Thermodynamically Efficient Heat Exchangers

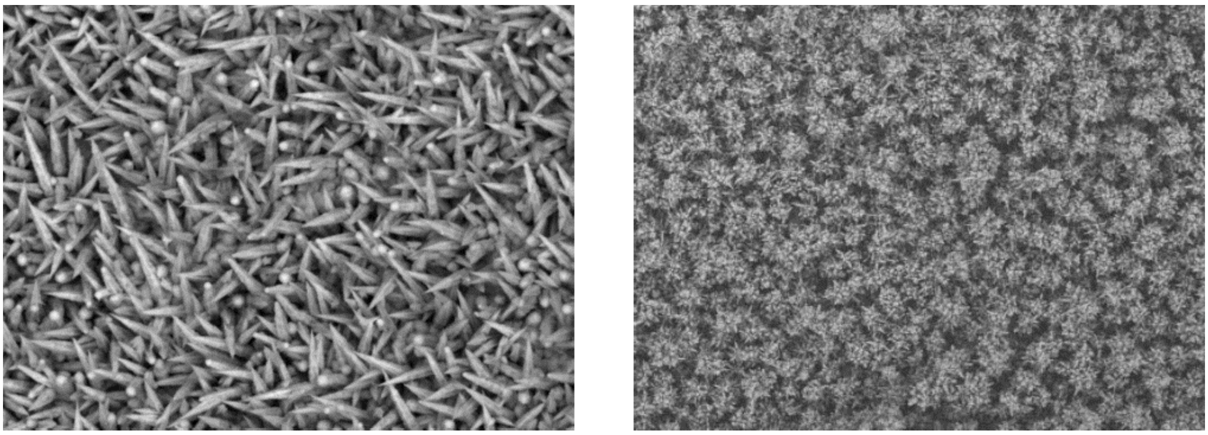
Modifying heat transfer surfaces with nanocoating has the potential to increase the thermal performance in two phase flow as the structure of the coating is expected to increase the number of nucleation sites and hence the heat transfer rate.

It is envisaged that this technique will enhance the performance of heat exchangers, saving space and contributing to improvements in the energy efficiency of thermal systems.

The aim of this project is to compare the thermal performance in two-phase flow of a plate heat exchanger (PHE), with and without nanocoating on the refrigerant side of the heat transfer surface. The goal is to quantify possible enhancements in the overall heat transfer coefficient, and to record the effect of the coating on the pressure drop across the PHE.

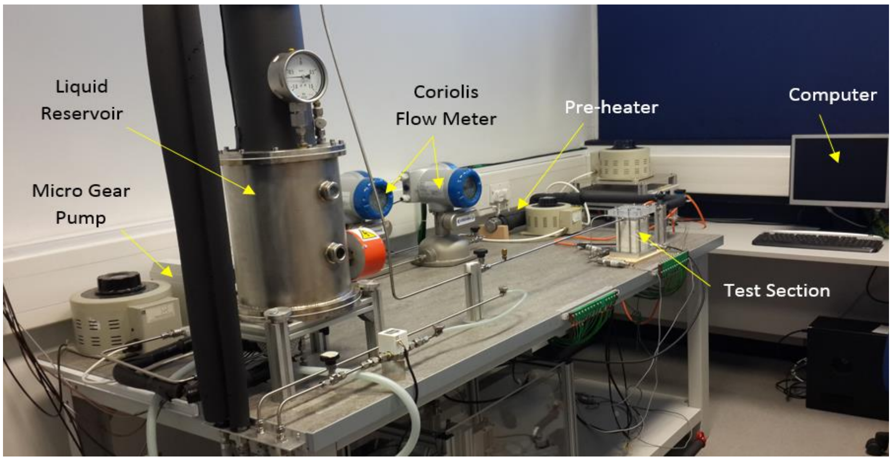
The operating pressure and mass flow rate of refrigerant (R245fa), as well as the heat applied on the water side of the heat exchanger are varied during experimentation. These parameters affect flow boiling characteristics and this effect is quantified as changes in the overall heat transfer coefficient and the pressure drop.

