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Title

Improving cooling channel heat transfer via femtosecond laser texturing

Authors

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Abstract

The design of efficient cooling devices is crucial in a multitude of space applications [1]. Although cooling technologies have existed for decades there is still a lack of efficient heat dissipation methods, especially for space applications where thermal management devices must be capable to dissipate heat in reduced gravity environments. In this context, boiling heat transfer is a logical step to take since it also makes use of the fluid's latent heat. However, commonly used empirical correlations for boiling heat transfer are inaccurate in this case since they come from terrestrial experiments where buoyancy has a strong impact [2, 3]. In our research, we investigate the impact of femtosecond laser texturing on the heat transfer coefficient (HTC) and Critical Heat Flux (CHF) during flow boiling in a cooling channel using a high thermosensitive fluid, Novec 7000. We also analyze the flow topology and provide the pressure drops as a function of the gravity direction using a set-up in which the channel can be oriented at different angles.

Our experimental set-up is presented in Fig.1. It is composed of a magnetic gear pump, a filter bypass circuit, a preheater connected to a chiller to control the degree of subcooling, a Coriolis mass flow meter, a rotatable square 5x5mm test section with one heated side with embedded thermocouples, a radiator heat exchanger to condense the bubbles, an accumulator to stabilize the pressure, a high-speed camera to visualize the bubbles and a NI cDAQ system to log the sensor data in a LabView environment.

Results of a baseline plain surface test campaign show that mass flow rate, subcooling, and channel inclination are the parameters influencing the heat transfer phenomena. The higher the mass flow rate, the lower the wall superheats and the higher the HTC at a given heat flux, and the less severe the impact of the inclination since the flow becomes more inertia driven. More subcooling results in lower wall superheat at a given heat flux but also leads to a lower HTC compared to similar cases at lower subcooling. Of cases where gravity plays a dominant role, vertical up-flow shows the best performance. Some of these results can be found in Fig.2 below.

Using high-speed (3000fps) bubble visualization, e.g., Fig.3, several parameters such as bubble detachment diameter, detachment frequency, and nucleation site density can be assessed and linked to the geometry of the texture and the heat transfer phenomena.

The first surface texture under consideration is made of pure LIPSS, or Laser-induced Periodic Surface Structures. These are periodic structures at the sub-micron scale that are intrinsic to femtosecond laser processing. As they will be superimposed to all micro-textures manufactured, their effect should be understood and decoupled. Especially with highly wetting fluids like Novec 7000, this scale of surface textures should have a clear impact on the boiling process.

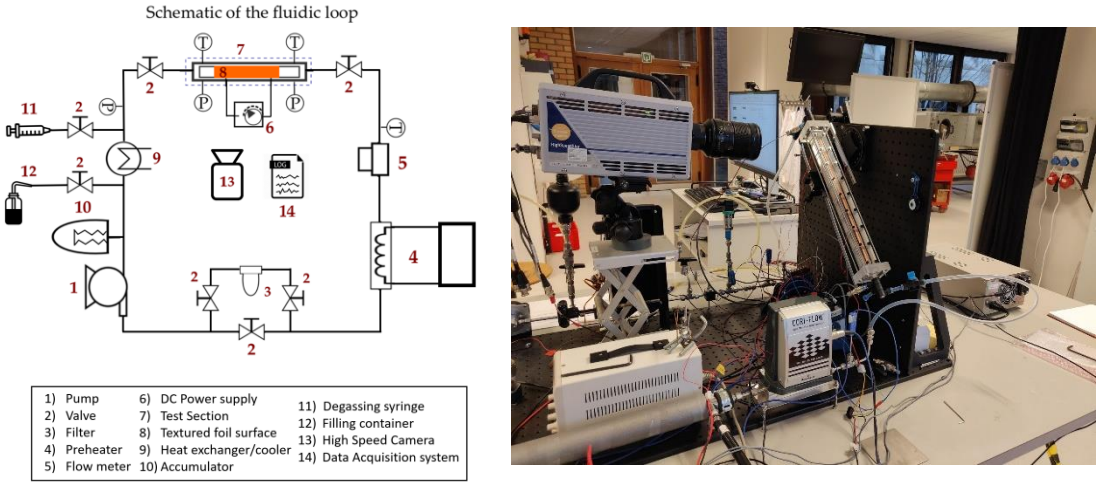

Figure 1 Experimental terrestrial flow boiling setup

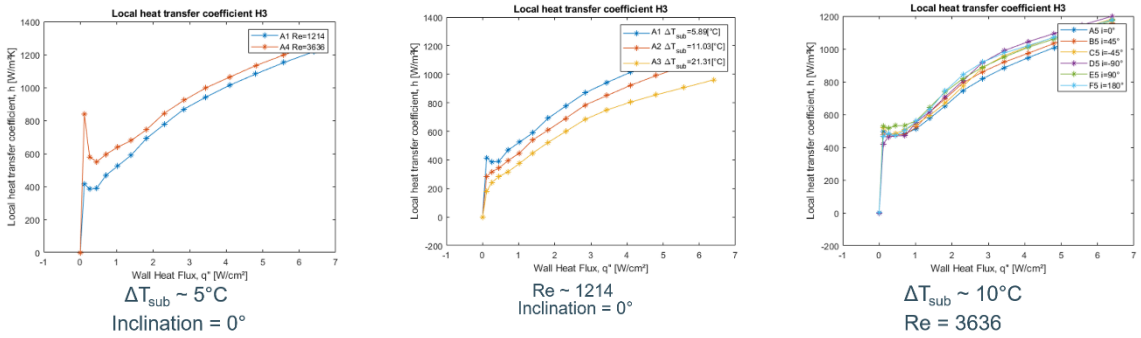

Figure 2 Some HTC curves for different conditions

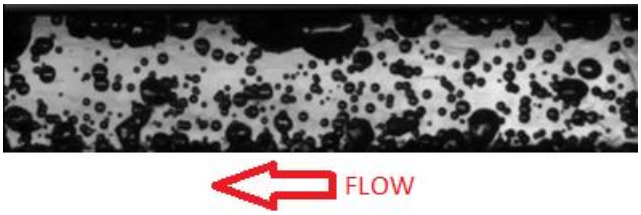

Figure 3 Flow visualization image

References

[1] M. Williams et al., "Advanced Heat Exchanger Technology for Aerospace Applications," SAE Technical Paper 2008-01-2903, 2008

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