POOL BOILING ON 3D-PRINTED SURFACES

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INTRODUCTION

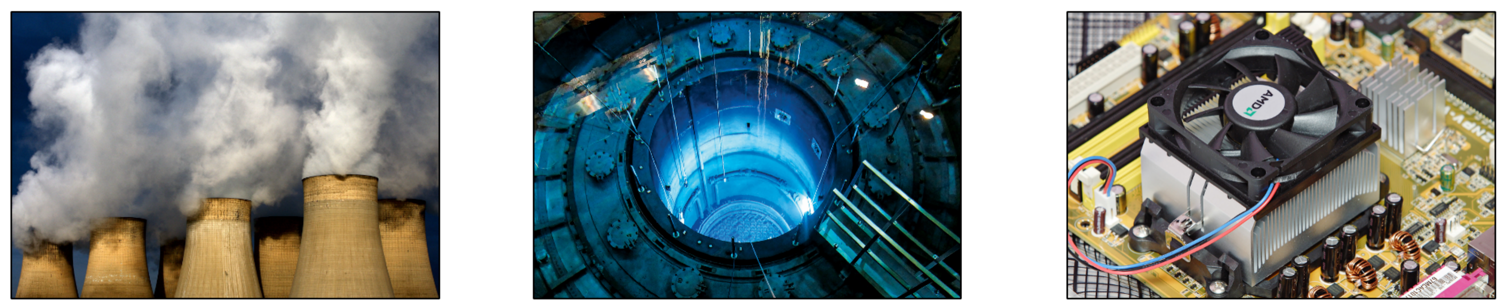

Figure 1. Thermal Management Challenges Across Applications.

- Efficient cooling is critical across scales, from power plants & nuclear reactors to compact electronics (Fig. 1).
- Pool boiling, a key strategy for thermal management, enables efficient, passive, & scalable heat removal.

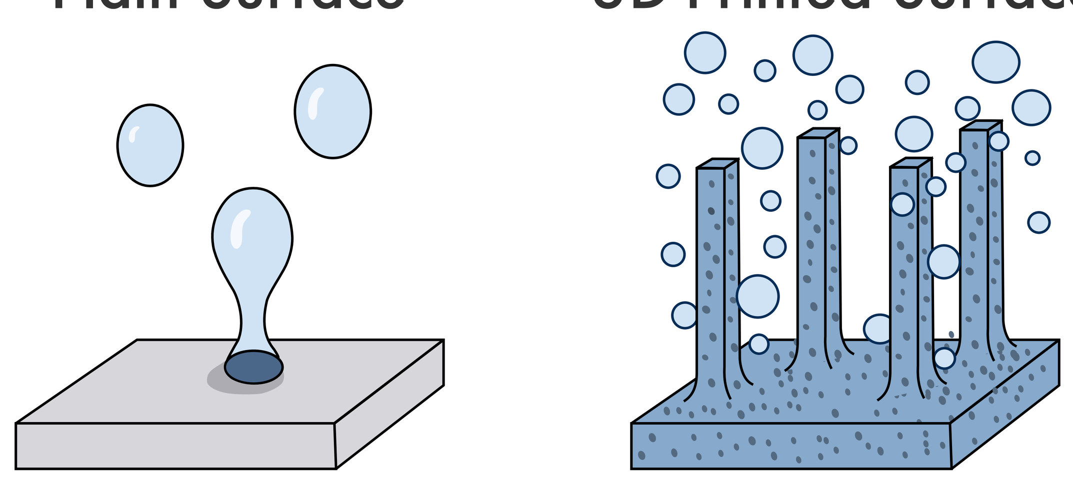

Figure 2. Plain vs 3D-Printed Surface Showing Enhanced Bubble Generation.

- 3D-Printed Surface Improves Boiling by Adding Roughness & Porosity for Better Heat Transfer (Fig. 2).
- Fused Deposition Modeling (FDM) Creates 3D-Printed Surfaces that Enhance Heat Transfer (Fig. 3).