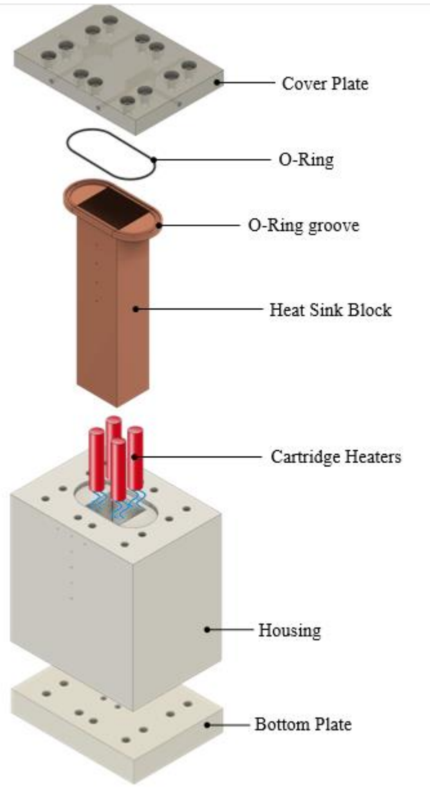
The research is funded by Innovate UK and is in collaboration with ***Oxford Nanosystems*** and ***SWEP***.



nanoFLUX® heat transfer coating by Oxford nanoSystems

Two-Phase Flow in Rectangular Multi-microchannels using HFE-7100 as a Dielectric and Eco-friendly Fluid



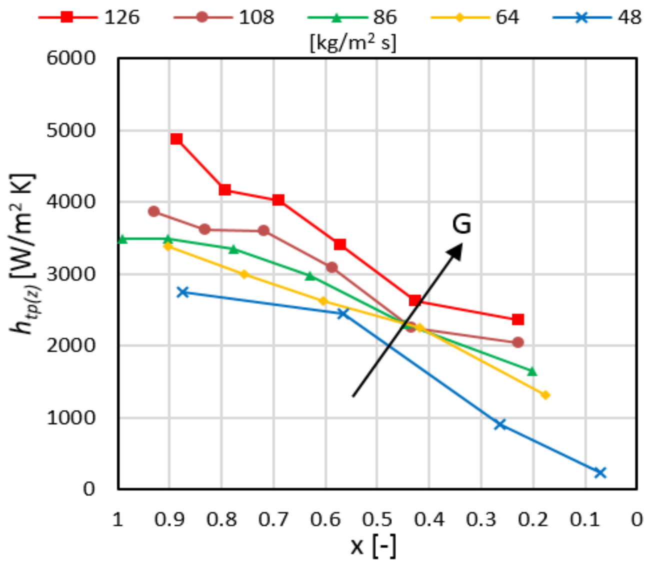


The dissipation of high heat fluxes from small areas at uniform surface temperatures is one of the greatest challenges in the thermal design of electronic devices and other high heat flux devices such as laser diodes, supercomputers etc. Two-phase flow boiling in microchannels has received considerable attention recently to develop microscale systems for such devices that can remove heat fluxes up to 10 MW/m^2.

The understanding of flow boiling characteristics in microscale flows is therefore essential to design and fabricate robust multi-microchannel evaporators and small-scale pumped loop cooling systems for such applications. A state-of-the-art research facility was designed and constructed to study flow boiling behaviour in microscale flows using HFE-7100, a non-toxic, environmentally-friendly heat transfer fluid.

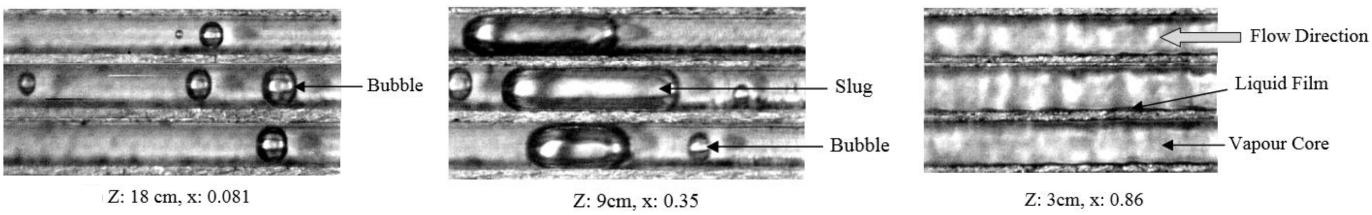
The objectives of the work, summarised below, are to:

- Investigate the effect of aspect ratio and type of material on the flow boiling heat transfer coefficient and pressure drop.
- Investigate the effect of refrigerant mass flux, vapour quality and coolant side on the condensation heat transfer.
- Evaluate the existing flow pattern maps, heat transfer correlations and pressure drop correlations.
- Design an integrated multi-microchannel evaporator and condenser system for cooling electronic components in the high heat flux range.



