THERMASMART
Thermal Management of Microprocessors

Hosted by

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Welcome to ThermaSMART

Smart thermal management of high-power microprocessors using phase-change.

Project ThermaSMART is an international and intersectoral network of organisations working on a joint research programme in the area of phase-change cooling of microprocessors and high-power electronic devices.

ThermaSMART, which began in December 2017, aims to gain a competitive advantage through the exposure of secondees to new research environments both in academia and industry which will enable exchange of crucial skills and knowledge and empower their career prospects in this increasingly important area.

Our partners span across 5 continents: Europe, Asia, Africa, North America and South America. Our project will promote international and inter-sector collaboration through research and innovation staff exchanges, and sharing of knowledge and ideas from research to market (and vice-versa).

ThermaSMART has been offering a unique opportunity to train 41 early stage researchers (over 285 exchange months) in state-of-the-art experimental and modelling techniques for phase-change and microfabrication both in participating Universities and industries.

In addition to regular consortium meetings, technical workshops and research publications, we have held workshops, summer schools, and co-hosted events alongside major conferences at Tianjin, Dublin, Kyushu, Toronto and Edinburgh alongside several exchange programmes to sustain a long-term interaction between the partners.

This workshop is the last of the current ThermaSMART series. We are grateful to our hosts and partners, University of Pretoria, for curating such a fascinating event – right in the auspices of the 17th International Heat Transfer Conference which follows on after the ThermaSMART workshop.

The ThermaSMART project ends in September 2023. We are indebted to the European Commission's Horizon 2020 RISE programme which gave us this opportunity. The project is a major success scientifically with many publications, theses and successful graduates. We wholeheartedly thank all the partners who have contributed excellently by hosting students, training and upskilling them on specialist expertise.

ThermaSMART has been addictive – especially with the science and engineering that has been generated and the strong inter-continental collaborative partnership that it has established! We will strive to continue this legacy by applying for follow-up grants.

Thank You!

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1. Thermal hysteresis in the Leidenfrost effect

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Our recent experiments on the evaporation of water drops on heated substrates show that there is a temperature hysteresis in the Leidenfrost temperature. We attribute this to the change in surface wettability caused by substrate heating. More specifically, the contact angle of our substrate (stainless steel) was reduced from 60° to 10°, approximately. It is believed that hydrocarbons, which lowers the surface energy, were removed when the substrate was maintained at high temperatures. The contact angle was then recovered to the original (or saturated) value after a long exposure to the air. This implies a practically negligible influence of the intrinsic wettability on spray quenching as it usually takes place from a very high temperature. Also, I will briefly discuss our hydrodynamic / thermal observations of impacting drops near the Leidenfrost point and pose open questions around the mechanism of boiling transition.

2. Fluid motion without energy supply

Panagiotis Theodorakis[1*], Russell Kajouri[1], Piotr Deuar[1], Rachid Bennacer[2], Jan Židek[3], Sergei Egorov, Andrey Milchev

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We demonstrate various system designs that enable the autonomous motion of droplets by means of extensive molecular dynamics simulations of liquid droplets on gradients substrates. The characteristics of the self-sustained droplet motion and the underlying mechanisms are analysed. We anticipate that our studies indicate further possibilities for the nanoscale motion of fluids without energy supply.

3. TACoolTPS – Advanced Cooling of high power microsystems using Two-Phase Flows Systems in Complex Geometries

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We present the development and benchmarking of the ultimate two-phase flow solver using arbitrary quadrilateral meshes and the finite element method within the context of the ACoolTPS project sponsored by The Royal Society - Advanced Newton Fund. The two-phase interface mesh is not embbed to the fluid mesh, therefore avoiding complicated remeshing algorithms. Results are satisfactory for the several test cases simulated in this project.

4. Surprising dynamics of ellipsoidal particles in flow

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We will discuss how ellipsoids move in initially still fluid in steady stokes flow and in the other extreme of inviscid (and very high Reynolds number) flow. In the former we will talk about the basic reasons for the clumping instability and its possible stabilisation in an array of falling ellipsoids. In the latter we will discuss the origins of chaotic motion. Finally we will talk about phase change in these situations, in terms of possible avenues for future research.

