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ENHANCING HEAT TRANSFER IN MICRO PIN FIN HEAT SINKS USING FLOW OSCILLATIONS

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1. ABSTRACT

There is a growing need to develop high flux cooling solutions to address thermal management challenges in a range of applications, including data centres, power electronics and microprocessors. Micro pin fin heat sinks are a state of the art liquid phase cooling solution, but high heat transfer coefficients remain dependent on high flow rates, leading to large pumping costs. This paper investigates the use of oscillating flows in micro pin fin heat sinks to enhance heat transfer at lower net flow rates. Brightfield micro particle image velocimetry was used to assess flow patterns and the turbulent kinetic energy was measured around 9 different micro pin designs. Once the flow became fully reversing the turbulent kinetic energy plateaued. The best performing pin was the 750 μm triangular pin with a normalised turbulent kinetic energy of 1.7.

2. INTRODUCTION

To meet net zero targets the data centre industry must be made more energy efficient. They created 1 % of the energy demand in 2018 and is predicted to grow to 21 % of global energy demand in 2030 [1]. Between 30% and 50 % went on cooling the data centre [2]. It is clear from this that a key to reducing the energy consumption is to reduce the energy required to cool the data centres. Micro pin fin indirect water-cooling heat sinks are a promising technology which have a cold plate mounted to the computer with an array of micro pins are attached to the other side which a liquid coolant is passed through. This has several advantages: high surface area, high Nusselt number and high convective heat transfer coefficient all of which make them very well suited to cooling datacentre electronic equipment. The issue is that as with all micro scale fluid flow high pressure drops are required to unlock high heat transfer coefficients that come with turbulent flow. In previous studies in baffled tubes, turbulent-like heat transfer coefficients have been observed at laminar net flow rates (and low overall pumping power) when sinusoidal flow oscillations are applied [3]. The pins in a micro pin fin heat sink resemble the periodic contractions in the orifice baffled tube so the potential to enhance heat transfer in pin fin heat sinks whilst reducing the overall pumping duty is clear.

3. METHDOLOGY

Probing the flow will enable us to observe the characteristic vortex winding and unwinding present in oscillatory flows. Being able to observe these will enable quantification of the mixing in the system as an

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approximation of heat transfer without requiring the costly manufacture of prototype heat sinks. To do this a Brightfield micro particle image velocimetry rig was constructed where a Photron Fastcam SA3 observed the micro pin fin which was backlit using a halogen light source. The flow was pumped through the channel using two Tricontinent C3000 syringe pumps where one provided the net flow and the other the oscillation. The rig is shown in Figure 1. Single pin channels of 3 shapes and 3 sizes were investigated. Triangular, square and circular at 250 µm, 500 µm and 750 µm each. These channels were all 2.1 mm deep by 1.9 mm wide made using a Formlabs 3+ stereolithography resin printer to make the body and pin and then an acrylic lid was glued on for optical clarity. To assess the mixing the turbulent kinetic energy was assessed. This measure is strongly correlated with mixing and heat transfer so it can be used to assess the variation in the heat transfer without machining each heat sink [5]. The equation used can be seen in equation 1 where the TKE is the normalised turbulent kinetic energy (TKE) which is unitless, v'_x and v'_y the velocity fluctuation in the x and y directions respectively in ms^{-1}, and U the velocity magnitude in ms^{-1}. The velocity ratio is used to model the strength of the oscillation given in equation 2 where Ψ is the velocity ratio which is unitless and $2\pi f x_0$ the angular velocity in ms^{-1}. If the velocity ratio is greater than one the flow is said to be fully reversing, i.e. the velocity becomes negative on the downstroke of the oscillation.