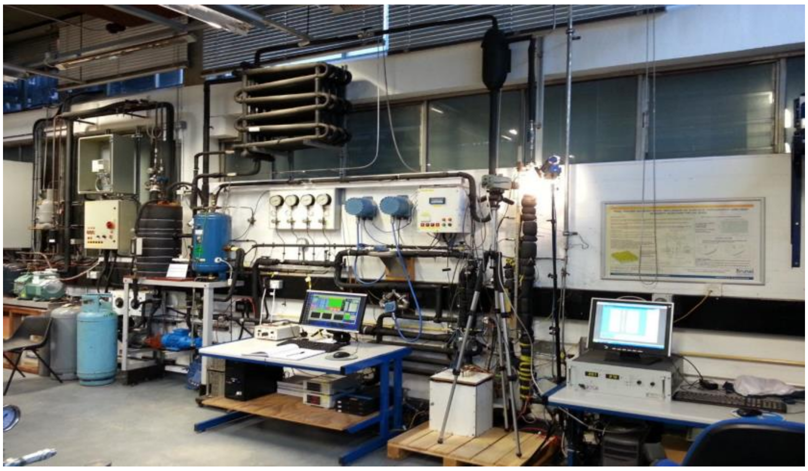
Effect of refrigerant mass flux on the condensation heat transfer

The project was funded by ***EPSRC*** in collaboration with ***University of Edinburgh***, ***Thermacore Europe Ltd, Selex*** and ***Rainford Precision***. Support for Ali is provided by the government of Iraq.



Flow patterns along the condenser

Flow Boiling Characteristics of R245fa in a Vertical Small-diameter Tube



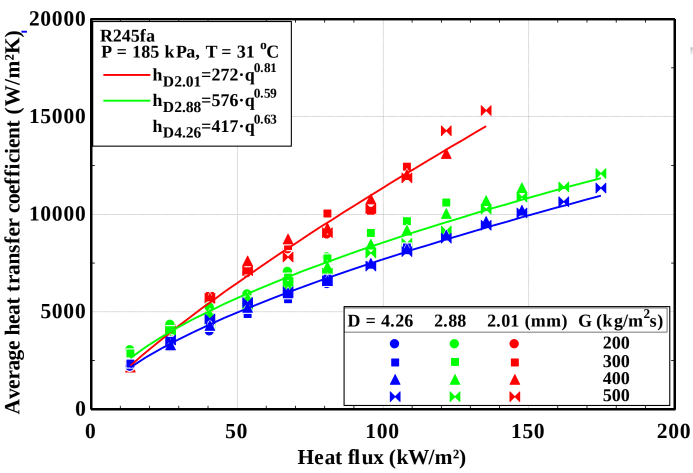
The miniaturisation and rapid developments in the performance of electronic systems have resulted in high heat flux levels and necessitated research in innovative cooling systems. Flow boiling in micro-tubes and single/multi microchannels is one of the most promising solutions.

However, progress in this area is hindered by the lack of understanding of the flow boiling heat transfer mechanism(s) and the availability of accurate correlations predicting flow patterns, heat transfer rates, pressure drop as well as the occurrence of dry out.

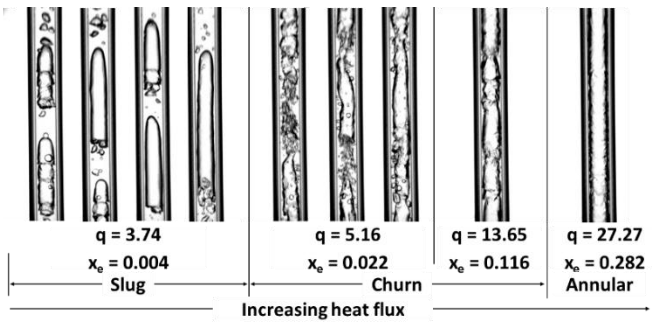
The study focuses on flow boiling in vertical tubes of R245fa and has the following specific objectives:

- Study the effect of tube diameter on local heat transfer coefficient and flow patterns.
- Study the effect of heat and mass fluxes on local heat transfer coefficient and flow patterns.
- Investigate the effect of system pressure on local heat transfer coefficient and flow patterns.
- Study the effect of coatings on the heat transfer rates at microscales

This study is a part of a long term investigation at Brunel University London to help elucidate the prevailing fundamental phenomena and develop correlations capable of predicting flow pattern transition boundaries, heat transfer rates and pressure drop.