5. Chaotic Orbits of Immersed Ellipsoids

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Building on previous work (Essmann et al, 2020) exploring the complex dynamics of a single immersed ellipsoid, we investigate the dynamics of multiple immersed ellipsoids under both inviscid and viscous environments. Earlier, using our in-house fully-coupled 6DoF solid-fluid DNS solver, GISS (https://github.com/eessmann/GISS, Essmann et al 2020), we showed that a single body can present chaotic motions even under viscous environments under certain conditions due to vortex shedding. Here, we extend Kirchoff's equations to multiple bodies under inviscid conditions, using Lamb (1932) as a starting point. Analytical solutions for added mass and inertia are no longer available for multiple bodies, and so we solve for the potential flow using boundary integral equations, and resolve for the forces on the bodies through surface integrals. Rotational motion is represented using quaternions. Using recurrence quantification and cross-correlation analyses (Marwan et al, 2007), we will present how we can characterise chaos and how the number of solids affects chaos.

6. Exploring Dynamics and Hazards of Levitating Droplets on Superheated Gallium: Implications for High-Temperature Applications

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Understanding the dynamics of the liquid droplets levitating above superheated surfaces is crucial for applications like nuclear reactor cooling and concentrated solar power (CSP). As we strive towards net zero, technologies such as CSP and Solar Central Receiver Systems (SCRS) require heat transfer fluids capable of withstanding temperatures up to 1000 °C. Hence, exploring new generations of fluids, like gallium, becomes vital. In our experiments, we investigate the behaviours of droplets on a heated pool of liquid gallium, considering pool temperature and droplet temperature. Our focus investigates the Leidenfrost effect in high-surface tension fluids. Remarkably, we find that levitating water droplets, experiences heat transfer limitations that cause the vapour layer to break, resulting in explosive behaviours. This highlights the potential hazards of employing Room-Temperature Liquid Metals (RTLMs) in high-temperature CSP or SCRS applications. Additionally, we discover that lowering the initial temperature of water droplets increases the evaporation rate. We also observe the growth of a thin oxide layer on a gallium pool when exposed to the atmosphere, which hinders heat transfer. However, this oxide layer can be mitigated by introducing a carbon dioxide and/or nitrogen-rich environment. Furthermore, our experiments demonstrate how Faraday waves affect the behaviours of levitating droplets on a gallium pool. Ethanol droplets exhibit oscillation patterns between ellipsoidal and spherical shapes, while water, due to its high surface tension, has limited oscillations. We also anticipate the presence of "chimney instability" in water droplets, similar to ethanol, pending further exploration with larger droplet sizes.

7. Heat transfer characteristics in high temperature thermal energy storage

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High temperature thermal energy storage plays an important role in utilizing solar energy and recovering industrial waste heat. Thermal properties of molten salts with various component fractions are measured, and a molecular dynamics simulation is performed to provide microscopic insights. Ceramic foam is used to address the low thermal conductivity of molten salts. For pure molten salt, heat conduction is the major heat transfer mechanism at the early stage, while natural convection becomes the major heat transfer mechanism after 4000s. For the molten salt/ceramic foam composite phase change material, heat conduction is always the major heat transfer mechanism. In a shell-and-tube unit, which is a popular heat storage device, the effect of the ceramic foam position is significant in the melting process but insignificant in the solidification process. The lower-inserted ceramic foam is superior in the melting process, and the complete melting time is 20% shorter than the upper foam-inserted unit. By contrast, in the solidification process, the upper-inserted ceramic foam is slightly superior.

8. Effect of Needle and Dosing Parameters on Contact Angle Hysteresis

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This research aims to examine the influence of needle type and size, and dosing parameters on the measurement accuracy of contact angle hysteresis using the optical drop shape analysis method. The study focuses on deionised water droplets on a smooth silicon wafer coated with a hydrophobic self-assembled monolayer, perfluorodecyltrichlorosilane (FDTS), as well as on an uncoated silicon wafer, which is intrinsically hydrophilic. In addition, an optical needle method is coupled to the classical drop shape analysis method to assess the interaction between the needle and the droplet at their meeting point and its potential impact on droplet shape, consequently affecting the baseline contact angle measurement and, thus, the contact line dynamics.

