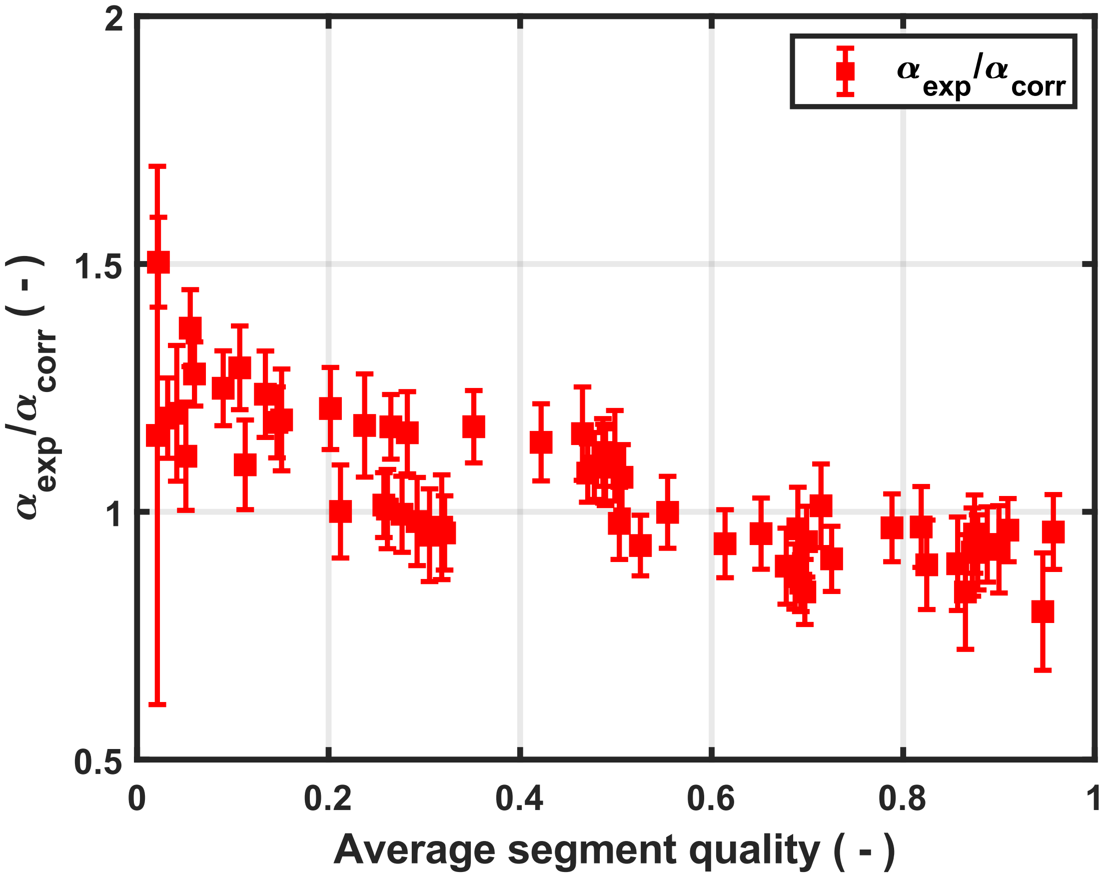


[3] Cavallini, A., Col, D. D., Doretti, L., Matkovic, M., Rossetto, L., Zilio, C., & Censi, G. (2006). Condensation in horizontal smooth tubes: a new heat transfer model for heat exchanger design. *Heat transfer engineering*, *27*(8), 31-38.