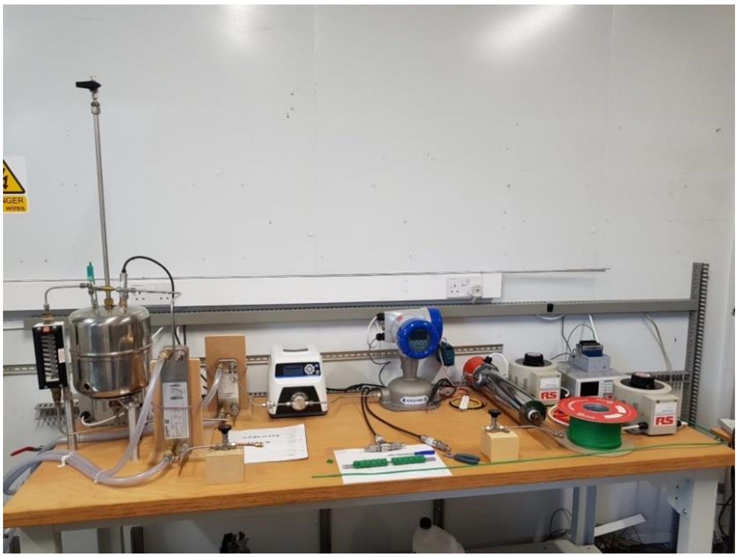


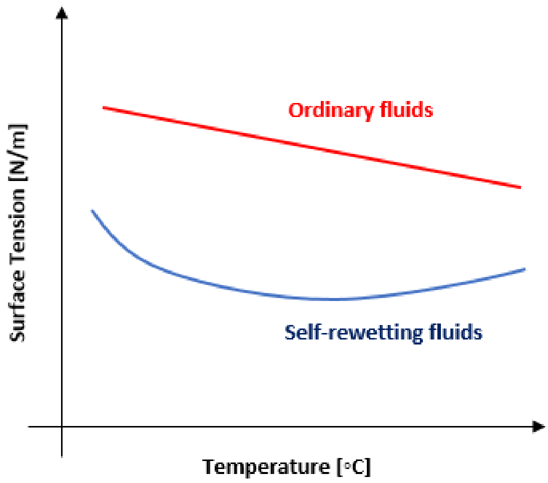
Effect of diameter on average flow boiling heat transfer coefficient of R245fa



Flow patterns of R245fa in a 4.26 mm inner diameter tube

Flow Boiling and Condensation of Mixtures in Microscale



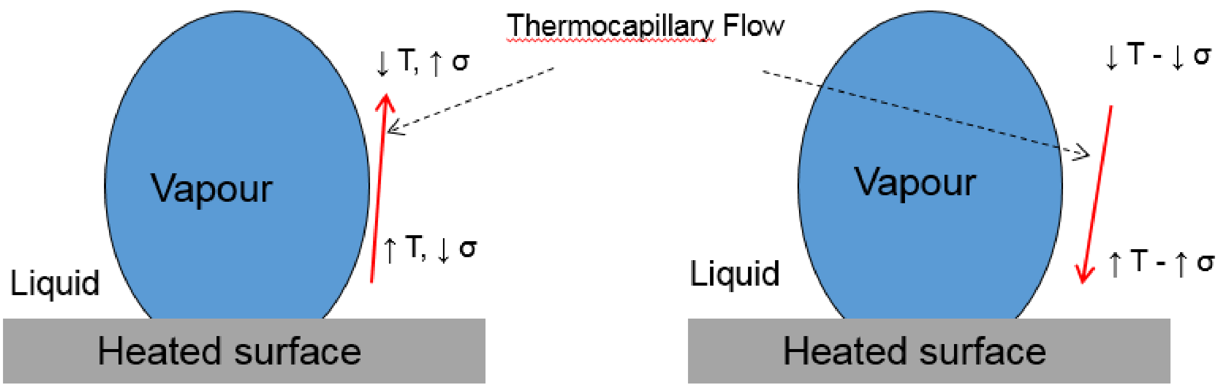


Mixtures of small amounts of certain alcohols in water provide significant benefits when used for cooling in flow boiling and condensation in microchannels. However, the underlying mechanisms are still not well characterised nor understood. This project aims to provide a detailed understanding of the mechanisms occurring in evaporation of ordinary (e.g. water-ethanol) and self-rewetting (e.g. water-butanol) mixtures in micro-scale channels.

The study of the flow boiling mechanisms of these mixtures will provide the necessary knowledge basis to develop design tools for ultra-compact and highly efficient cooling systems. The experimental investigation will test a wide range of compositions to determine the optimum one for a closed evaporator-condenser unit. The specific objectives of the project are to:

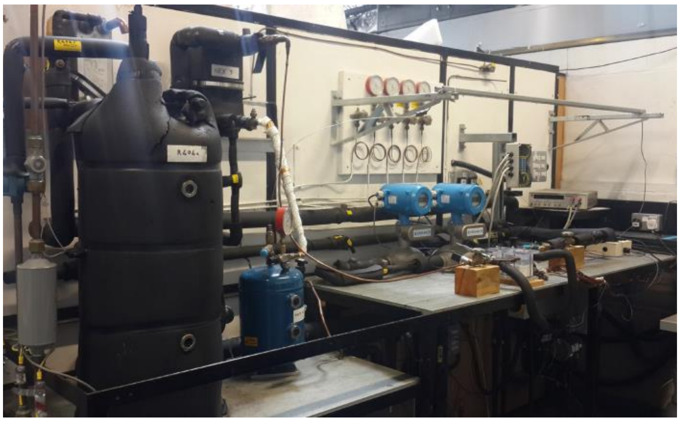
- Assess flow boiling heat transfer rate differences and parametric dependence of ordinary and self-rewetting mixtures in a single microchannel with variable surface characteristics.
- Assess flow boiling heat transfer capabilities of ordinary and self-rewetting mixtures in metallic multi-microchannels.
- Develop correlations predicting heat transfer, pressure drop and CHF of boiling of mixtures in microchannels.
- Design and build a prototype thermal management system transferring heat at a rate in excess of 2 MW/m^2.

