EHD Driven Smart Vapor Compression Cycle

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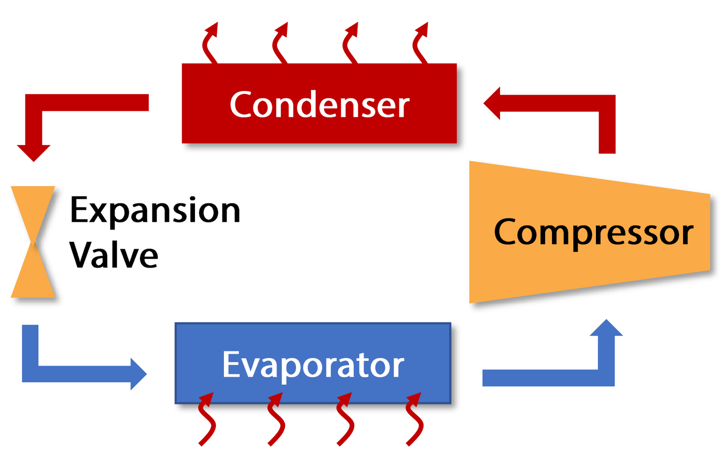
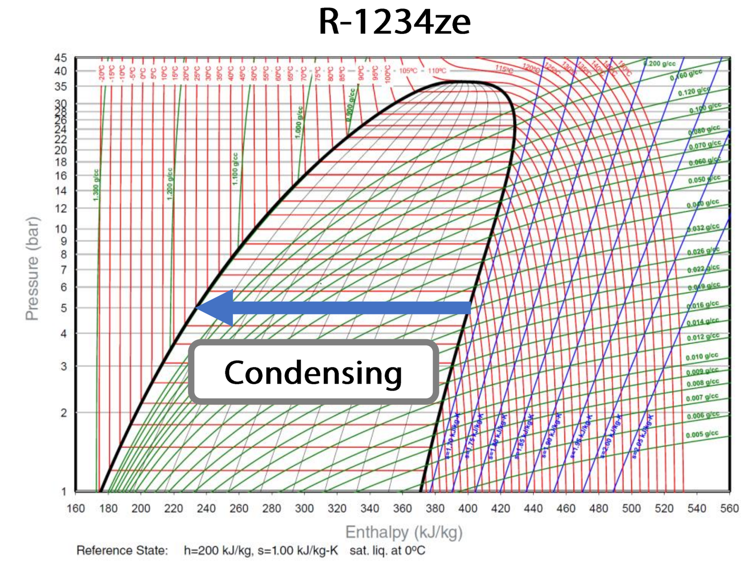
Vapor Compression Cycle Introduction

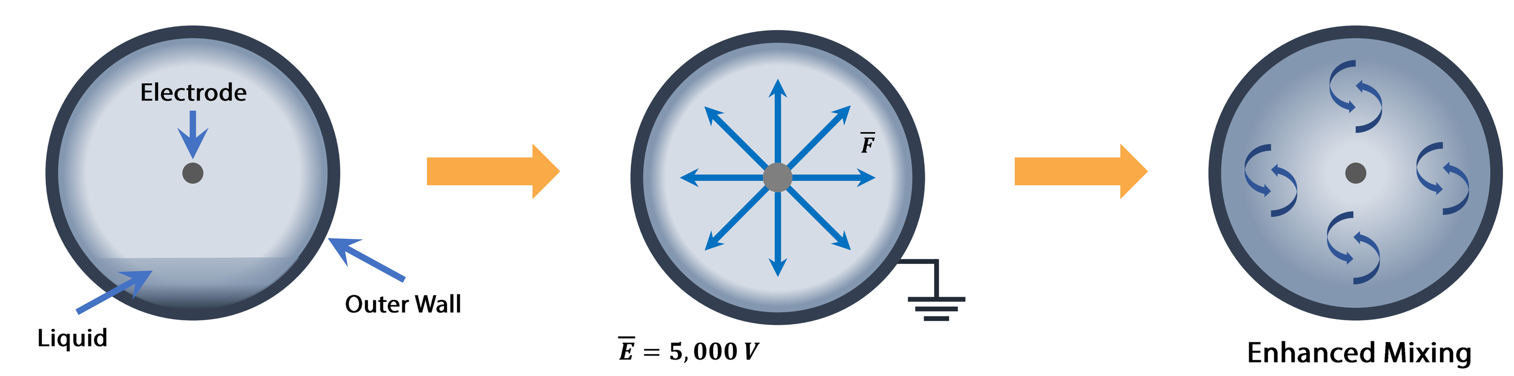
- The Vapor Compression Cycle (VCC) drives modern living: refrigerators, air conditioners, dryers, atmospheric water collection, and more.
- VCC systems are energy intensive, accounting for 22.6% of residential and 25.5% of commercial electricity use in the US.[1] Small efficiency increases could lead to large global energy savings.
- This project seeks to improve the efficiency in the condenser section of the VCC, where refrigerant vapor is cooled.