Independent variables are investigated, including dosing flowrate, needle size in terms of external and internal diameter, and needle material/coating varying from hydrophilic stainless steel to superhydrophobic Glaco coated needles. The objective is to determine the optimal combination of these parameters for the most accurate measurement of contact angle hysteresis when using the needle method during drop shape analysis. A comprehensive protocol will be developed based on the findings to enhance the accuracy and reliability of future experiments.

Additionally, the subsequent phase of the study will involve comparing the results obtained from the optical needle method to those acquired using a needleless approach via a microgoniometer. This ongoing fundamental investigation holds promise for establishing a refined methodology for precise contact angle hysteresis measurements, enabling researchers to obtain more accurate data characterisation in various surface-wetting studies.

9. Effect of surface curvature on confined jet impingement boiling

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Surface topography such as concave curvatures offer a simple and compact solution to reduce the Critical Heat Flux (CHF) of impinging jets by increasing surface area, average streamwise surface velocity, and normal pressure gradients. These factors actively contribute to increased bubble departure, thereby enhancing boiling. Furthermore, surface curvature influences the formation of Taylor-Görtler vortices which enhance turbulent mixing. In this study, we implement the Eulerian RPI boiling model coupled to a standard RANS turbulent model (such as k-epsilon) to simulate the boiling phenomena resulting from a turbulent jet of liquid nitrogen impinging onto concave surface subject to constant heat flux. Our results are validated against the boiling curve and wall-superheat obtained from the experimental work of Zhang et al. [2010]. Our results from an in-depth parametric study reveal the influence of surface curvature, Reynolds number, dimensionless nozzle height, and confinement domain size on the boiling curves. These findings provide valuable insights into the design and optimization of surfaces for enhanced jet impingement boiling in confined environments.

10. Introducing Vortices via Vortex Generators as a method of Spent Vapour Removal during Jet Impingement Boiling

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The simulation of boiling, specifically jet impingement boiling, is a complex problem that has received increasing attention in recent years due to the promising improvement in heat transfer of two-phase systems for micro-electronics cooling over conventional single-phase systems. Previous research has found localised dry-out, an effect due to the formation of a vapour layer, to be a significant limitation in increasing the Critical Heat Flux (CHF) of jet impingement boiling systems. We, therefore, investigate the introduction of Vortex Generators as a method to remove the spent fluid (vapour), preventing the creation of a vapour layer, which may in turn increase the CHF of the system by allowing for rewetting. We computationally investigate the proposed Vortex Generator implementation using a Menter's Shear Stress Transport (SST) turbulence model coupled to a Rensselaer Polytechnic Institute (RPI) boiling model. Our simulations allow for detailed feedback that is not often available with experimental work, such as the dynamic variation of velocity and temperature fields throughout the domain. Our simulations have been validated against the Stanton numbers derived from single-phase wind tunnel experiments of Eibeck and Eaton (1987) and also against microchannel heat transfer experiments of Chen at al. (2014) using vortex generators. We present simulations that span over critical flow (such as inlet Reynolds numbers) and geometrical parameters (such as span, angle of attack and aspect ratios) of our vortex generators. Our analysis aims to reveal how vortices can influence flow-boiling.

11. Experimental and Numerical Heat Transfer Investigation of Reverse Jet Impingement

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This project aimed to study heat transfer and flow in double wall aerofoil cooling using two primary studies: a novel jet impingement cooling geometry. Experimental testing with thermochromic liquid crystal validated numerical work using ANSYS Fluent. A novel reverse jet impingement geometry was developed to enhance heat transfer performance, comprising of a dimple target enclosed within a cylindrical silo. Experimental variations included Reynolds number, jet-to-target, crossflow condition, and an extended nozzle geometry. An overall enhancement of heat transfer was achieved with the novel geometry, with optimum jet to target spacing found at around4 jet diameters, and some reduction in crossflow effects were observed. A numerical investigation validated against experimental data for a novel 'reverse 'jet impingement geometry was conducted. Optimizations in jet-to-jet and jet-to- target spacing were found. The effect of outlet condition on discharge coefficient was significant, with an optimum nozzle length of 1 jet diameter for heat transfer enhancement .Staggered and inline dimples were shown to provide similar enhancements to heat transfer, significant compared to a traditional flat plate target.