The project is funded by the ***EPSRC*** and is in collaboration with ***Queen Mary University,*** the ***University of Edinburgh, Oxford Nanosystems, Thermacore, Rainford Precision*** and ***Super Radiator Coils.***



Ordinary fluid **Self re-wetting fluid**

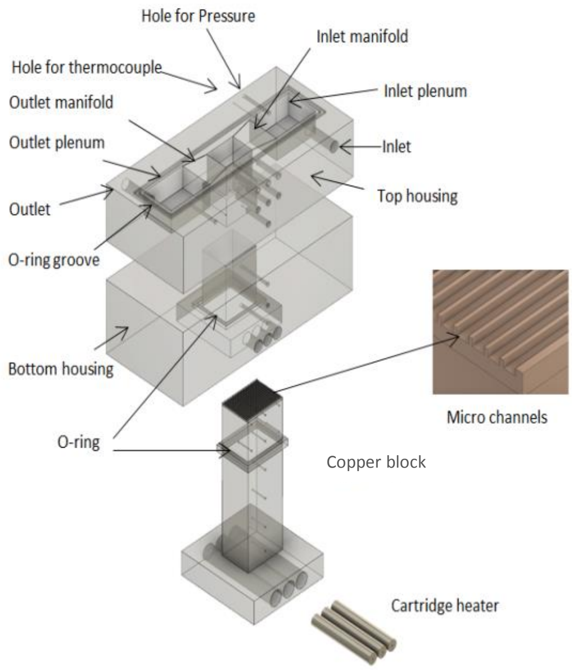
Flow Boiling in Multi-microchannel for Cooling High Heat-flux Devices Including Solar Concentrating Photovoltaics



As the world faces the challenges related to the ever increasing energy demand and global warming, there is an urgent need to develop cost-effective sources of clean energy.

Low carbon power generation technologies such as solar photovoltaic (PV) and, in particular concentrating photovoltaic (CPV) which uses lenses and mirrors to focus sunlight onto highly efficient solar cells, offer a promising sustainable solution to these challenges.

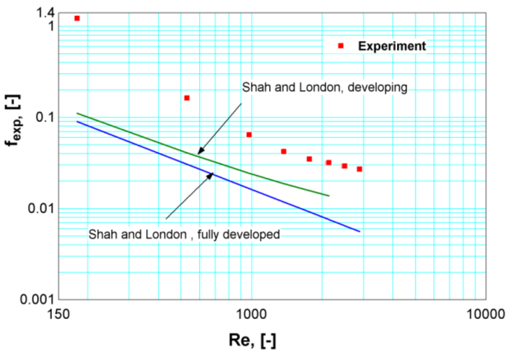
Currently one of the major limitations that prevents a large scale uptake of CPV technology is the significant reduction in the conversion efficiency caused by higher cell temperatures. This work focuses on cooling of CPV systems by using fluid boiling in multi-microchannel.

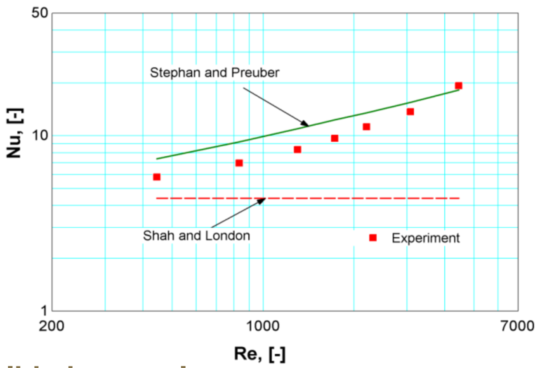


The main objectives of the project are to:

- Study the effect of aspect ratio on flow boiling heat transfer, pressure drop and flow patterns.
- Explore the effects of refrigerant type using R134a and R1234yf on microchannel performance.
- Investigate instabilities or flow reversal and the corresponding mitigating strategies.

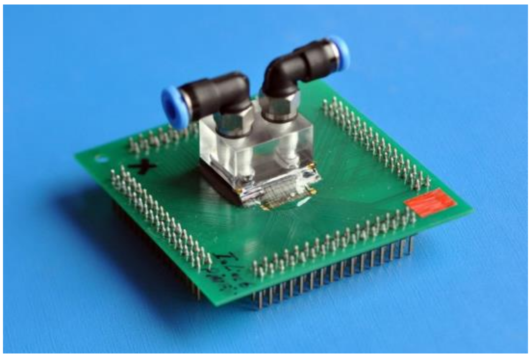
Recommendations for the design of appropriate microscale heat sinks that can meet typical loads encountered in electronic devices, including CPV cells and other similar high heat flux devices will be proposed.