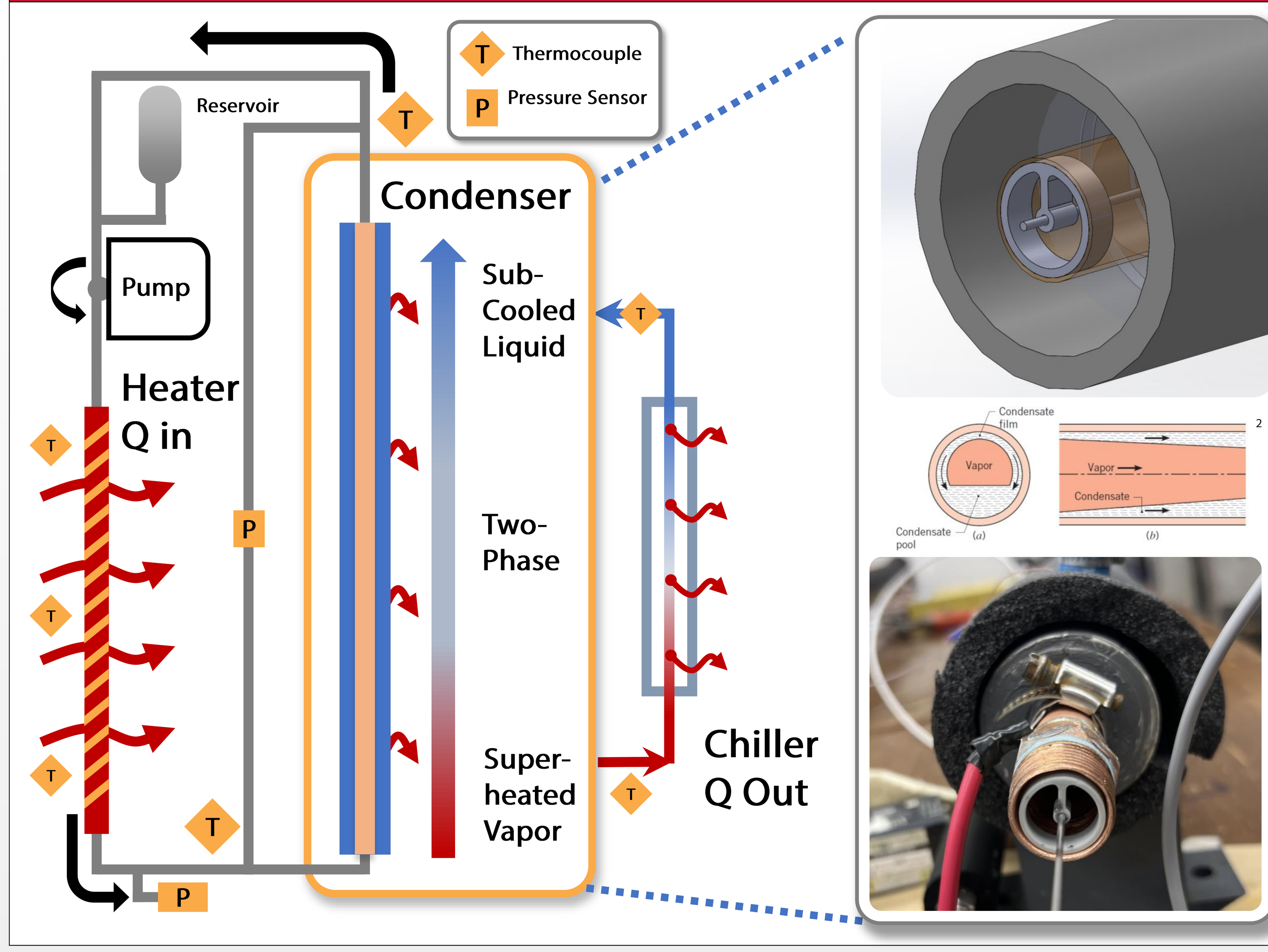


EHD Background

- Electrohydrodynamics (EHD) is the interaction between fluids and electrical fields.
- The EHD Body Force: $f_e = \rho_e \boldsymbol{E} \underbrace{- \frac{1}{2} E^2 \nabla \varepsilon}_{\text{DEP Force}} + \frac{1}{2} \nabla \left[E^2 \left(\frac{\partial \varepsilon}{\partial \rho} \right)_T \rho \right]$
- This experiment takes advantage of the Dielectrophoretic (DEP) Force, caused by differences in the electric permittivity in the refrigerant.
- Vapor phase refrigerant with low electric permittivity will be attracted toward the low electric field of the grounded tube, where it may be cooled faster.
- Meanwhile, liquid phase refrigerant with high electric permittivity will be attracted toward the high electric field at the center.