Progress – Initial Results

Smooth 9.5 mm OD Copper tube with **R454B** compared against Cavallini's correlation [3]





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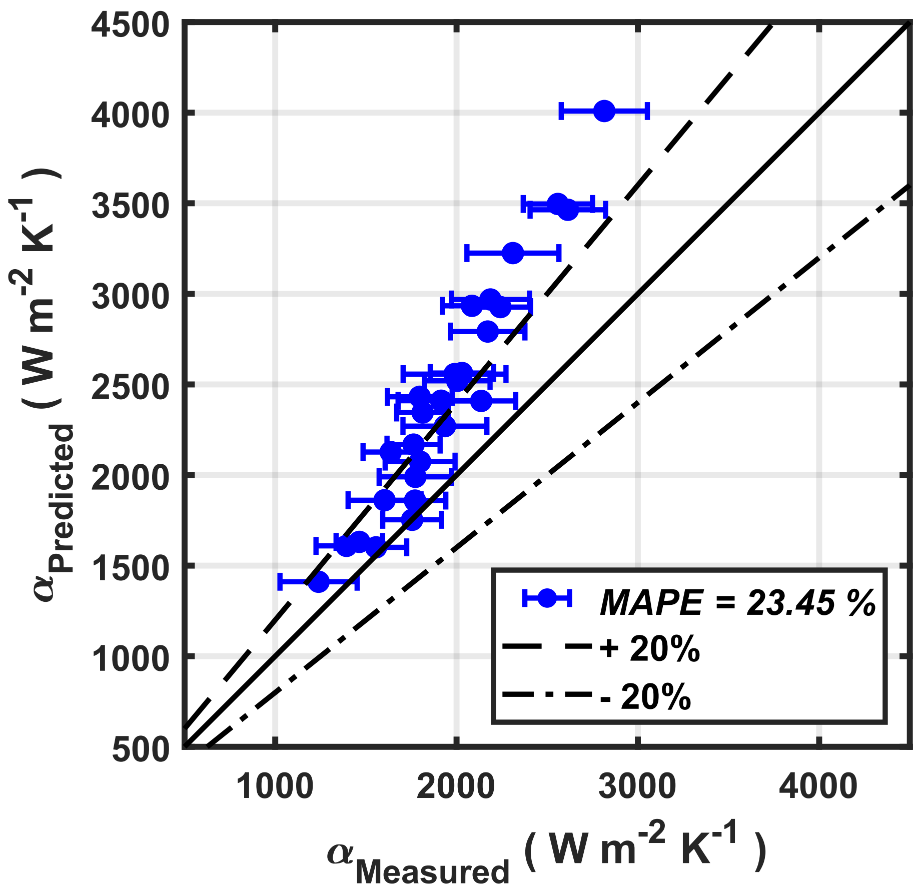
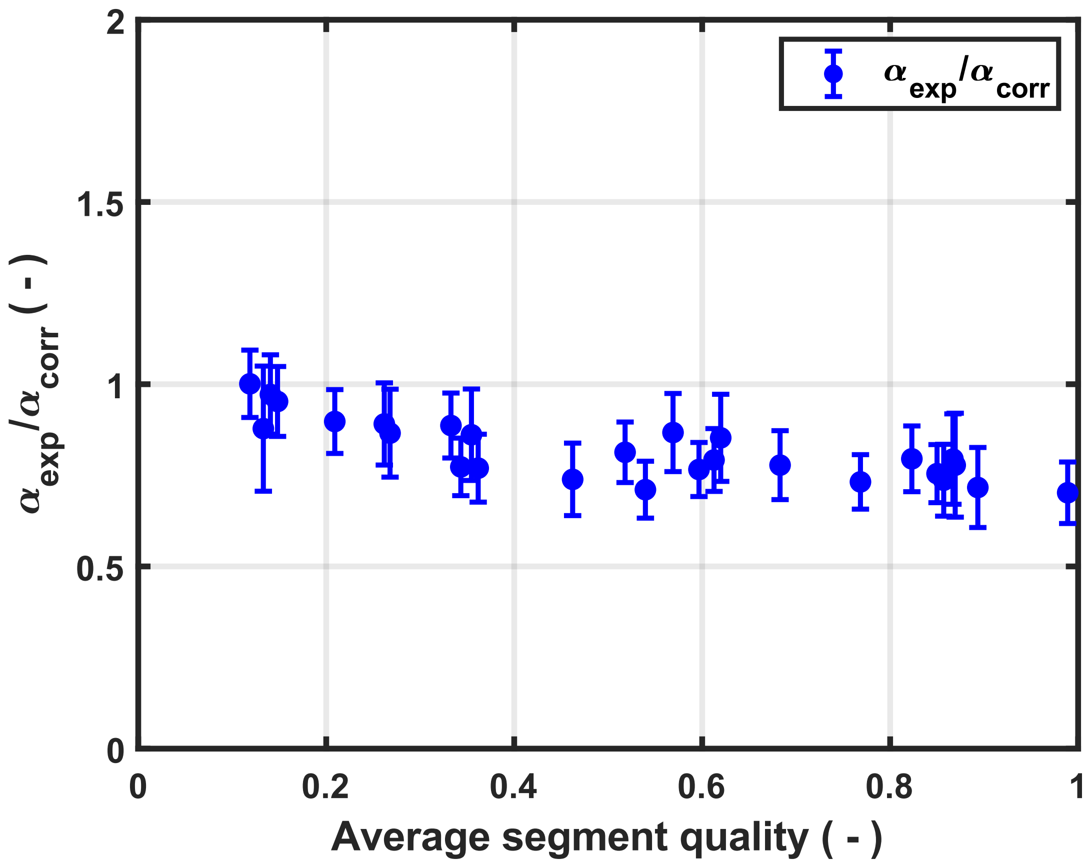
Progress – Initial Results