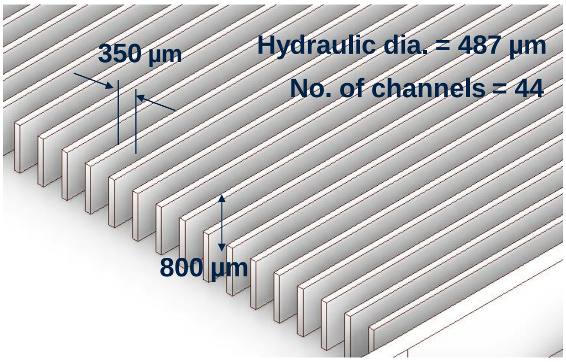


Single phase validation results

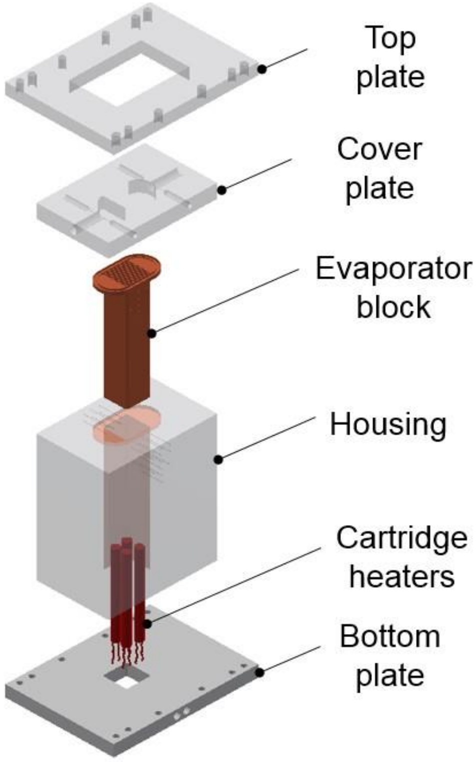
Integrated Cooling for High Heat-Flux Power Electronics



Integrated microchannel phase-change module, Atienza (2010)



Microchannel dimensions



Test section, evaporator footprint 20 mm x 20 mm

Heat dissipation requirements in power electronics are predicted to reach 5 – 10 MW/m^2 in the near future. Two-phase microchannel heat sinks are widely studied for compact heat exchanger applications. Recently, surface modified heat exchangers have received considerable attention due to the potential to reach higher thermal performance per footprint m^2. Surface structures in the micro-scale are used to manipulate flow and bubble dynamics to achieve heat transfer enhancement.

A comparative study of plain microchannel evaporators and enhanced channels of identical footprint area is conducted using environmentally-friendly refrigerant HFE7200. Surface modification techniques will be performed using ***electron beam enhancement (TWI)*** and ***nano-coatings (Oxford nanosystems)***. The main objectives are as follows:

- Compare flow boiling characteristics of modified surfaces with microchannel evaporator under similar operating conditions.
- Study the effect of surface morphology on flow boiling heat transfer and pressure drop of HFE7200.
- Evaluate experimental heat transfer and pressure drop data against existing prediction models.

The project aims to develop an integrated thermal management system for harsh-environment avionics with power dissipation of > 2 MW/m^2 in ambient conditions of -40 °C to +70 °C.

The research is funded by ***TMD Technologies Ltd***.

Protex: Prototype Electrochemical Device for Killing Bacteria in Recirculating Water Systems

The ever increasing number of systems storing water that by design, harbour bacteria such as cooling towers, hot water systems, spas, swimming pools and air-conditioning has resulted in disease outbreaks caused by opportunistic bacteria such as Legionella and Pseudomonas. Bacteria proliferate in hot water systems where suitable growth temperatures and scale sediments provide the ideal habitat; add in outlets where aerosols are formed and there is a potential lethal mix of factors that increase the risk from exposure to pathogens. Thus the hot water systems have been identified as the most common source of Legionnaires disease.

