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EXPERIMENAL HEAT TRANSFER INVESTIGATION OF SINGLE REVERSE JET IMPINGEMENT

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ABSTRACT

An initial experimental study has been conducted to evaluate the heat transfer, and pressure loss characteristics of the novel reverse jet impingement geometry, and benchmark against a typical flat plate target geometry. The discharge coefficient data provided in this study was conducted within a Reynolds number range of 20,000 – 60,000, jet-to-target spacing between 2 – 8 jet diameters, and compared against a free jet, a flat target, and a dimple target geometry. Average Nusselt number plots were provided as a function of surface distance from the impingement jet stagnation point, and evaluated within a Reynolds number range of 23,000 – 60,000, at H/d = 4, and against a flat plate target geometry. Results show that the reverse impingement geometry provides an increased overall heat transfer compared to a flat plate target, with a proportional relationship to Reynolds number. Evaluation of the discharge coefficient demonstrates that the reverse scheme has a lower recovery than a flat plate, but does show improvement over impingement into a dimple. The relationship between jet-to-target spacing and discharge coefficient shows that there is very little impact between 4 – 8 jet diameters, but when evaluated at 2 jet diameters, showed a severe reduction.

1. INTRODUCTION

Jet impingement is one of the most effective methods of single-phase heat transfer enhancement in practical applications, as it provides high, localised heat transfer coefficients without the high-pressure losses associated with flow through heavily turbulated channels. Therefore, there are many industries, including turbomachinery, high-powered electronics, and photovoltaic cell manufacture, which are interested in applying jet impingement as a method of enhancing heat transfer. When using an array or row of impinging jets, the jet-jet spacing affects the overall convective coefficient, due to the influence each jet's interference with its neighbours, as illustrated in Figure 1. This study provides an experimental technique for investigating the heat transfer effectiveness of a novel reverse jet impingement geometry, shown in Figure 2, and previously investigated numerically by Ahmed et al [1], with overall aim to reduce negative heat transfer effects of jet-to-jet interaction. This improvement also intends to improve overall heat transfer by increasing the effective internal heat transfer surface area, and by isolating the jet for each nozzle, negate the need to consider jet-to-jet spacing. When using cooling features, such as impinging jets, it is also important to optimise the use of cooling air, and therefore discharge coefficients (C_d) are essential to designers of such systems.

2. METHODS

A modular test section was created to allow for variation of H/d, and an air blower with in-line heaters were utilised to generate a bulk flow of heated air within the Reynolds number range of interest, with fast-action vales allowing for a step change in flow temperature and velocity to the impingement nozzle.

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The experimental work relies on using the Thermochromic Liquid Crystal (TLC) transient technique used previously by Wright et al [2]. Convection heat transfer coefficients from a heated jet to an impingement plate can be deduced by monitoring the time wise temperature rise of the model surface when subjected to a transient convective heating, as shown in figure 3. During a transient test, the coating layer colour change time-point of every pixel on the heat transfer surface is measured by using an image processing technique. Based on the obtained time responses of this TLC coating, the local distribution of Nusselt number could be estimated by solving the Fourier's equation.

To calculate nozzle discharge coefficient, pressure tappings were used to determine static pressure at locations before and after the nozzle.

3. RESULTS AND DISCUSSION

Results showing the radially varying heat transfer distribution were produced at H/d = 4, and for the Reynolds number range, 23,000 – 60,000, and compared against a flat plate at a baseline case of 23,000 Re. Discharge coefficients were provided for a free jet, a flat target, a dimple target, and the reverse impingement geometry at H/d = 4, and Re range, 20,000 – 60,000. C_ds are also provided for the reverse scheme for a H/d range of 2 – 8.

Figure 4 presents the comparisons of Nusselt number distribution over flat and concave targets at 23,000 Re. It is observed that at S/d < 0.5, Nusselt number distributions are very close for the two target plates, with the flat target marginally higher. However, the deviation is significant between the two targets at S/d > 0.5, where the concave reverse jet geometry curvature causes a thinning of the wall jet boundary layer, and therefore generates a larger magnitude of heat transfer. It can also be seen that the vertical walls of the reverse impingement target scheme allow for an extension of the effective heat transfer surface area relative to the flat wall.

