SCHULICH
School of Engineering
UNIVERSITY OF CALGARY

Numerical Simulation of Boiling Heat Transfer in Microchannels

Brady Kueneman; Connor Lowe-Wylde
Schulich School of Engineering, University of Calgary

ABSTRACT

- Microchannel heat exchangers are important for the efficiency and reliability of microprocessors.
- Certain parameters influence microchannel performance such as fluid properties, bubble dynamics, and bubble trains
- When analyzing these parameters, we found that:
    - Heat transfer is reduced when the bubbles coalesce in the heated region
    - Heat transfer is increased when the bubble coalesces upstream of the heated region due to the smaller liquid film thickness
    - Wall temperature can also be reduced by prevent coalescence which will keep the device cool and therefore reliable and efficient
    - Coalescence can be avoided by following specific bubble train conditions that have been mapped
- Our final design utilized case 1 with coalescence occurring upstream of the heated region, giving us a max heat transfer rate of roughly 30 kW/m^2 and an average wall temperature of 78 deg C, which meets our design parameters

REFERENCES

[1] R. Mishra, "electronics Cooling," 2004. [Online]. Available: https://www.electronics-cooling.com/2004/02/the-temperature-ratings-of-electronic-parts/. [Accessed 08 12 2021].

[2] M. Nabil and A. S. Rattner, "interThermalPhaseChangeFoam - A framework for two-phase flow simulations with thermally driven phase change," *ScienceDirect*, pp. 216-226, 2016.

CONTACTS

Brady Kueneman
Email: brady.kueneman1@ucalgary.ca
Phone: (403) 970-4096
Website: https://engineeringdesignfair.ucalgary.ca/mechanical/numerical-simulation-of-boiling-heat-transfer-in-microchannels/

Connor Lowe-Wylde
Email: john.lowewylde@ucalgary.ca
Phone: (403) 582-0150

INTRODUCTION

Background
- Microprocessors generate significant heat
    - Military High Power Optical Systems, Commercial Systems, Embedded Systems, and High-Performance Computing Systems
- Microchannel Cooling can be utilized
    - Imbedded very close to the heat sources
    - Large heat transfer area per unit fluid flow
    - Latent Heat of Working Fluid (Phase Change)
- Benefits of Microchannel Cooling
    - Improved device efficiency
    - Improved cooling; higher reliability

Problem
- How can we improve Microchannel cooling efficiency to keep up with microprocessor development?
    - Optimize bubble sizes to maximize heat transfer through increasing bubble volume
    - Determine how coalescence impacts the heat transfer and what conditions cause it
    - Determine what working fluids are most effective in the microchannel case

Design Parameters
- Wall temperature of approximately 70 deg C [1]
- Minimum heat transfer flux of 10 kW/m^2

METHODS

OpenFoam
- Used to develop accurate simulations for the boiling Microchannel
- Leading Open-Source Computational Fluid Dynamics (CFD) software
- Utilize custom interThermalPhaseChangeFoam solver [2]
- Finite Volume and Volume of Fluid Methods

Assumptions - Incompressible Flow, negligible gravity, and laminar flow

Setup
- 30mm x 1mm x 1mm
- Adiabatic and Heated sections
- Constant Heat Flux 90,000 W/m^2
- Inlet Velocity of 0.26m/s
- r134a Fluid initialized