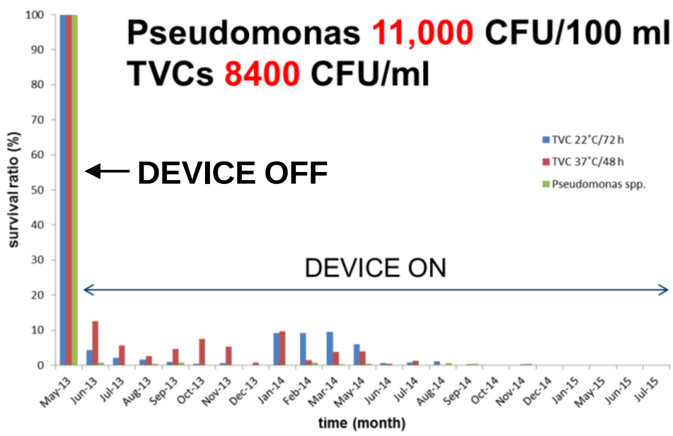
Protex is an electrolytic cell that uses uniquely designed electrodes to pass an electric current through the water. When water enters the reaction vicinity, bacteria are killed by direct contact with the electrodes and by the disinfectants formed from the electrolysis of the water and the natural salts dissolved within it.

The most evident advantage being that the disinfectants are generated in-situ, eliminating the transport, storage, handling and dosing of hazardous chemicals. Given that **Protex** generates disinfectants, **hot water temperatures can be lowered**, reducing the energy associated with heating water in buildings and enabling the use of greener technologies to heat the water. Research objectives are the following:

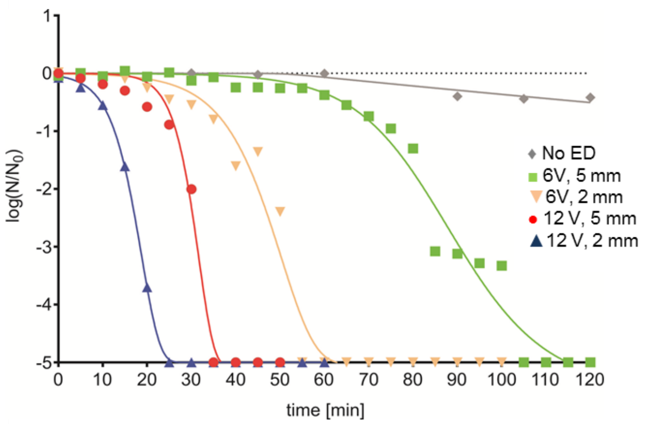
- To optimise the design of the device.
- To improve the durability.
- To reduce the manufacturing costs.
- To assess the long-term performance of the device for killing bacteria in recirculating water systems both under laboratory and actual building application.

The project is funded by ***Innovate UK***, supported by ***ESG***.

Protex installation in actual buildings



Effect of Protex on Pseudomonas flora in a medical centre



Inactivation rate of E.coli dependent on applied voltage/current & inter-electrode spacing

Energy-Use Minimisation via High Performance Heat-Power-Cooling Conversion and Integration: A Holistic Tailored-Molecules to Next-Generation Technologies to Smart-Systems Approach

This research project is funded by the EPSRC and is in collaboration with Imperial, Birmingham, Cambridge and 10 other industrial partners.

Project aims and objectives include:

The main aim of this project is to investigate a next-generation ORC device with the following characteristics:

- Significantly improved performance compared to current systems while observing simplicity of design and affordability of manufacture leading to significantly reduced capital costs and payback, thus making this an economically viable proposition;
- Built-in modularity and flexible transferability to a range of manufacturing applications and settings.

To achieve the aims above, the key focus areas of the project are:

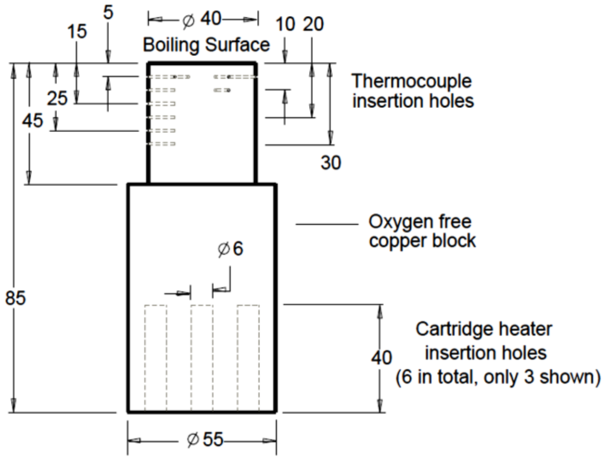
- Design of new, process-optimised mixtures of chemicals as working fluids, possibly with stable nanoparticle suspensions, with the help of computer-aided molecular-design methodologies;
- Design of minimal-cost heat exchangers with microchannels, patterned or structured surfaces. A second aim arises from the appreciation that any such solution must operate within a holistic energy framework. For this reason, a dynamic, interactive design and total energy integration tool will also be developed to help identify opportunities in specific settings/ case studies, based on actual detailed plant data.