Figure 5 shows the Reynolds number dependent local Nusselt number distributions for the case of H/d= 4. All the Nusselt number curves within the Reynolds number range show very similar profile, decreasing along the radial direction from the stagnation point. As expected, Nusselt number is seen to increase proportionally to Reynolds number.

While the local Nusselt numbers of the impinging jet were the main interest of this research, as part of this initial study into the novel reverse impingement geometry, there was also interest in studying the effect of the target plate shape on the jet discharge coefficient, compared against a free jet, a flat plate, and a dimple target, and at a range of Reynolds numbers, and H/d = 4, and is illustrated in Figure 6. The study indicated that whilst the reverse scheme provided a lower recovery than either a flat or dimple target, there was actually an improvement compared to a typical dimple target geometry. The magnitude of this improvement was observed over the entire Re range, 20,000 – 60,000, but was found to narrow as Re increased.

Within the reverse impingement geometry, the effect of the jet-target spacing (H/d) on the discharge coefficient was also assessed. Figure 7 shows that there is small difference between the discharge coefficients of H/d = 4, 6, and 8. Whereas there is sharp reduction in the discharge coefficient at H/d = 2. This reduction of C_d is likely attributable to an early disruption in the potential core, and subsequent choaking of the flow as it circulates towards the flow exits, it will therefore be important to further evaluate this effect, and consider it in any application.