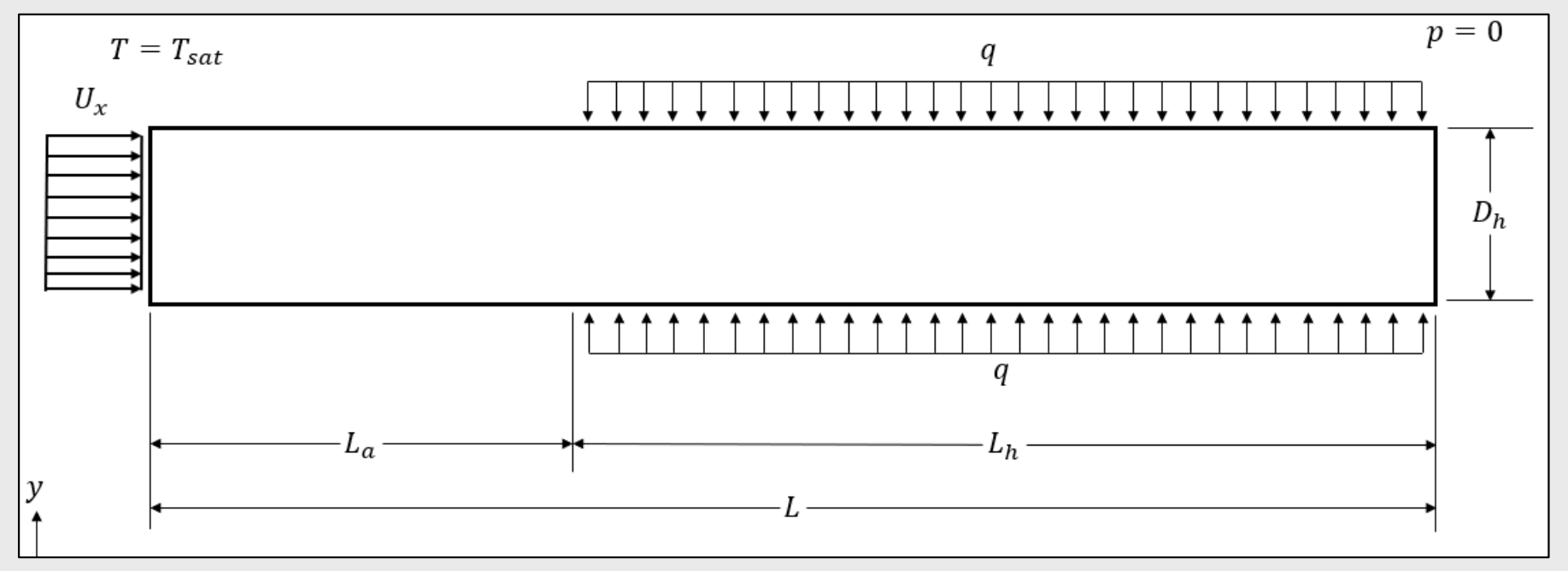

Figure 1. Microchannel Schematic

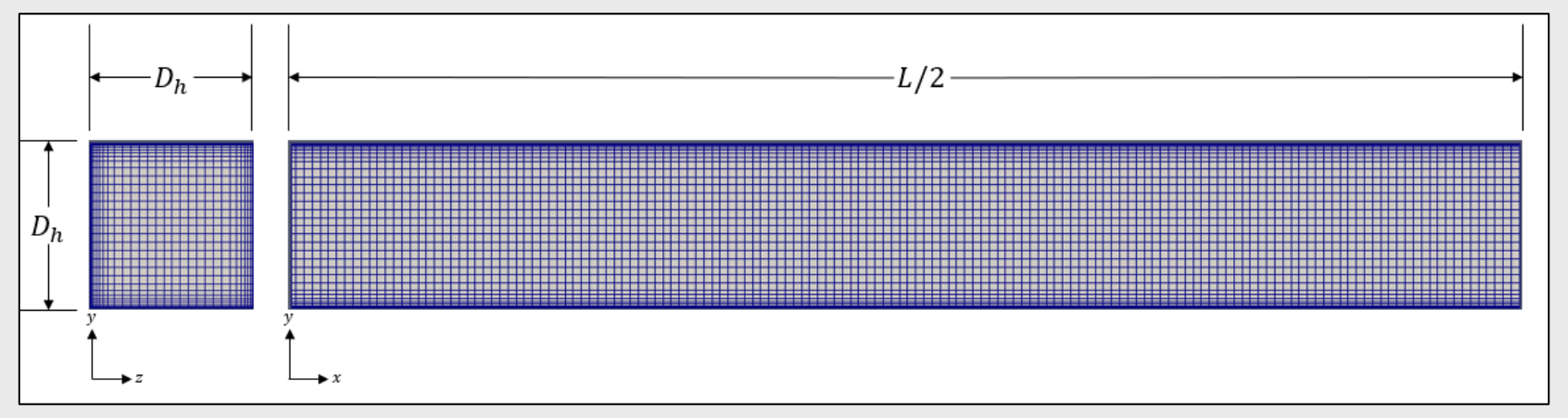

Figure 2. Microchannel Mesh – 30x30x600

RESULTS/DISCUSSION

Heat Transfer Optimization
- Five cases were analyzed with various bubble sizes to determine optimum conditions
- Initial Volume was held constant for each case

Table 1. Optimization Cases - Dimensionless Equivalent Diameters

Case	1st Bubble	2nd Bubble
1	0.768	0.963
2	0.826	0.922
3	0.877	0.877
4	0.922	0.826
5	0.963	0.768