12. Solar Evaporation Enhancement via Synergistic Cooperation between Copper Foam and Graphene Oxide Functionalisation

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Aiming to ensuring access to safe water to all, related to the United Nations Sustainable Development Goal 6: Clean Water and Sanitation, the development and implementation of easy and scalable passive technologies that can harvest freshwater from seawater and wastewater are paramount. To this end, solar evaporators represent an attractive mean to achieve such goal. In this work, we develop a 3D conical evaporator with enhanced solar absorption, solar-thermal efficiency and evaporation rates when compared to earlier literature. The enhanced solar performance is achieved by its high-efficiency solar absorption, continuous liquid film spreading and transport, enhanced interfacial local evaporation, and rapid vapour diffusion through the pores, empowered by the hierarchical micro-/nano-copper foam functionalised with graphene oxide. A solar-thermal efficiency as high as 93% with an evaporation rate per unit are of 1.71 kg·m−2·h−1 are here achieved under 1-Sun artificial illumination. While the more simplistic solar evaporator configurations as well as the state-of-the-art results on solar evaporators are presented for comparison.

13. Evaporating populations of sessile droplets comprising binary mixtures

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Evaporation of a sessile binary mixture droplet is a highly complex phenomenon due to dynamic interplay between thermal and solutal Marangoni flows. The presence of another neighbouring sessile droplet comprising the same binary mixture introduces further complexities via interactions through the substrate, pre-cursor film and vapour. Here, we propose a lubrication theory-based finite element model for two evaporating sessile drops comprising binary mixture such as ethanol-water deposited on a heated surface. We consider a diffusion-limited evaporation regime for thin droplets in the presence of a pre-cursor film. We consider that the liquid components are ideally mixed and that both the components are volatile. The net surface tension is taken as a linear function of both temperature and concentration. Further, we also solve for the vapour concentration for both the volatile components in the presence of air in 2D using the standard diffusion equation. Our solutions for two adjacent droplets comprising the same binary mixture compositions demonstrate attraction, coalescence, and repulsion between the droplets as a function of thermal Marangoni, solutal Marangoni, and substrate thermal conductivity. In addition, we also observe the so-called vapor-shielding effect making the evaporation time for two droplets significantly higher than for a single droplet. In the region between the droplets, we also note condensation of the least volatile component under conditions of higher relative humidity. We also predict condensation of the most volatile component at higher solutal Marangoni numbers.

14. Binary Mixture Droplet Wetting and Evaporation Phase Change on Hydrophilic Structured Surfaces

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There is a promising future for the development of structurally and chemically decorated surfaces in a variety of applications, including everyday practices as well as industrial and biomedical applications. When structured surfaces are used, their intrinsic hydrophobicity/hydrophilicity strongly affects the wettability and evaporation process of microliter droplets. In this work, pure water, pure ethanol, and their binary mixtures are used to examine their wettability and evaporation behaviour on 6 intrinsically hydrophilic micro-structured surfaces having the same height-to-diameter aspect ratio and varying the spacing between pillars. Upon deposition, the wettability of droplets on short-spacing surfaces depends highly on the liquid surface tension and spacing between pillars; however, on large-spacing surfaces, droplets behave similarly as on their smooth counterparts independently of the liquid studied. Thereafter, the full evaporation process for the same liquids is examined on the same hydrophilic structured surfaces, where three different evaporative modes are revealed: the constant contact radius (pinning), stick-slip mode and mixed mode, in the absence of the constant contact angle mode. The duration of each mode has been analysed to clearly show the dependency of the evaporation modes on the different initial wetting regimes and liquid surface tensions used. Accordingly, choosing the proper spacing of the structure combined with the proper binary mixture concentration, the initial wetting regime, the initial pinning time, and the duration of evaporation modes can be optimized according to the application and objective, making these fundamentals useful in a variety of biological, agricultural and medical fields among others.

15. Transient growth stability analysis of evaporating sessile drops comprising binary mixtures

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The evaporation and spreading dynamics of a binary mixture sessile drop are complex due to the interplay of thermal and solutal Marangoni stresses alongside the hydrodynamic transport, evaporation, mass diffusion and capillary stress of the drop. Our quasi-steady linear stability analysis of volatile bicomponent sessile drops comprising ethanol-water mixtures placed on heated hydrophilic substrates demonstrates that evaporation is highly unstable with several competing modes. Whilst the analysis qualitatively agrees with the experiments, presence of multiple competing modes indicates that the quasi-steady analysis may not be fully representative and suitable for volatile bi-component sessile droplet systems. To understand the roles of these modes better, we perform a transient growth analysis of this system. Here, we apply small disturbances to the binary system base state governing equations, giving perturbed stability equations that evolve with time. The lubrication approximation is used to derive our one-sided model, and the stress singularity at the contact line is avoided by including a thin precursor film. Perturbations are introduced into the system at an early time instance. These are solved alongside the base state to find the linear stability growth characteristics, in order to compare to the dispersion curves obtained from the quasi-steady state stability analysis. Similar to the findings from our quasi-steady state analysis, our results show droplet interfacial instabilities occur predominantly at the contact line.