4. FIGURES

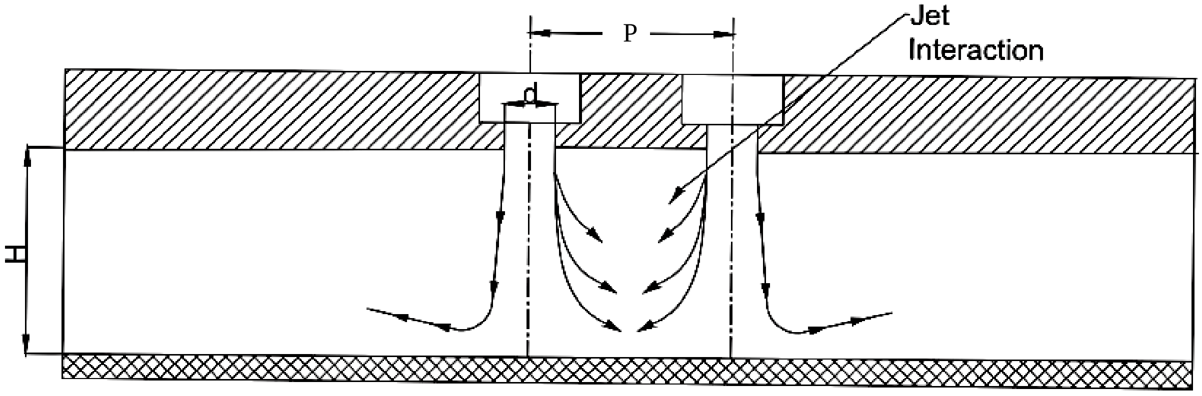

Figure 1 – Multi-jet impingement system

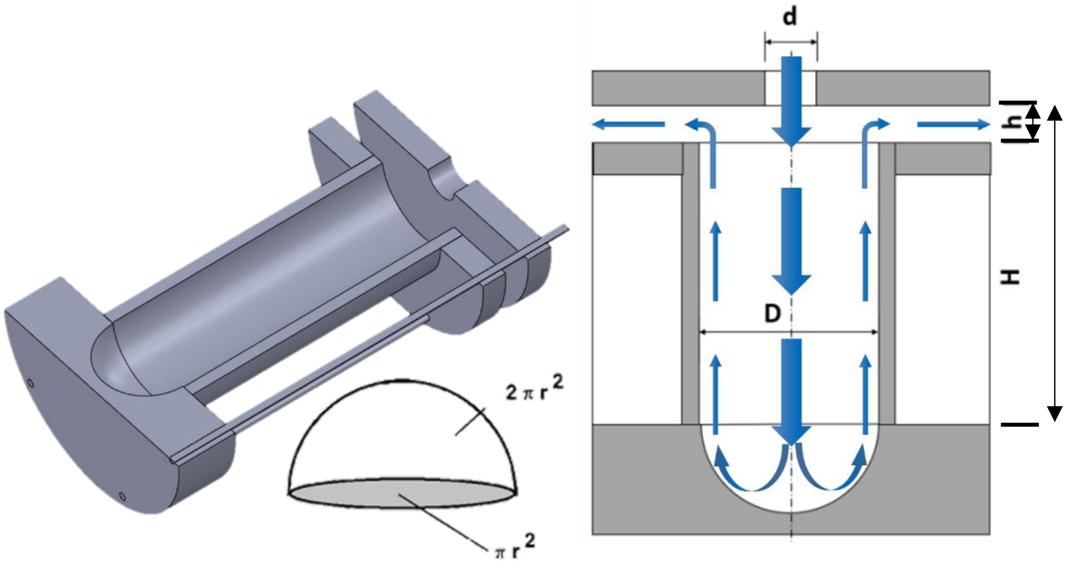

Figure 2 – Cross-section of test piece.

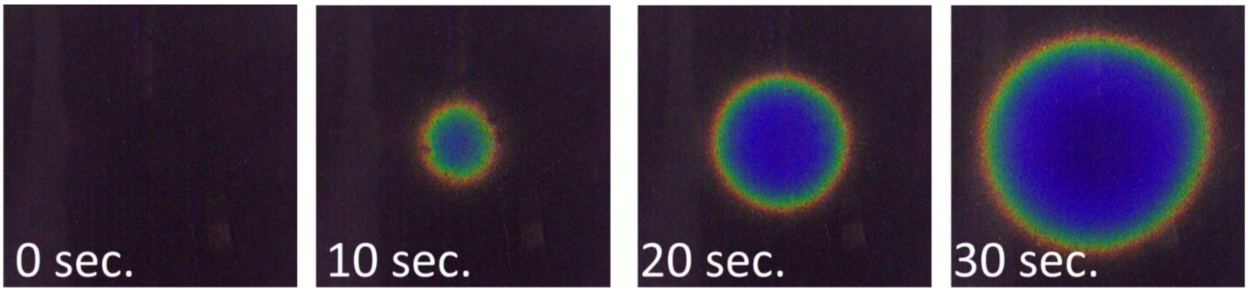

Figure 3 – Representative development of impingement jet target liquid crystal response over time.

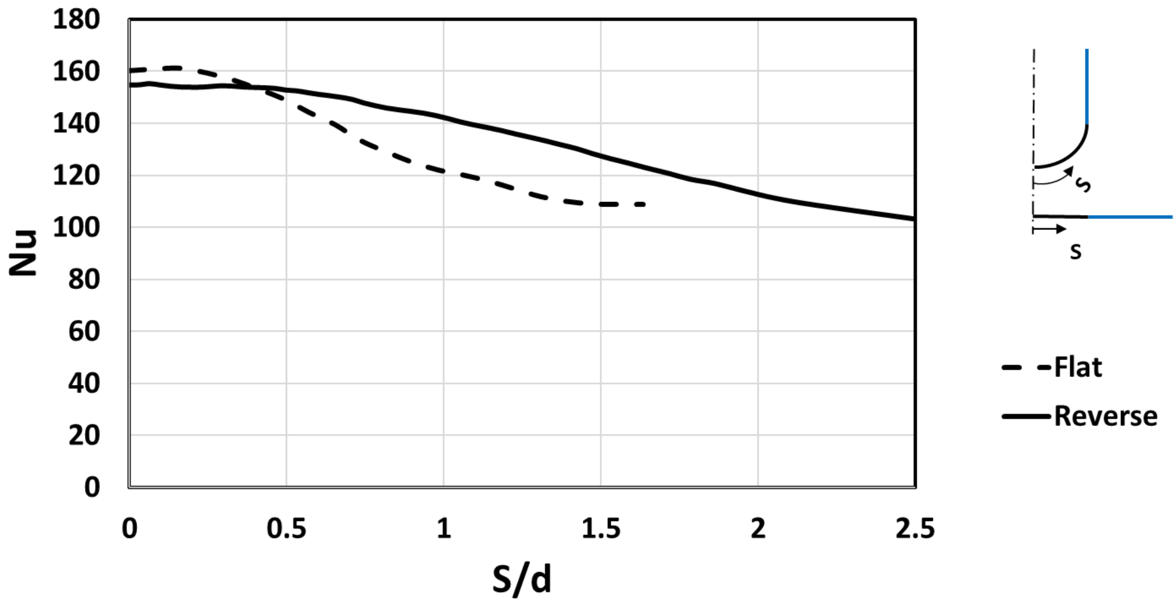

Figure 4 - Nusselt number distribution comparison between flat and concave reverse targets