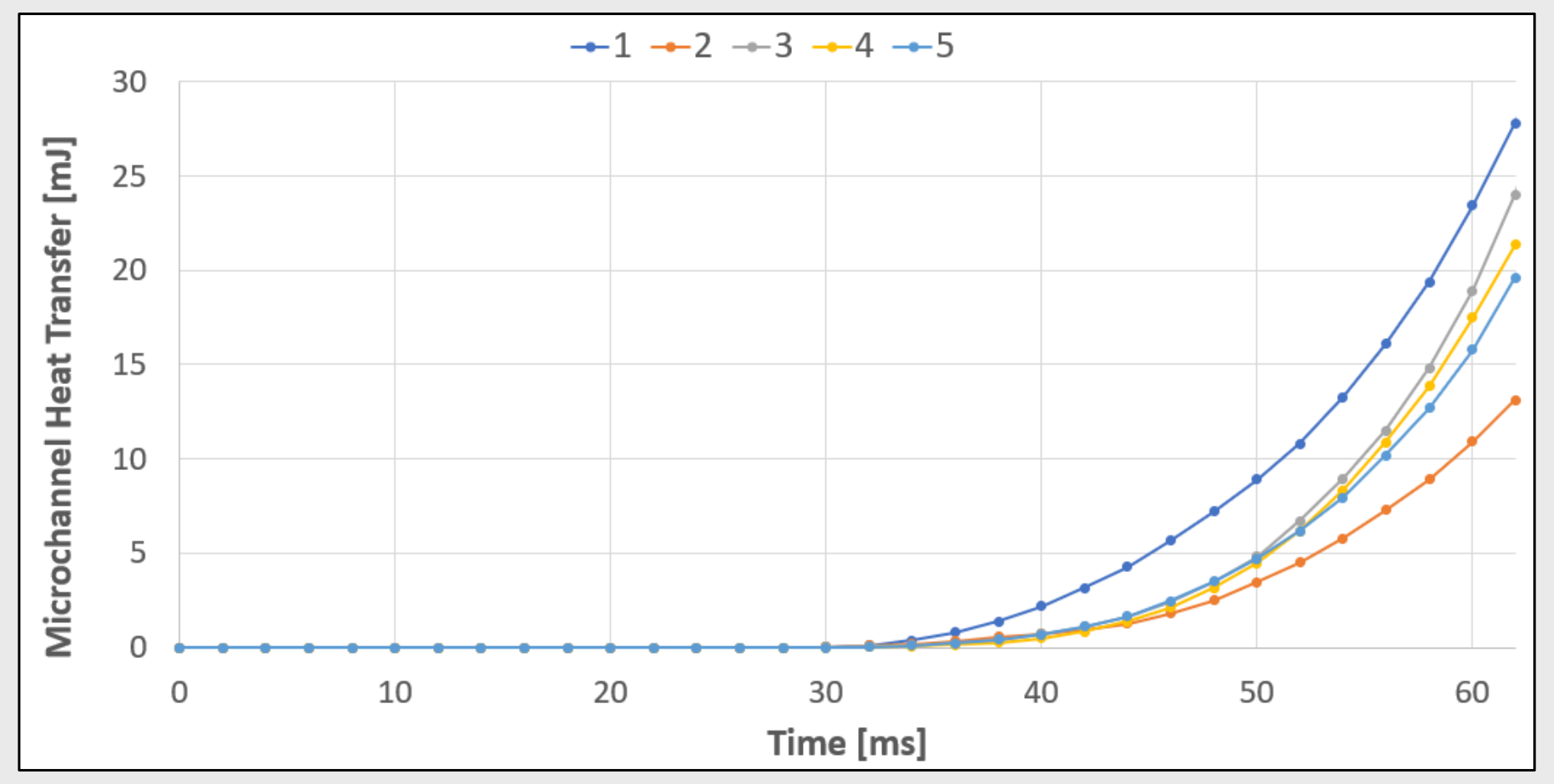

Figure 3. Microchannel Heat Transfer Optimization

- Figure 3 above shows the first case which generates the highest heat transfer, with peak a peak power of roughly 30kW/m^2
    - This is because it coalesces before the heated region
- The second case generates the lowest heat transfer
    - This is because it coalesces inside the heated region
- Coalescence in heated region causes less heat transfer due to a large liquid film between the bubble and wall
- Cases 3, 4, and 5 do not coalesce and thus all behave very similar.