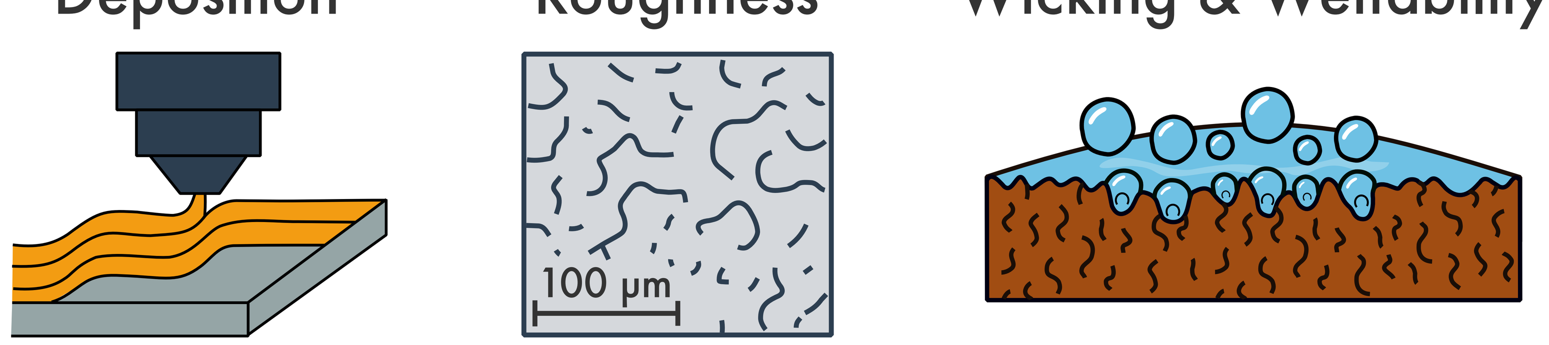

Figure 3. FDM Capabilities for Boiling Applications.

ACKNOWLEDGMENTS

Dr.Abishek Balsamy-Kamaraj, Grand Valley State University
Saketh Merugu, The University of Toledo
Samuel Joel Menzie, Grand Valley State University

METHODS

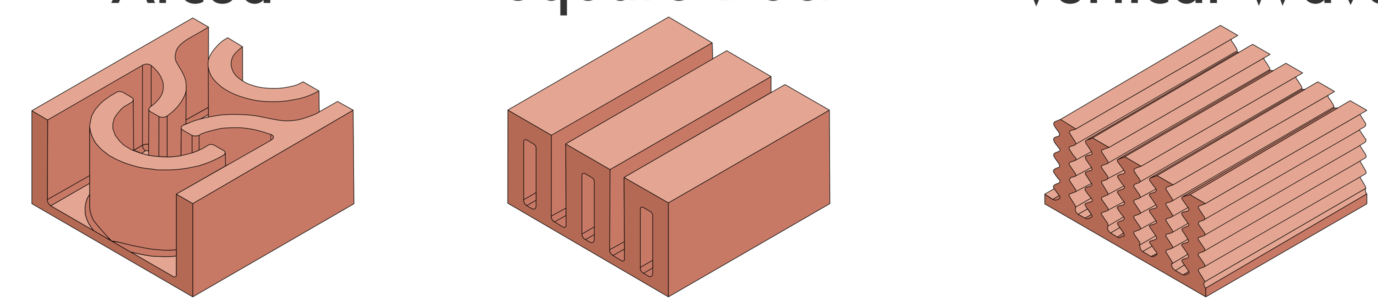

Figure 4. 3D-Printed Surfaces with Three Distinct Geometries.

- Three 3D-printed surfaces (Fig. 4) were fabricated on the Markforged Metal X & post-processed (Fig. 5).