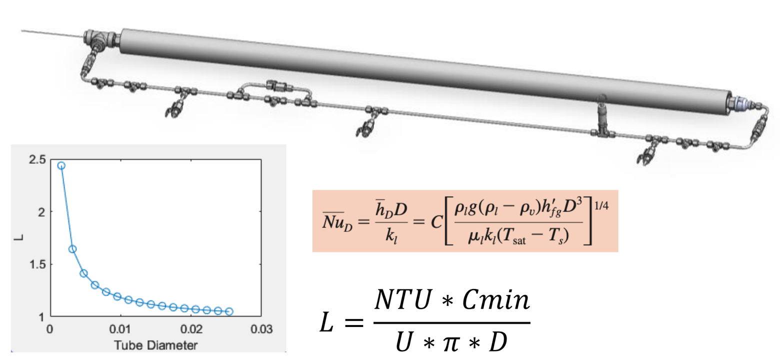


Experimental Condenser Schematic

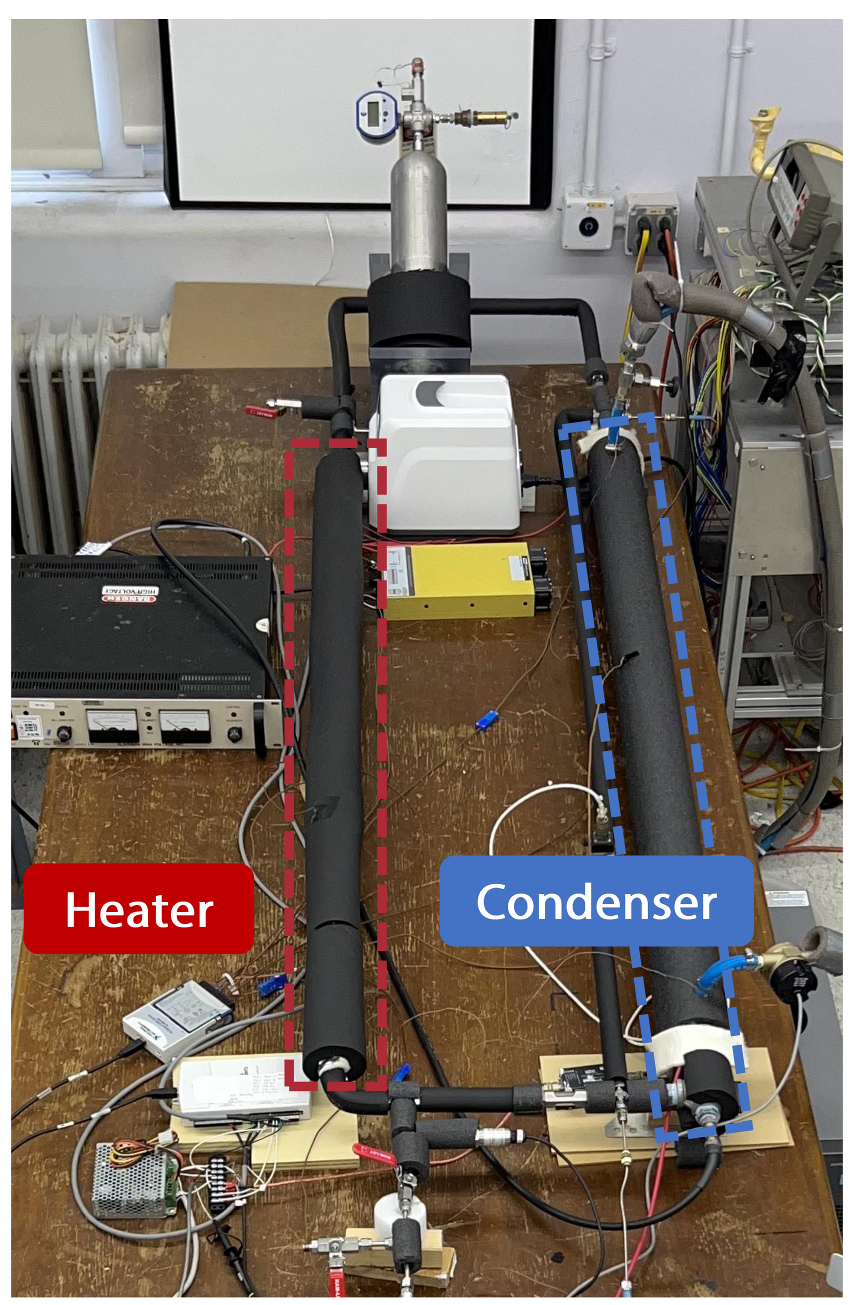


Experimental Setup

This system was designed, optimized, and fabricated from scratch to implement and test EHD in the condenser.

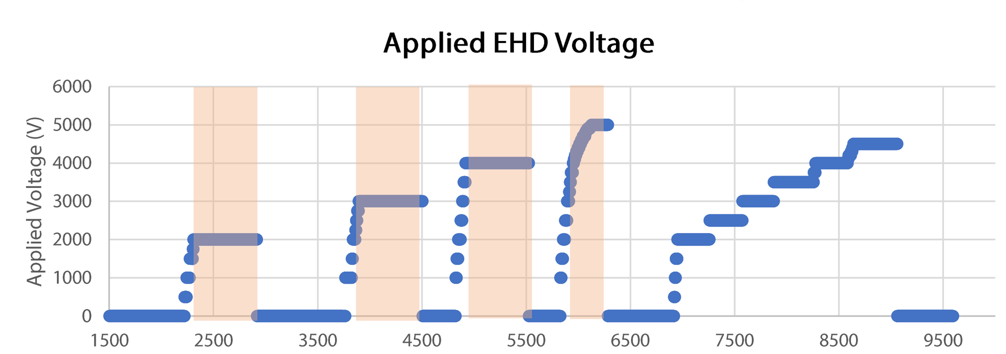


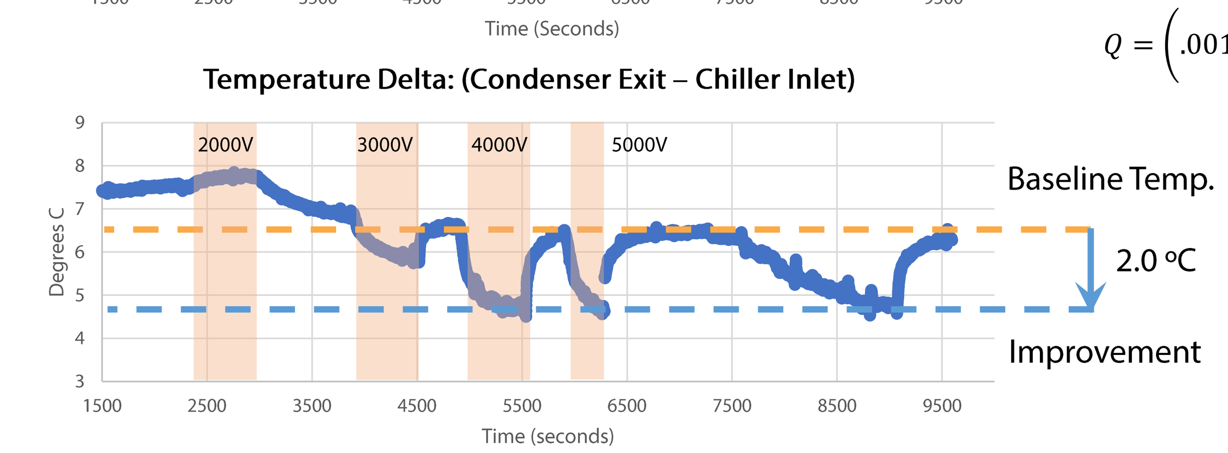
- Calculated required length and optimized 0.75" tube diameter
- Working Fluid: R-1234ze, ultra-low Global Warming Potential.
- System pressure: 5 atmospheres.
- 200 W of heat added and refrigerant superheated.
- Shell and tube heat exchanger sub-cooled refrigerant.
- Recorded condenser temperatures and pressures with LabView data acquisition tools.