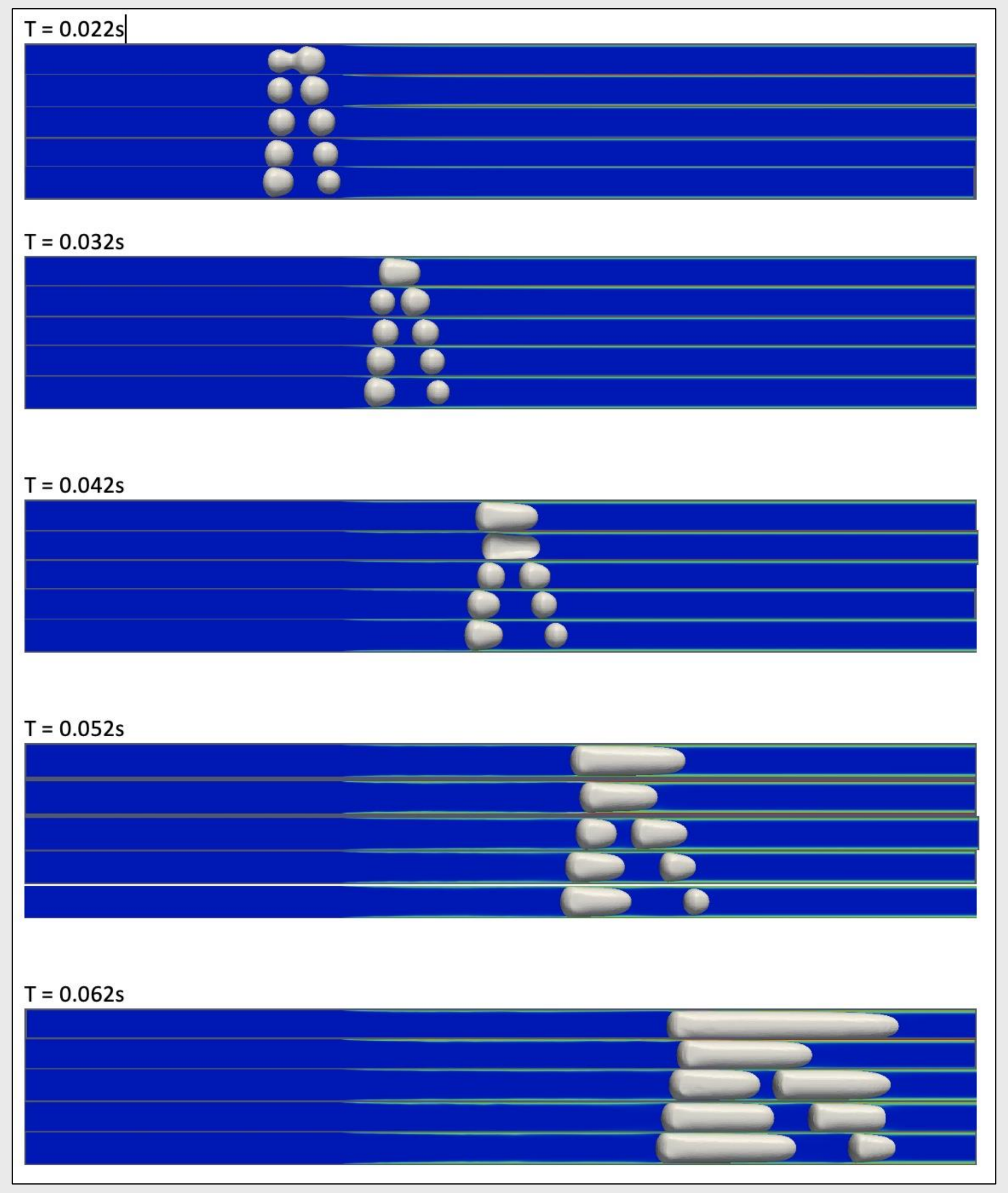

Figure 4. Optimization cases at various time steps

RESULTS/DISCUSSION CONT.

- Figure 4 displays Cases 1, 2, 3, 4, and 5 in sequential order at varying time steps
- Case 1 coalesces before the heated region allowing it to have a thin liquid film and generate higher heat transfer
- Case 2 coalesces in the heated region and thus oscillations cause the liquid film to be thick which drives lower heat transfer (smaller bubble volume)
- Case 3 does not coalesce, so the heat transfer is still decent, but the front bubble does most of the heat absorbing.
- Cases 4 and 5 have a very small bubble in the front and thus the film is thin and is unable to absorb much heat
    - Thus, the back bubble absorbs more heat and becomes larger
- From the above points, it's clear Case 1 is the most efficient at increasing heat transfer
- We also observe that coalesce is not desirable, unless it's before the heated region in which case it acts the same as a single larger bubble.
    - Devise a map to understand what conditions cause coalescence so we can avoid it.