$$TKE = \frac{\left(\overline{v_x'}^2 + \overline{v_y'}^2\right)}{U^2} \qquad (1)$$

$$\Psi = \frac{2\pi f x_0}{U} \qquad (2)$$

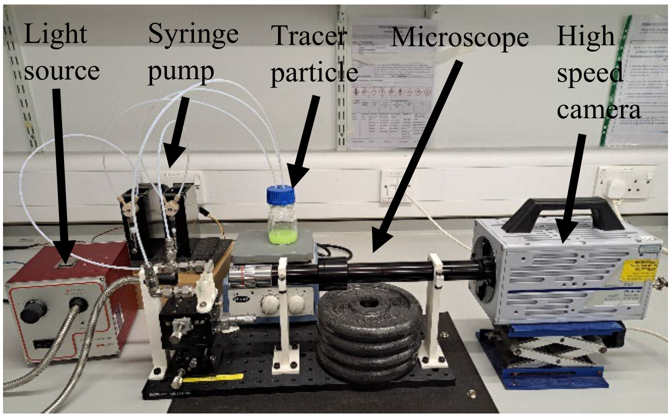

Fig. 1 The bright field micro particle image velocimetry rig.

4. RESULTS

Figure 2 shows that the turbulent kinetic energy increased rapidly from Ψ=0 to Ψ=2, when Ψ=2 the flow is fully reversing and vortex creation and destruction is occurring enhancing mixing, after this the vortexes are only growing bigger. After Ψ=2 the TKE plateaus between 1.2 and 1.8 at Ψ=5. The best performing pin was the 750 µm triangular pin at a velocity ratio of 3. This could be explained by the larger pin creating a greater disturbed region of flow behind the pin. The TKE values are clustered based on pin hydraulic diameter hence the pin Reynolds number not channel Reynolds number influenced it. The clustering shows that the best mixing and heat transfer may be found with larger pins however you could get fewer larger pins in a fixed area reducing the potential surface area which is an exchange that needs assessing with a heat transfer rig. Future work includes an assessment of the heat transfer performance of full pin-arrays.

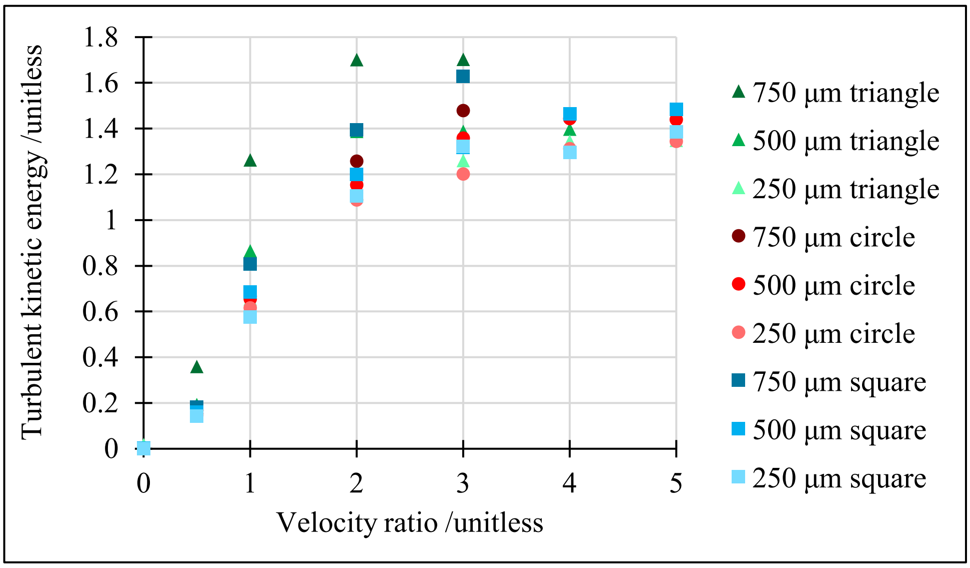

Fig. 2 The variation of the turbulent kinetic energy with velocity ratio as a function of pin shape and size.

5. CONCLUSIONS

1. The results show that flow oscillations significantly enhance TKE in micro-fin heat sinks.
2. The TKE undergoes a plateauing off after Ψ=2 suggesting limited gains can be made after this point.
3. The pin TKE clustered based on hydraulic diameter suggesting the TKE is strongly dependent on pin Reynolds number.
4. The 750 μm triangle performs the best out of all the pins.
5. Future work is underway to assess the thermal hydraulic performance of full pin fin arrays subject to oscillating flows.

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