Smooth 7.2 mm OD Aluminum tube with **R410A** compared against Cavallini's correlation [3]





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Progress – Initial Results

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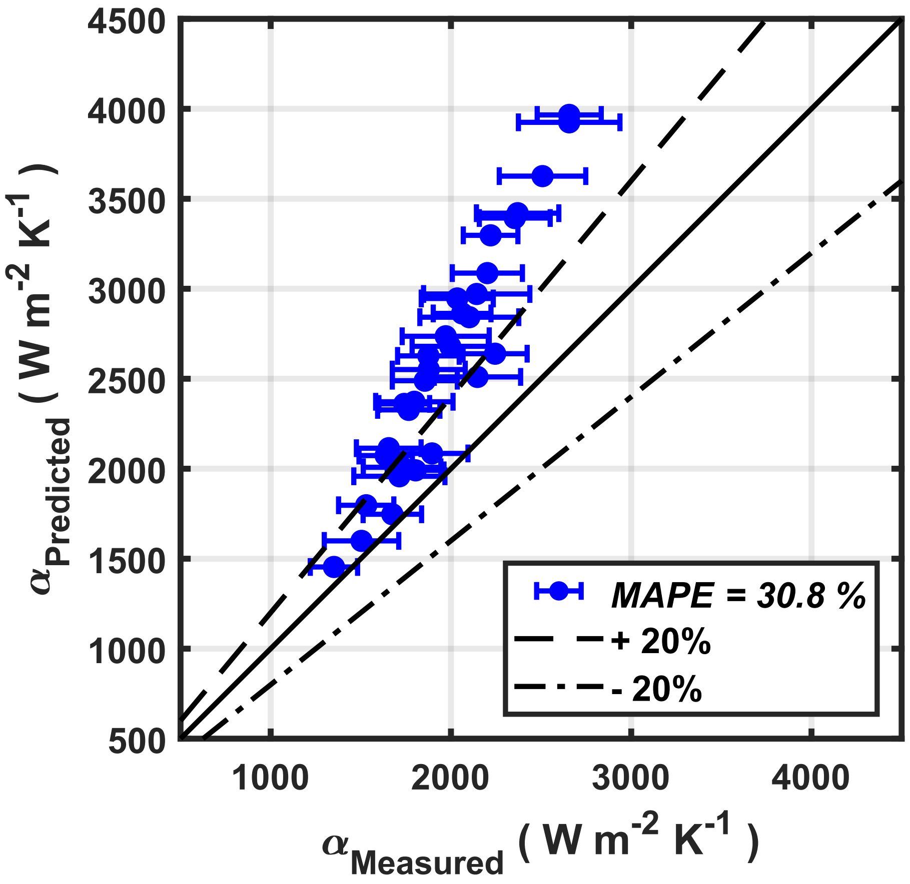