The specific objectives are to:

1. Compile an ORC model with detailed component descriptions: pump, expander, heat exchangers.
2. Develop SAFT group-contribution methodologies for working fluid (mixture) property prediction.
3. Propose nano-working fluids and coated heat exchange components, adding integrated storage.
4. Combine the models from (1) & (2) into a whole-energy-system design and optimisation platform.
5. Demonstrate the platform from (3) in two case studies based on actual plant data, focusing specifically on optimised working-fluid mixtures and innovative heat-exchanger designs.

If successful, the incorporation of novel, advanced heat-exchange configurations and architectures (with microchannels and/or nanofluids) into next-generation heat exchangers will improve thermal transport and reduce component size and cost, while unlocking the potential of application-tailored working-fluid mixtures for high efficiency and power. This unique position will act as a springboard for the further development of breakthrough waste-heat recovery solutions with the potential to transform industrial practices and capabilities, leading to step-change energy-input reductions to manufacturing, and significantly increased resilience of manufacturing to uncertainty in primary energy supply.

Enhanced Pool Boiling Heat Transfer Facility: Passive and Active Heat Transfer Enhancement

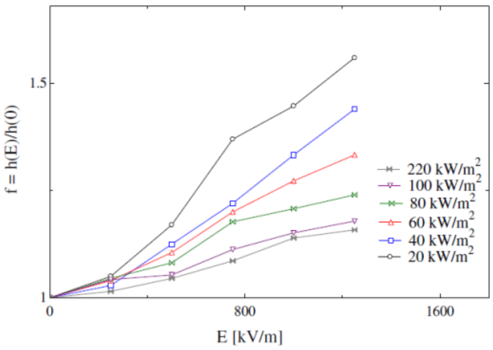


Flow visualization and heat transfer experiments on pool boiling on flat surfaces are carried out to assess the performance of both active and passive heat transfer enhancement techniques with this heat transfer mode.

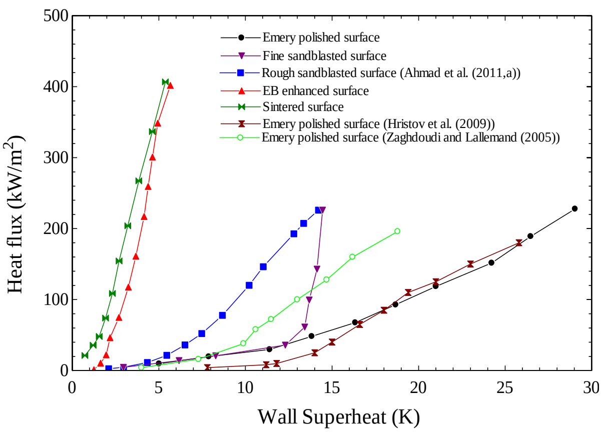
The experimental facility consists of a boiling chamber housing the heater block, a condenser, the cooling water loop and an R134a cooling unit. The system operates as a two-phase thermosyphon where the vapour produced in the boiling chamber condenses in the water-cooled condenser and the condensate returns to the chamber via a filter/dryer. The cooling water used in the condenser is circulated and chilled in a heat exchanger using an R134a vapour compression refrigeration unit. The boiling chamber is a vertical stainless steel 304 cylinder diameter in 220 mm and 300 mm high. Two circular glass windows with 140 mm diameter were mounted on the sides of the chamber in order to visualize the boiling process. The boiling surfaces are formed on the 40 mm upper face of a cylindrical heater block manufactured from oxygen-free copper. Cartridge heaters at the lower end of the heater block are regulated using a variac to provide the heat source.

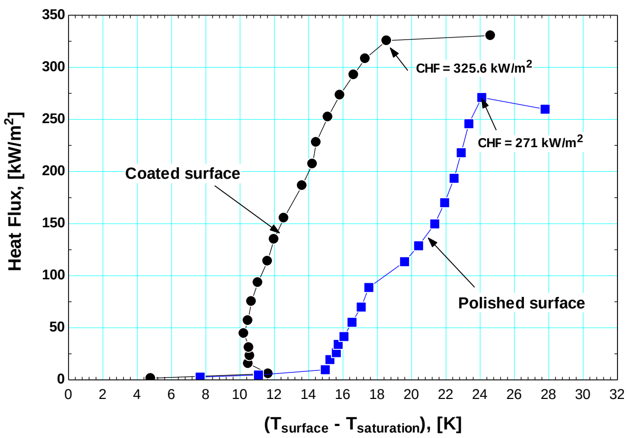
A high intensity electric field can be applied between an electrode and the earthed boiling surface to provide active heat transfer enhancement – Electrohydrodynamic (EHD) Heat Transfer Enhancement. At the same time various enhanced surfaces – passive heat transfer enhancement - can be examined by changing the boiling surface.

This facility is used both for research and constancy work by the Group.



Electrohydrodynamic enhancement





Passive heat transfer enhancement on modified surfaces