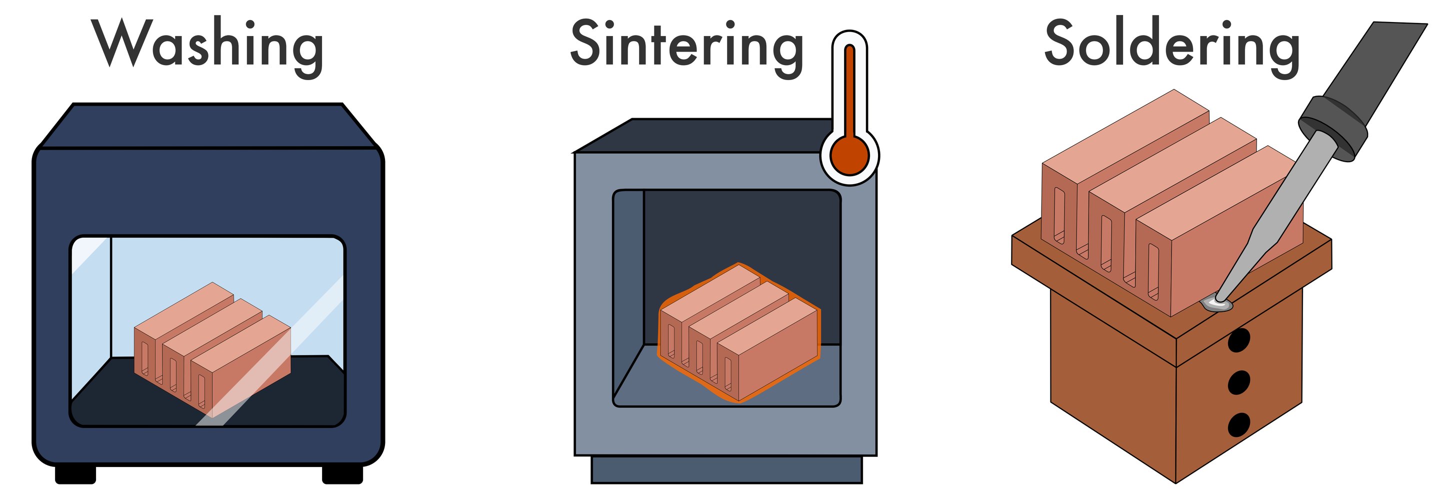

Figure 5. Post-Processing of 3D-Printed Surfaces.

- A cartridge heated copper block with thermocouples was used with a reservoir & condenser (Fig. 6). Working fluids: DI water, ethanol, & their binary mixtures.
- Heat flux was calculated via Fourier's law. Critical heat flux (CHF) enhancement factor (ER_{CHF}) quantified boiling performance vs plain copper, defined as:

$$ER_{CHF} = q''_{CHF,\ Enhanced}/q''_{CHF,\ Plain}$$

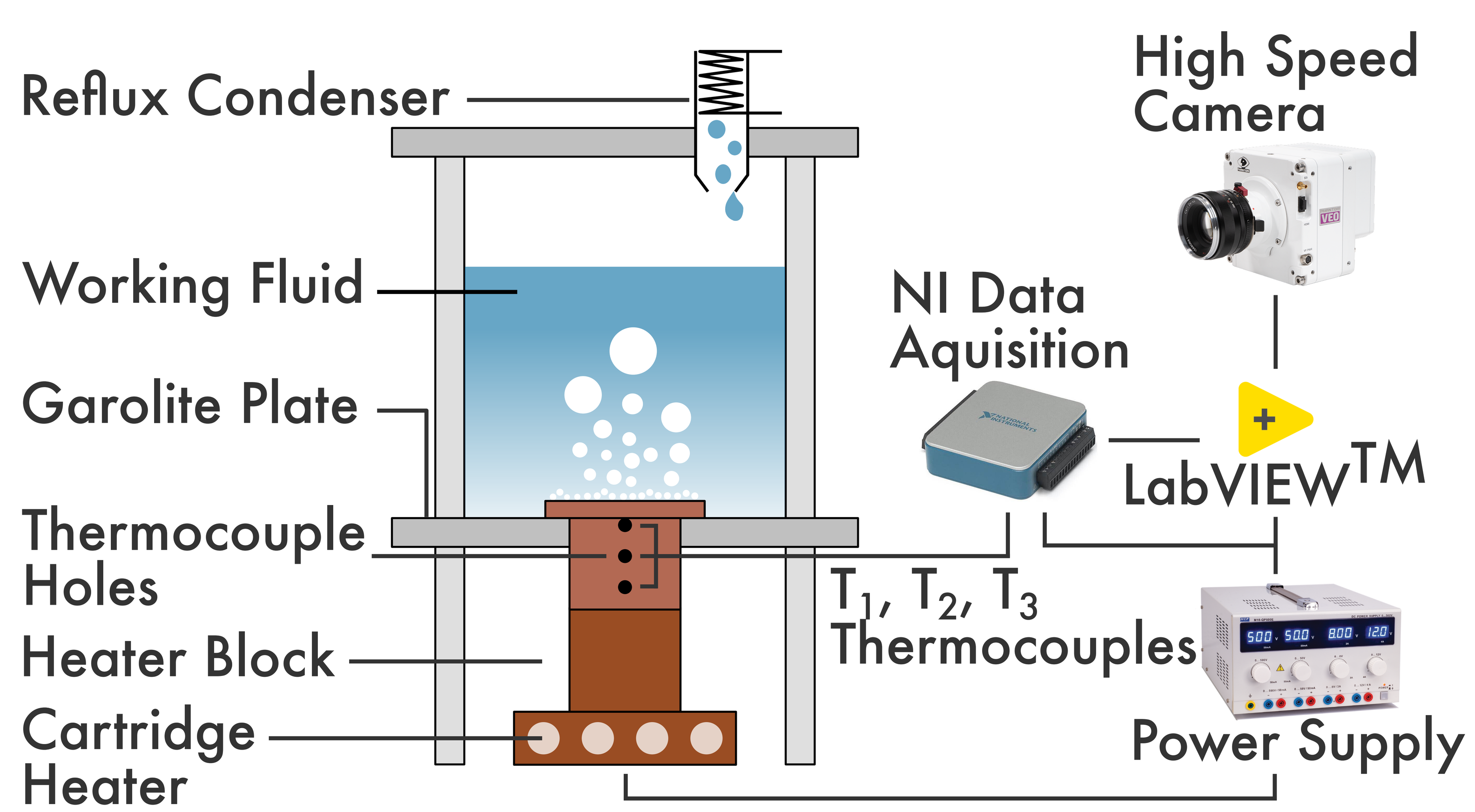

Figure 6. The Experimental Pool Boiling Setup.