Inducing Coalescence
- Coalescence of bubbles significantly impacts heat transfer
- Initialized two bubbles and systematically varied their volumes
    - Normalized to the Hydraulic Diameter to give us equivalent diameter
- Figure 5 shows that the green triangles under the black line we will induce coalescence
- The back bubble must be smaller than the front to induce coalescence
    - Smaller bubbles move faster due to the higher velocity at the center of the channel

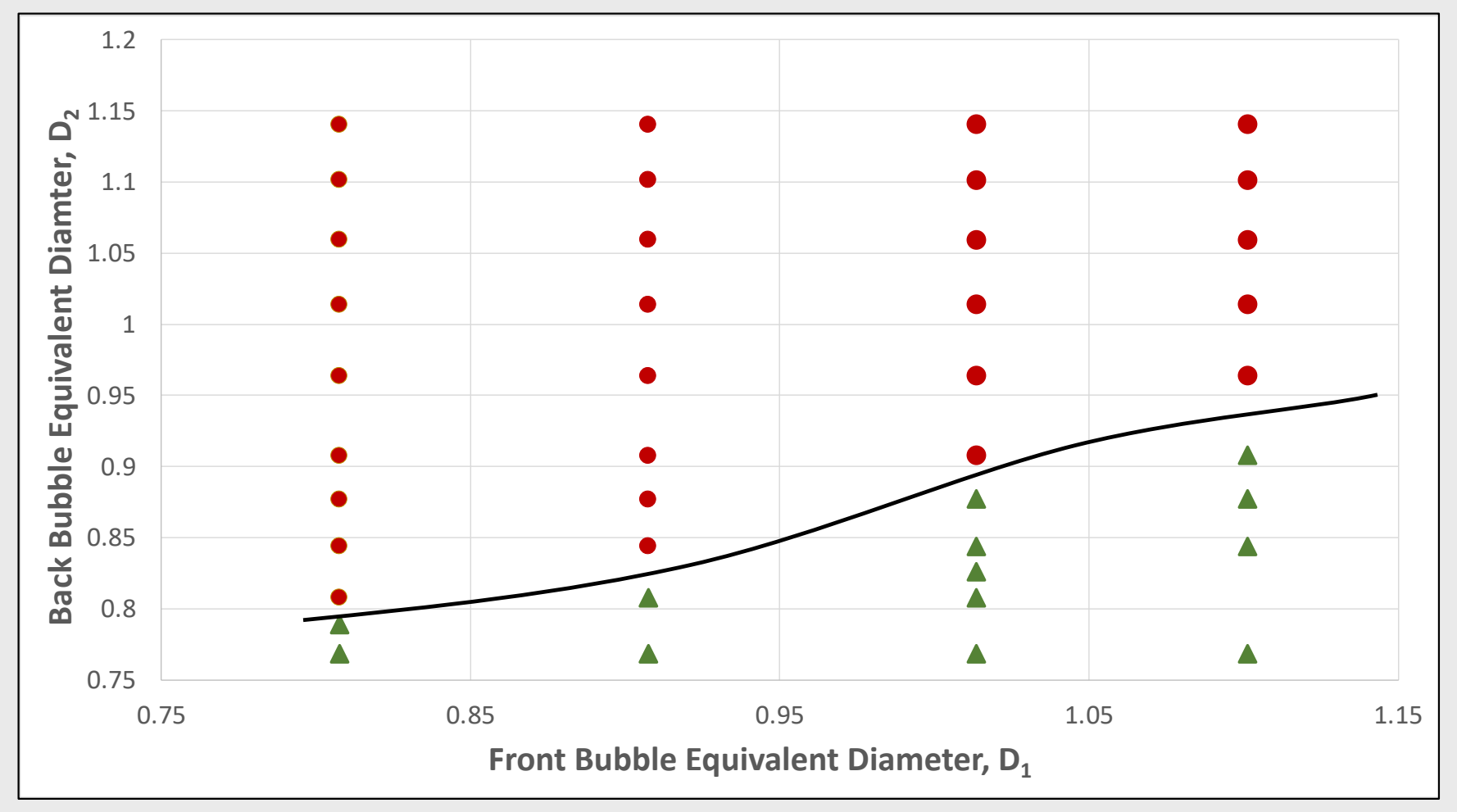

Figure 5. Coalescence Mapping of Varying Bubble Sizes

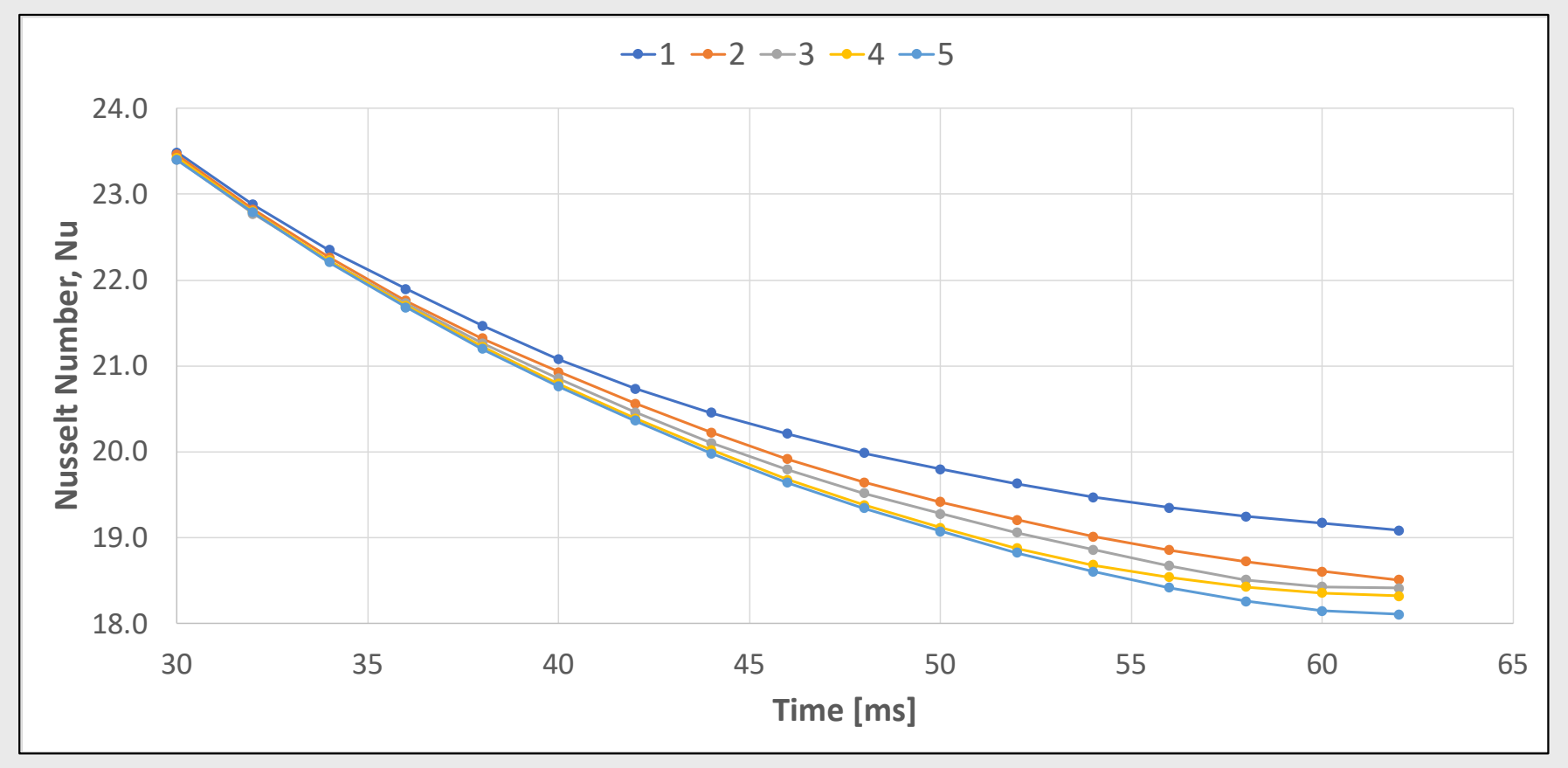

Figure 6. Nusselt Number vs. Time for 5 Optimization Cases

RESULTS/DISCUSSION CONT.