16. Dropwise Condensation on Silicone Oil Grafted Surfaces

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Condensation is an important phenomenon, which has been critically investigated for many industrial applications related to heat transfer. It has been proved that dropwise condensation can enhance heat transfer rates 6-8 times more than filmwise condensation. In recent years, various surface modification techniques such as coatings, ambient exposure, or lubricant infusion have been explored to stimulate dropwise condensation. To promote dropwise condensation, low contact angle hysteresis (CAH) surfaces are key, which can be achieved via grafting silicone oil. Oil grafting transforms an intrinsic hydrophilic silicon substrate (CA ≈ 60°) into a hydrophobic surface (CA ≈ 108°) after grafting just one layer of silicone oil while the CAH can be tuned by changing the fabrication parameters, which are viscosity of the oil grafted, volume and/or number of layers of the oil grafted as well as oil application method. Condensation experiments on these surfaces have demonstrated the occurrence of dropwise condensation initiated and promoted on all surfaces independent of the viscosity of the oil grafted (5, 20 and 100 cSt) and/or the fabrication parameters. However, different droplet mobility, and as such different droplet size distribution, is expected depending on the CAH, this latter in turn function of the fabrication parameters. On high viscosity oil grafted surfaces showing the lowest of the CAH, smaller sized droplets are mobile and can be easily removed, creating space for new droplets to nucleate, grow, coalesce and shed. Overall grafting silicone oil promotes dropwise condensation over filmwise condensation with the consequent expected better heat transfer rates.

17. Use of an Agent Based Approach to Study Drop-wise Condensation Heat Transfer

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Dropwise condensation is a complex matter that involves nucleation of drops, its growth and finally removal from the surface to renew the cycle. We have seen promise in using a simple interdigitated electrode to promote droplet ripening and subsequent shedding by an air flow to improve drop-wise condensation heat transfer. The above idea poses a complex parameter domain (e.g., shape of the electrodes, current level and its frequency, etc.) that needs to be explored and can be quite tedious using the traditional approach. In this talk we will discuss a method to take advantage of artificial intelligence (AI) and specifically the use of Large Language Models (LLM). With LLM systems such as ChatGPT and associated API's, it is possible to accelerate research. This is possible by the use of "Agents". Our findings using a developed Python based system to realize the above Intelligent Assistant to accelerate the research for drop-wise condensation will be discussed. The Python based Intelligent Assistant is designed to communicate with various software tools and resources including APIs, indexes, and databases using largely the available systems such as LangChain, and MS Guidance. For example, we will use a majority voting scheme to sift through available literature and select the most relevant to be retrieved. Then by implementation of Chain of Thought type algorithms to evaluate the relevance. The same strategy is used to develop a Suggester as shown above to determine new strategies for design and operational parameters of an electrowetting assisted drop-wise condensation systems.

18. Experimental Flow Boiling with Binary and Self-Rewetting Mixtures at Low Mass Fluxes in a High Aspect Ratio Microchannel at Different Inclinations with One-sided Heating