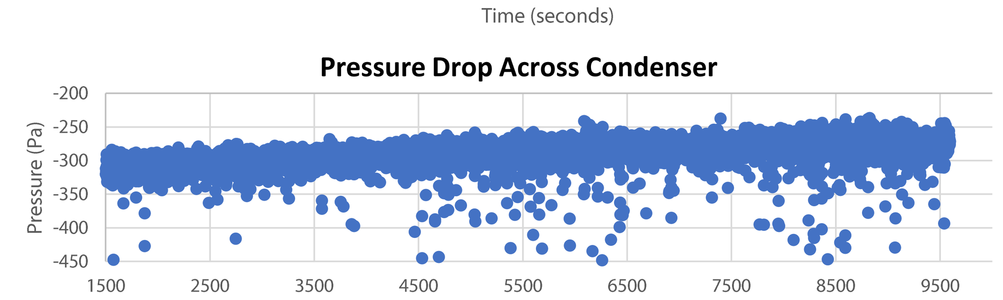


Experimental Results

- Condenser exit temperature and pressure drop was compared at various EHD voltages.
- 5 kV EHD achieved until sparking inside tube.







Heat Transfer Analysis:

In single-phase liquid zone, **2.87** W is saved using EHD:

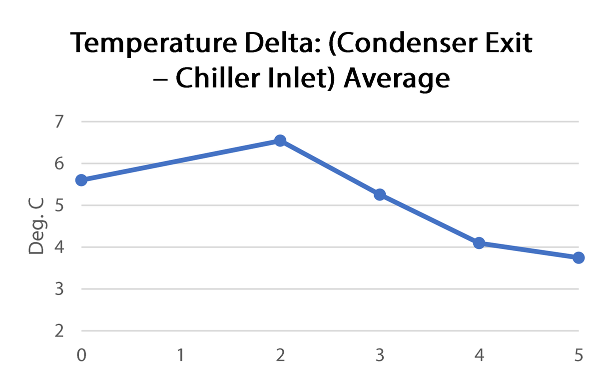
$$Single\ Phase\ Mass\ Balence:\ Q = \dot{m} c_p \Delta T$$

$$Q = \left(.00118 \frac{kg}{s}\right)\left(1383 \frac{J}{kg*K}\right)(25 - 13.5) = 18.77\text{ W}$$

$$Q = \left(.00118 \frac{kg}{s}\right)\left(1383 \frac{J}{kg*K}\right)(25 - 15.25) = 15.9\text{ W}$$

EHD Power Consumed: $P = V * I$

$$P = 5000V * 0.01mA = 0.05\text{ W Consumed}$$



Conclusions

- An experimental VCC condenser with integrated EHD technology was designed, optimized, and constructed.
- Condenser was operated at various levels of EHD interaction.
- **Condenser successfully achieved high-voltage EHD operation.**
- **Heat exchanger performance was measured to be higher with integrated EHD technology.**
- **Power savings were achieved with EHD applied.**

Acknowledgements

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[1] "Use of Electricity - U.S. Energy Information Administration (EIA)." Accessed April 10, 2023. https://www.eia.gov/energyexplained/electricity/use-of-electricity.php.

[2] Bergman, T. L., and Frank P. Incropera, eds. *Fundamentals of Heat and Mass Transfer.* 7th ed. Hoboken, NJ: Wiley, 2011.

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