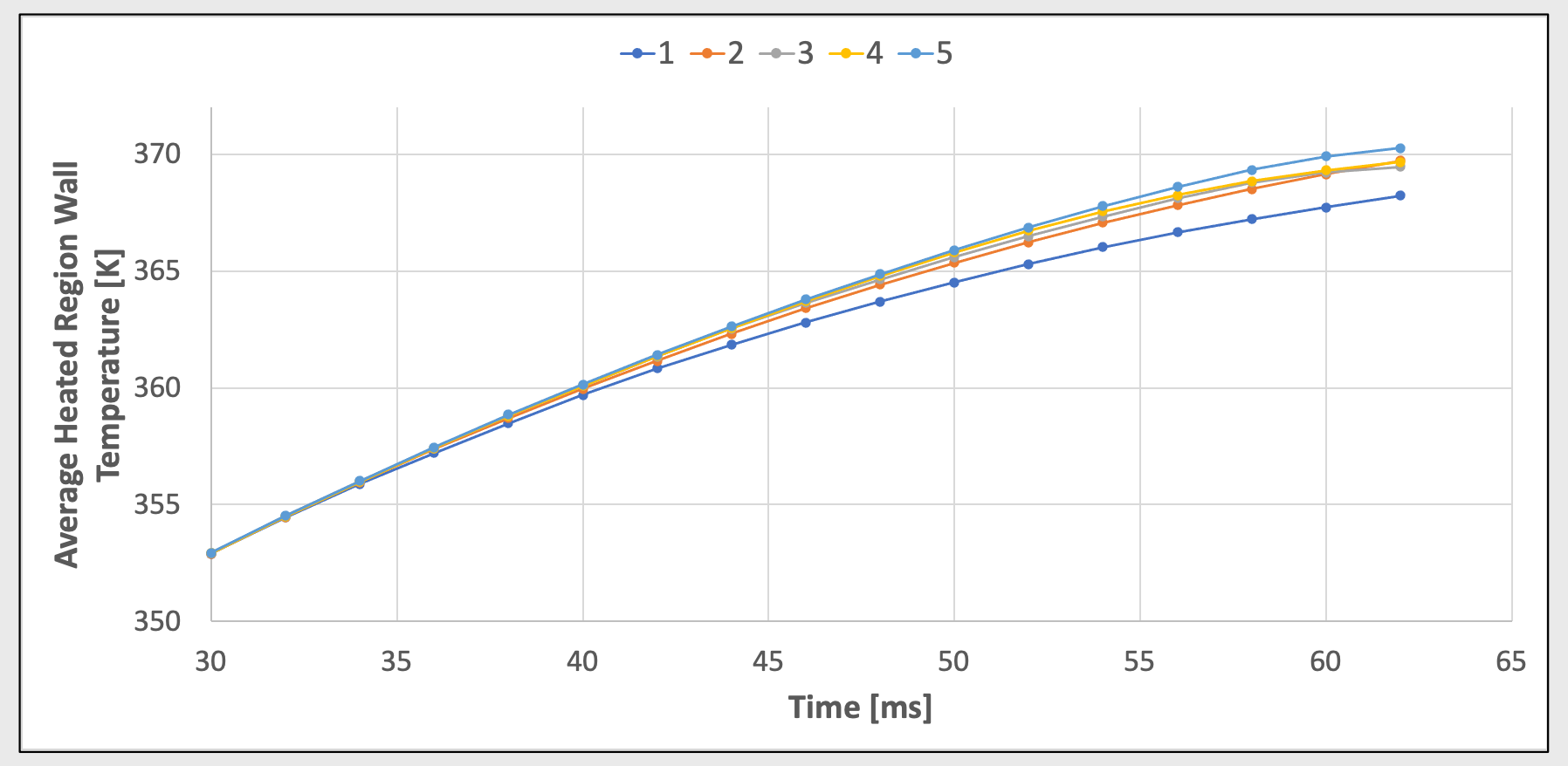

Figure 7. Average Heated Wall Temperature vs. Time for 5 Optimization Cases

- Figure 6 above displays that the Nu number from largest to lowest is case 1, 2, 3, 4, and then 5
- This tells us that keeping the back bubble smaller will drive slightly higher convective heat transfer..
- Figure 7 displays that the average heated wall temperature from largest to smallest is case 5, 4, 3, 2, and then 1
- This tells us that ensuring the back bubble is smaller and that if coalescence occurs before the heated region, we can keep the wall temperature of the electronic device cooler and thus provide higher efficiency and reliability.