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Microchannel flow boiling is regarded as a promising electronic cooling solution. Due to its applicability to various other industries, it has attracted increased research attention however, various aspects remain misunderstood and ill-defined. The complex phenomenon is driven by multiple parameters, which influence heat transfer capabilities and performance. Besides parameters like the channel geometry, orientation, and operational conditions (heat and mass flux), the working fluid properties also play a key role in the flow boiling dynamics. Previous researchers have pointed out that certain water-alcohol mixtures might inhibit positive attributes leading to increased two-phase heat transfer performance. This experimental study considered 5% v/v aqueous solutions of Ethanol, 5% and 7 % v/v 1-Butanol, alongside their pure substance counterparts. Locally uniform one-sided heating was applied to a borosilicate glass microchannel with a width and height of 6 mm and 0.3 mm respectively. Three mass fluxes (10, 15 and 25 kg/m²s) and a range of applicable heat fluxes at a horizontal orientation were considered for each fluid. The heat transfer performance was evaluated by considering both local and average heat transfer coefficients, heat transfer efficiencies, microchannel wall temperatures and vapour qualities. The results indicated that the heat transfer coefficients of the different fluids were closely grouped. The self-rewetting effect associated with the 1-Butanol-and-water mixture resulted in lower wall temperatures, indicating an improved heat transfer performance. The best-performing fluid (5% v/v 1-Butanol-water mixture) were also investigated at four different inclinations (+/- 45° and +/- 90°). Trends were identified by comparing the average wall heat flux, heat transfer coefficients and wall temperatures for the range of heat fluxes, all working fluid and different inclination cases.

19. Experimental Study of Flow Boiling Characteristics in High Aspect Ratio Microchannels with the Effect of Flow Orientation

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The high energy dissipation rate that can be achieved by utilising flow boiling in mini/micro systems triggers extensive research in this area. One of the important aspects that need to be resolved is the importance of flow orientation on boiling performance. The aim of this study is to investigate the flow boiling characteristics of flow boiling in the high aspect ratio microchannels, which consider the effect of flow orientation. The present experimental study utilised HFE7000 as a working fluid with a mass flux of 28 kg m-2 s-1. In addition, a rectangular borosilicate channel, with a width-to-height aspect ratio of 10 and a hydraulic diameter of 909 µm, was used. It was coated by a tantalum layer on the four sides of the channel to act as a heating source. Here, the heat flux was set between 4.7 kW m−2 and 18.6 kW m−2. The wall temperature was recorded using a thermal camera. It is combined with pressure measurement to record the pressure fluctuation during the flow boiling. The analysis of the experimental data reveals that thermal performance is influenced by both heat flux and flow orientation. Equally important, the result of FFT analysis on the pressure data shows that the vertical upward flow produces a higher dominant frequency compared to the horizontal flow.

20. Flow boiling heat transfer with self-rewetting fluids

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Self-rewetting fluids offer a promising solution in boiling compared to conventional fluids by delaying surface dry-out regions through their unique surface tension characteristics. However, questions remain on the heat transfer capabilities of these fluids in microchannel flow boiling applications. Studies so far rely primarily on experiments which are limited by the data acquisition and, in particular, key information such as dynamic variation of heat-transfer coefficients as a function of flow-regime transition cannot be captured. In this study, we perform a comprehensive numerical investigation to explore the flow boiling heat transfer characteristics of water (as the conventional fluid) and a 5% v-v butanol-water mixture (as the self-rewetting fluid) in microchannels. To accurately capture the intricacies of flow boiling at the microscale, we employ the Volume of Fluid (VOF) method along with the modified Schrage evaporation model by Hardt and Wondra (2008). Our Nusselt number predictions have been validated against our experimental data by Venter et al (2023). Also the bubble shapes are qualitatively similar to those found in our experiments. Our simulations further analyse heat transfer capabilities and surface dry-out region formation rates as a function of flow-rates. This is important given surface tension effects are more dominant at low Reynolds numbers. This analysis aims to deepen our understanding of the potential of self-rewetting fluids under flow boiling conditions, at low Reynolds numbers.

21. Analysis of wettability effect on the heat transfer coefficient in pool boiling

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Multi-phase systems with phase-change phenomena, in particular boiling, are common in many industrial applications, including power generation plants and thermal management of high-power and high-dissipation-rate micro-devices which would burn out if not cooled properly. Due to the non-equilibrium thermodynamics and the complexity of coupling the heat and mass transfer in phase-change and surface processes, these systems are difficult to describe accurately. Although experiments have been conducted to study boiling, its mechanisms and heat transfer characteristics are still not understood completely. We simulate pool boiling using the diffuse interface method (DIM) embedded in our home-grown "TPLS" solver. This method allows the imposition of a boundary condition to prescribe wettability removing the stress singularity at the three-phase contact line, thus enabling us to analyse the role of surface features on heat transfer coefficient, bubble growth and bubble departures. Our framework also allows simulation of populations of bubbles and analyse bubble interactions at varied bubble sizes for different wettabilities as a function of superheat. We compare our simulations with our nucleate boiling experiments using FC72 on silicon surfaces. Our simulations show the importance of surface tension on departure conditions, suggesting a higher heat transfer coefficient in hydrophilic cases. Conversely, we have found limited bubble growth rate on hydrophobic surfaces. In hydrophobic cases, the larger amount of residual vapour left on the heater surface after bubble departure limits the coolability of the substrate but it might promote the growth of forming bubbles subsequently.