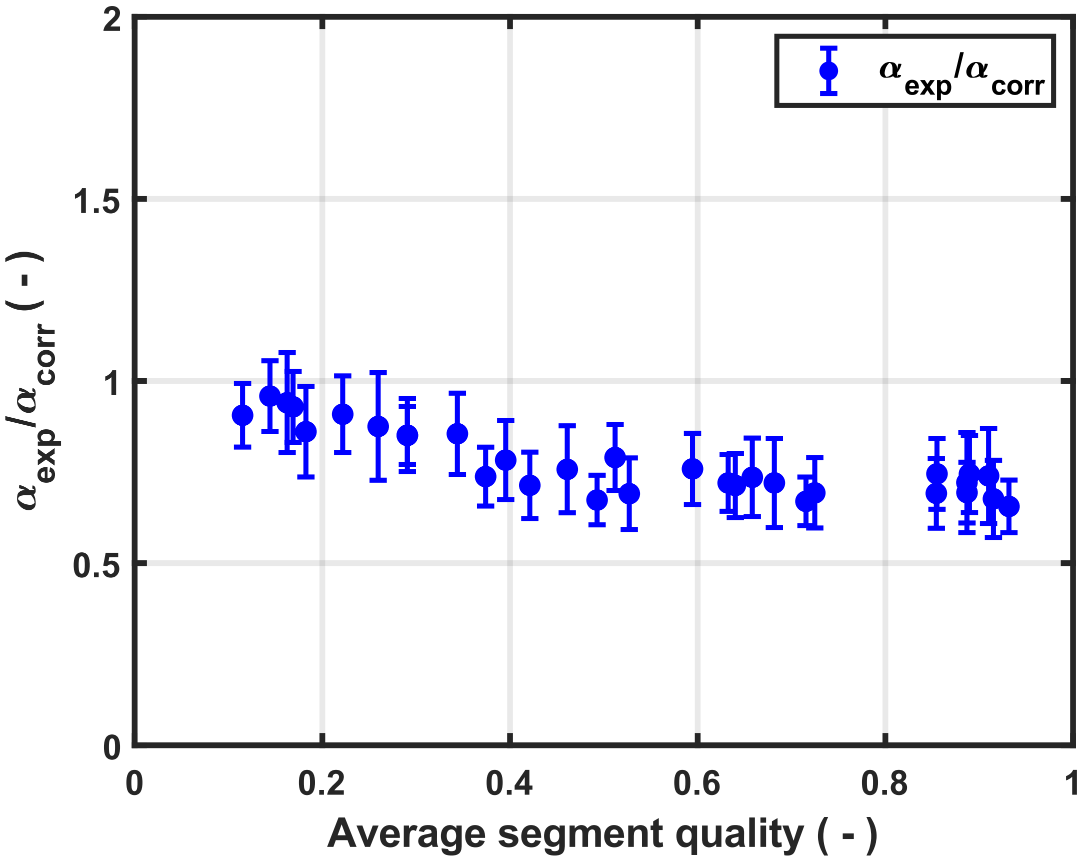

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Progress – Initial Results

Tube Geometry	R-454B vs Cavallini *MAPE*	R-410A vs Cavallini *MAPE*
9.5 mm OD Copper	10.5%	9.9%
7.2 mm OD Aluminum	30.8%	23.45%