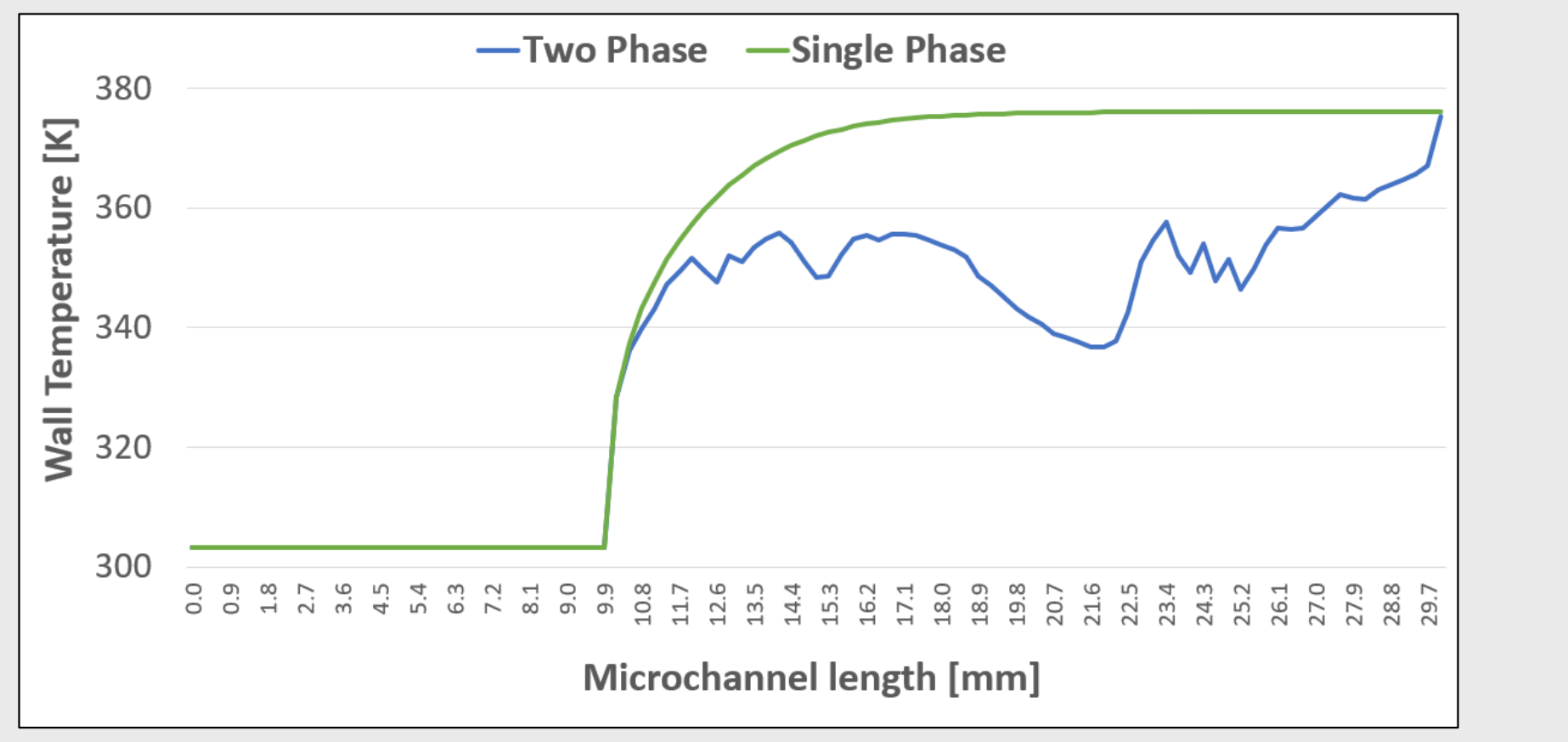

Figure 8. Design Wall temperature vs. baseline single phase

- Figure 8 shows the performance of the two-phase microchannel compared to the single-phase counterpart
- The two-phase design can significantly reduce the wall temperature to an average value of 78 deg C

CONCLUSIONS

- Coalescence of bubbles in the heated region is not desirable as it reduces the heat transfer of the microchannel
- Coalescence of bubbles before the heated region is preferred as it allows time for the bubble to take shape and reduce the liquid film thickness which drives higher heat transfer
- While preventing coalescence increases heat transfer, it also reduces the wall temperature which improves efficiency and reliability of the device it's cooling
- We can follow a coalescence map to ensure we can create a bubble train which avoids coalescence but also maximizes heat transfer and minimizes the wall temperature.