22. Numerical modelling of bubble dynamics on roughened surfaces

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The continuous trend of increasing computational power is coupled to ever increasing heat generation that has to be dissipated. Pool boiling of specialised refrigerants or sub-atmospheric pressurised water, coupled with simple mechanically roughened surfaces, is a potent candidate for this. To date, however, boiling processes are not fully understood yet, resulting in over- or under-design of critical components. Active experimental research is in progress globally. Computational fluid dynamics (CFD) is a powerful supplement to experimental work, which is practically limited in terms of equipment, measurement, and visualisation. The focus of this work would be the numerical investigation of the effects differing roughness magnitudes and topologies have on the bubble dynamics of a single bubble. Before any CFD work could be attempted, methods of meshing a roughened surface were investigated that would communicate well with the CFD package used (OpenFOAM). Due to its scripting power and relative speed, gmsh, an open source meshing tool, was selected. The simulation was validated against recent experimental work with water at atmospheric pressure on a perfectly smooth surface. Random roughness profiles of varying average magnitudes were then simulated for water at atmospheric pressure, and the bubble growth rate, departure time, and departure radius are compared to that of the smooth surface. Recommendations were also made for future experimental work on the level of roughness required to guarantee nucleation site preference.

23. Numerical Investigation of the Influence of Cavity Geometry on Bubble Dynamics in Nucleate Pool Boiling Conditions

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Nucleate boiling is a highly efficient heat transfer process and is found in a wide array of applications from large-scale energy production to the small-scale cooling of electronics. The boiling process has been shown to be highly dependent on the geometry of the heated surface with investigations focusing on surface roughness, surface porosity and structured surface enhancements such as micro channels and cavities. A better understanding of how surface geometry influences the nucleate boiling process will allow for more optimized designs of boiling applications. In this study we focus on structured micro-cavities, specifically how the shape and size of cavities influences the growth and dynamics of a single nucleating bubble. Investigating this topic experimentally is an expensive endeavor as it requires precise manufacturing of several cavities. Approaching the topic numerically will allow for a large range of cavity sizes of varying shapes to be tested and additionally allow for observations of the bubble growth within the cavity (which is not easily achieved with experimental methods).

THERMASMART
Thermal Management of Microprocessors

4th ThermaSMART Workshop with University of Pretoria, Cape Town – 10 & 11 August, 2023

Thursday – 10th August 2023		
9:00 – 9:30	Registration opens	Light refreshments
9:30 – 10:00	Opening of the workshop	Prof. Prashant Valluri Dr. Marilize Everts
10:00 – 11:00	Keynote 1	Mr John Ferreira
11:00 – 11:20	Coffee break	
11:20 – 11:40	Thermal hysteresis in the Leidenfrost effect	Yutaku Kita
11:40 – 12:00	Fluid motion without energy supply	Panagiotis Theodorakis[1*], Russell Kajouri[1], Piotr Deuar[1], Rachid Bennacer[2], Jan Židek[3], Sergei Egorov, Andrey Milchev
12:00 – 12:20	TACoolTPS – Advanced Cooling of high power microsystems using Two-Phase Flows Systems in Complex Geometries	Gustavo R. Anjos, Prashant Valluri
12:20 – 12:40	Surprising dynamics of ellipsoidal particles in flow	Rama Govindarajan
12:40 – 13:40	Lunch & Networking	
13:40 – 14:00	Chaotic Orbits of Immersed Ellipsoids	Andrew Boyd, Prashant Valluri, David Scott, Mark Sawyer, Rama Govindarajan