RESULTS & DISCUSSION

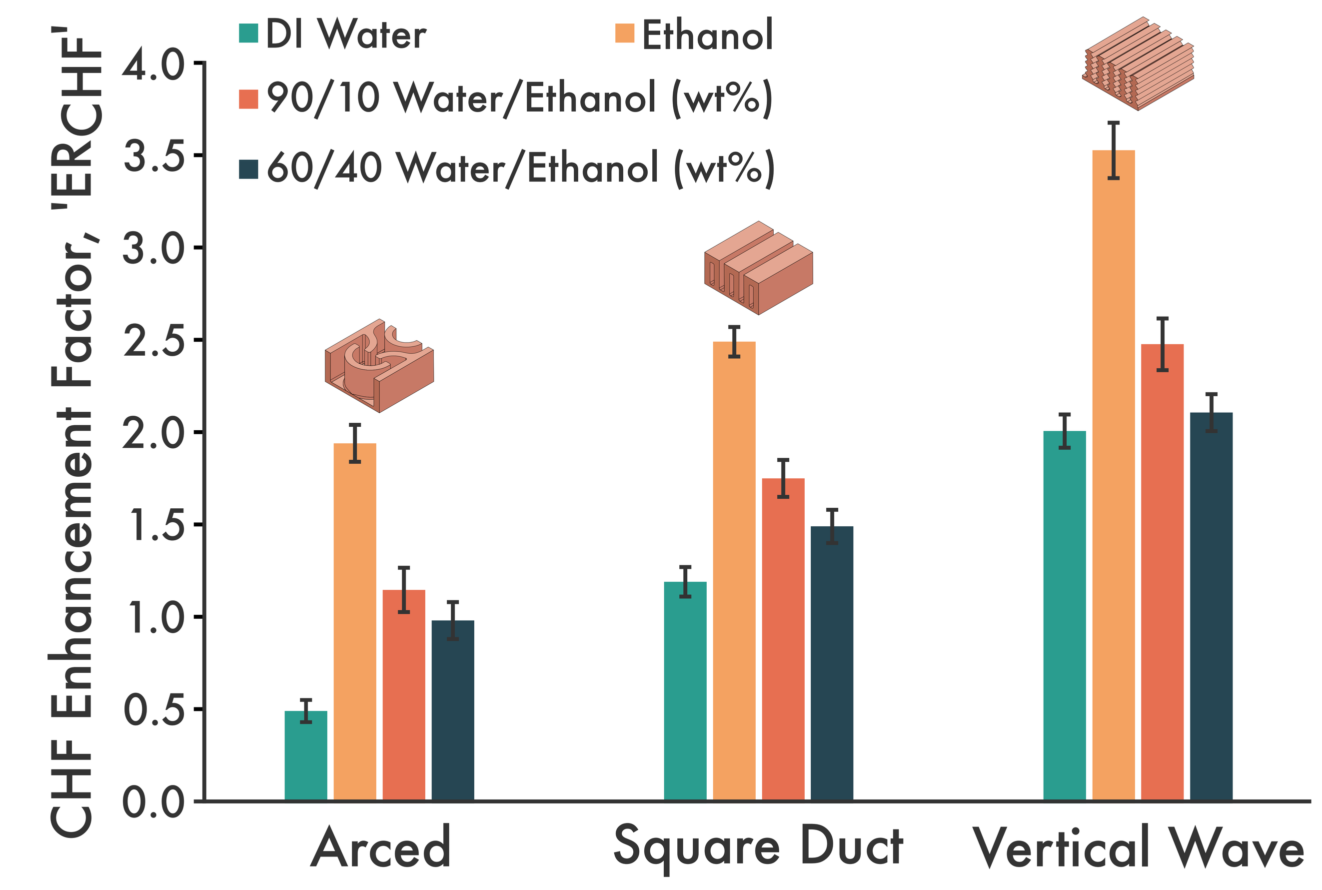

Figure 7. ER_{CHF} of 3D-Printed Surfaces with Different Working Fluids.

- $ER_{CHF} > 1$ indicate enhanced cooling.
- Vertical wave surface achieved the highest CHF enhancement factor ($ER_{CHF} \approx 3.53$) with ethanol (Fig. 7).

Figure 8. Electron Microscopy Images of 3D-Printed Surfaces.

- Vertical wave surface has the highest roughness (Fig. 8), enhancing bubble nucleation, wicking, and detachment.
- High-speed visuals (Fig. 9) revealed bubble dynamics & liquid resupply on vertical wave, proving its superiority.

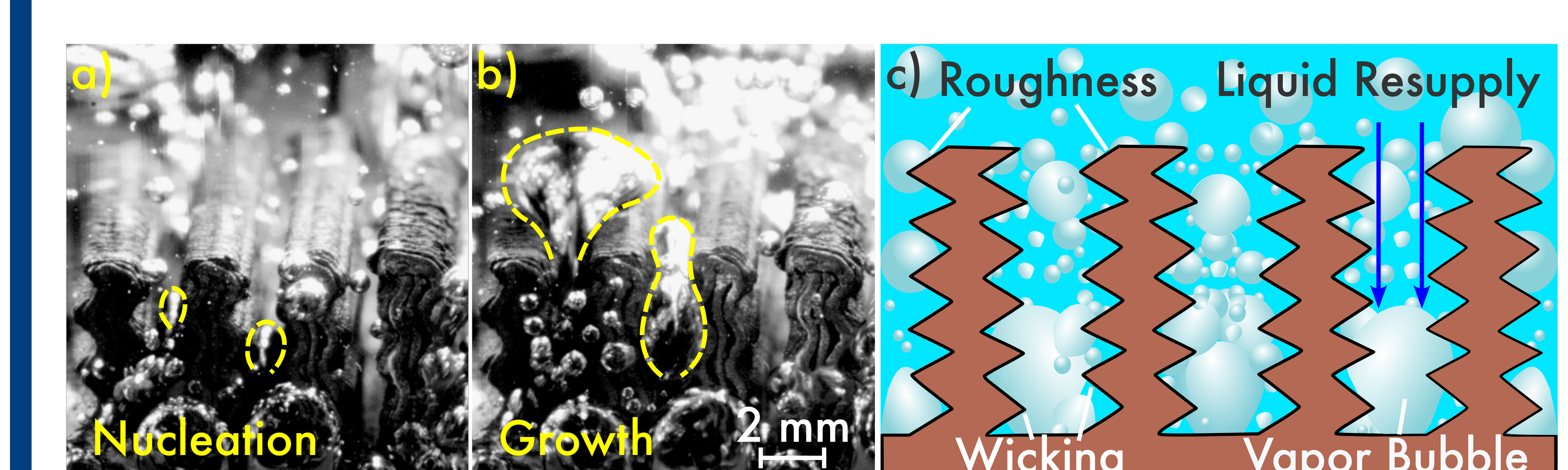

Figure 9. Bubble Dynamics on Vertical Wave 3D-Printed Surface: a) Nucleation, b) Growth, c) Schematic of Mechanisms Across All Fluids.

Full Research Work: Kamaraj, A.B., Hasan, M.M., Merugu, S., Gupta, A*, Comparison of 3D-Printed Copper Surfaces for Enhanced Pool Boiling Heat Transfer, *Manufacturing Letters*, 2025