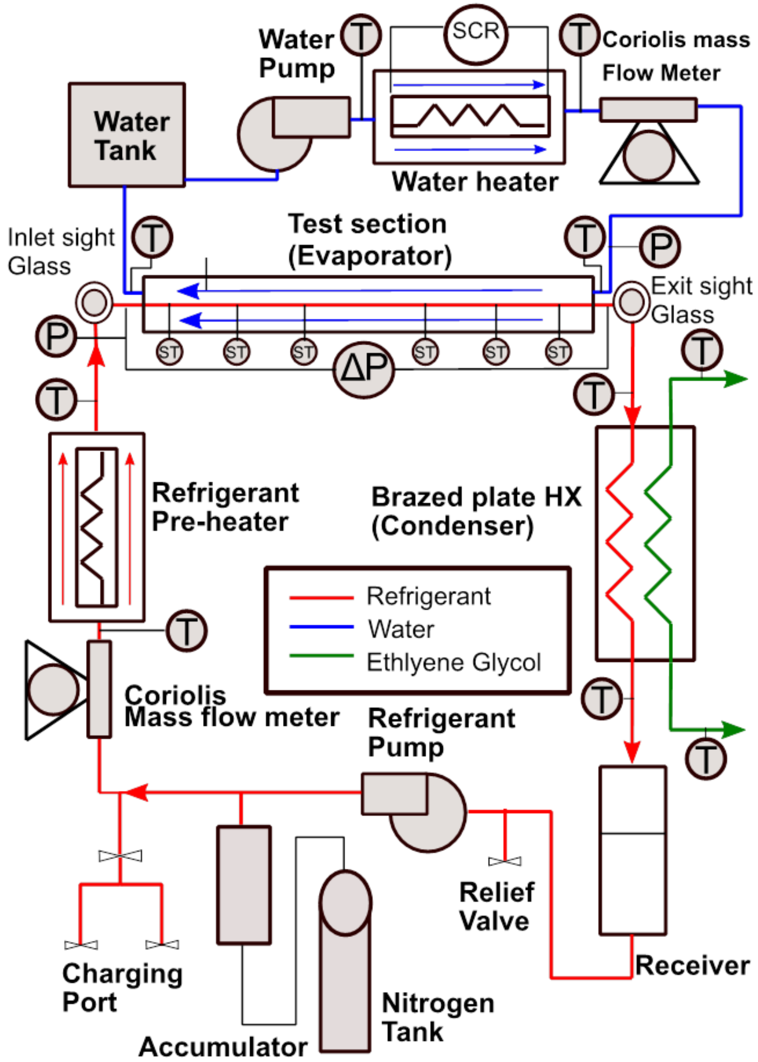
- The magnitude of axial conduction varies across the two tube materials. (the resistance to axial conduction in aluminum tubes is approximately four times higher than the copper tubes)
- It appears that when semi-empirical heat transfer correlations were developed using data obtained in copper tubes, effects of axial conduction on heat transfer were not accounted for.

Key Conclusions and Future Work Direction

1. The data for condensation and boiling heat transfer of GWP < 150 is lacking. ***This is particularly true in the case for aluminum tubes (smooth and enhanced).***
2. Our preliminary work on condensation heat transfer indicates that the correlations which predicted the condensation data for 9.5 mm copper tubes with good accuracy, appear to lose this capability for 7.2 mm OD aluminum tubes.
3. This indicates that there is a need for developing accurate heat transfer correlations for phase-change phenomena of GWP < 150 refrigerants in aluminum tubes. Additionally, data for copper tube geometries < 9 mm will be obtained

Progress on Flow Boiling Apparatus

- Shakedown testing to begin around July 2023



Challenges

- Compatibility of Aluminum tubes with water in condensation experiments. Need to investigate why this is occurring?
- Delays in some instruments for the flow boiling apparatus

Pathways to Commercialization

- We make our findings and data publicly available which is used by thermal engineers in HVAC& R industry to update their design methods.

ELSEVIER

International Journal of Refrigeration
Volume 144, December 2022, Pages 238-253

In tube condensation heat transfer and pressure drop for R454B and R32—Potential replacements for R410A ☆

Transfert de chaleur par condensation en tube et chute de pression pour le R454B et le R32 : substituts potentiels au R410A

Saad Ayub Jajja, Kashif Nawaz, Brian Albert Fricke

In tube condensation heat transfer and pressure drop for R454B and R32_potential replacements for R410A_Data.xlsx

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Version 4 Dataset posted on 2022-04-07, 17:07 authored by Saad Jajja, Kashif Nawaz, Brian Fricke

This data set accompanies the paper titled " In Tube Condensation Heat Transfer and Pressure Drop for R454B and R32--Potential Replacements for R410A" to be published in the International Journal of Refrigeration. The data set contains the test conditions for these refrigerants and the corresponding results that are reported in the paper.

HISTORY

- **2022-04-07** - First online date, Posted date

USAGE METRICS

137 views | 21 downloads | 1 citations

CATEGORIES

- Mechanical engineering not elsewhere classified

KEYWORDS

R-134a, R410A, R32, R454B, Con...