14:00 – 14:20	Exploring Dynamics and Hazards of Levitating Droplets on Superheated Gallium: Implications for High-Temperature Applications	Adrian Jonas, Daniel Orejon, Khellil Sefiane
14:20 – 14:40	Heat transfer characteristics in high temperature thermal energy storage	Shuai Zhang and Yuying Yan
14:40 – 15:00	Effect of Needle and Dosing Parameters on Contact Angle Hysteresis	Janice To, Rodrigo Ledesma Aguilar, Khellil Sefiane, Daniel Orejon
15:00 – 15:20	Coffee break	
15:20 – 15:40	Effect of surface curvature on confined jet impingement boiling	Daiman Somerville, Kenneth Craig, Prashant Valluri
15:40 – 16:00	Introducing Vortices via Vortex Generators as a method of Spent Vapour Removal during Jet Impingement Boiling	Francois le Roux, Kenneth Craig, Prashant Valluri
16:00 – 16:20	Experimental and Numerical Heat Transfer Investigation of Reverse Jet Impingement	Abdallah Ahmed, Yuying Yan
18:30	Networking Dinner	Lagoon Beach Hotel

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4th ThermaSMART Workshop, with University of Pretoria, Cape Town – 10 & 11 August, 2023

Friday – 11th August 2023		
9:00 – 9:30	Registration opens	
9:30 – 10:30	Keynote 2	Prof Tunde Bello-Ochende
10:30 – 10:50	Coffee break	
10:50 – 11:10	Solar Evaporation Enhancement via Synergistic Cooperation between Copper Foam and Graphene Oxide Functionalisation	Fengyong Lv, Jie Miao, Jing Hu, and Daniel Orejon
11:10 – 11:30	Evaporating populations of sessile droplets comprising binary mixtures	Debarshi Debnath, Anna Malachtari, George Karapetsas, Daniel Orejon, Khelil Sefiane, Alidad Amirfazli, and Prashant Valluri
11:30 – 11:50	Binary Mixture Droplet Wetting and Evaporation Phase Change on Hydrophilic Structured Surfaces	Khaloud Moosa Al Balushi, Gail Duursma, Prashant Valluri, Khellil Sefiani, Daniel Orejon
11:50 – 12:10	Transient growth stability analysis of evaporating sessile drops comprising binary mixtures	Katie Thomson, George Karapetsas, Yutaku Kita, Prashant Valluri, Khelil Sefiane, Daniel Orejon
12:10 – 13:10	Lunch, Networking	
13:10 – 13:30	Dropwise Condensation on Silicone Oil Grafted Surfaces	Anam Abbas, Gary G. Wells, Glen McHale, Khelil Sefiane, Daniel Orejon
13:30 – 13:50	Use of an Agent Based Approach to Study Drop-wise Condensation Heat Transfer	Joaquin E. Ramirez-Medina, Mehdi Ataei, Alidad Amirfazli

13:50 – 14:10	Experimental Flow Boiling with Binary and Self-Rewetting Mixtures at Low Mass Fluxes in a High Aspect Ratio Microchannel at Different Inclinations with One-sided Heating	Mandi Venter, Arif Widyatama, Daniel Orejon Mantecon, Jaco Dirker, Khellil Sefiane
14:10 – 14:30	Experimental Study of Flow Boiling Characteristics in High Aspect Ratio Microchannels with the Effect of Flow Orientation	Arif Widyatama, Daniel Orejon, Khelil Sefiane
14:30 – 14:50	Flow boiling heat transfer with self-rewetting fluids	André Pienaar, Jaco Dirker, Prashant Valluri
14:50 – 15:10	Coffee break	
15:10 – 15:30	Analysis of wettability effect on the heat transfer coefficient in pool boiling	Giada Minozzi, Alessio D. Lavino, Edward R. Smith, Jionghui Liu, Tassos Karayiannis, Khellil Sefiane, Omar O. Matar, David Scott, Timm Krüger, and Prashant Valluri
15:30 – 15:50	Numerical modelling of bubble dynamics on roughened surfaces	Wilhelm Johann van den Bergh, Panagiotis E. Theodorakis, Marilize Everts
15:50 – 16:10	Numerical Investigation of the Influence of Cavity Geometry on Bubble Dynamics in Nucleate Pool Boiling Conditions	Mitchell Whiting, Marilize Everts, Panagiotis E. Theodorakis
16:10 – 17:10	Business meeting - All	Next Steps for ThermaSMART Network & concluding remarks
18:30	Networking Dinner	Quay 4 (V&A Waterfront)