Mechanical Engineering

Thank you

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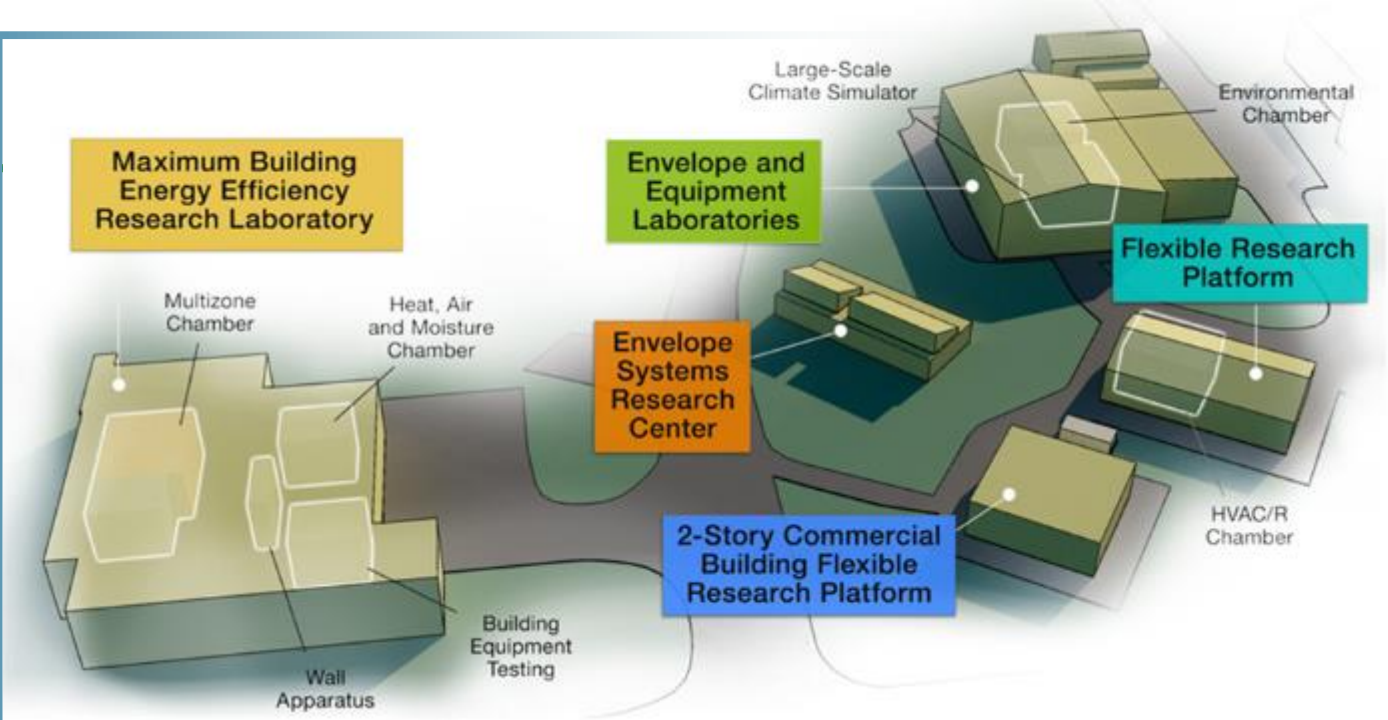

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Scientific and Economic Results

236 publications in FY22
125 industry partners
54 university partners
13 R&D 100 awards
52 active CRADAs

BTRIC is a DOE-Designated National User Facility

REFERENCE SLIDES

Project Execution

Required to complete, but does not count towards total slide count and doesn't need to be focused on during presentation

	FY20XX				FY20YY				FY20ZZ			
Planned budget												
Spent budget												
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q1 Milestone: Example 1												
Q2 Milestone: Example 2 (◆ is planned date of milestone)												
Q3 Milestone: Example 3												
Q4 Milestone: Example 4												
Q1 Milestone: Example 5												
Current/Future Work												
Q3 Milestone: Example 6												
Q4 Milestone: Example 7												
Insert more Milestones as needed												

- Go/no-go decision points
- Explanation for slipped milestones and slips in schedule