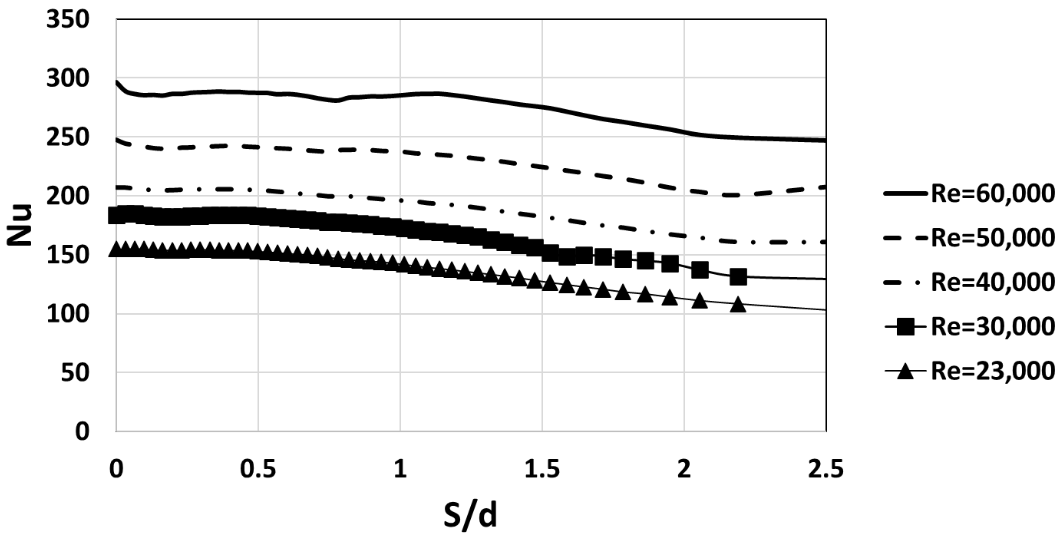

Figure 5 - Effect of Reynolds number on average Nusselt number at varying radial positions

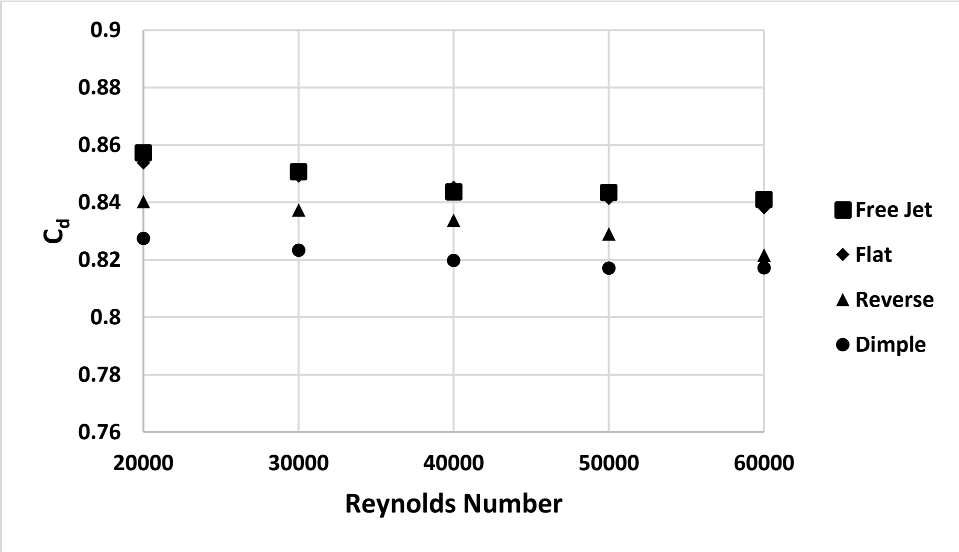

Figure 6 - Discharge coeffiecent comparison between free jet and different target shapes

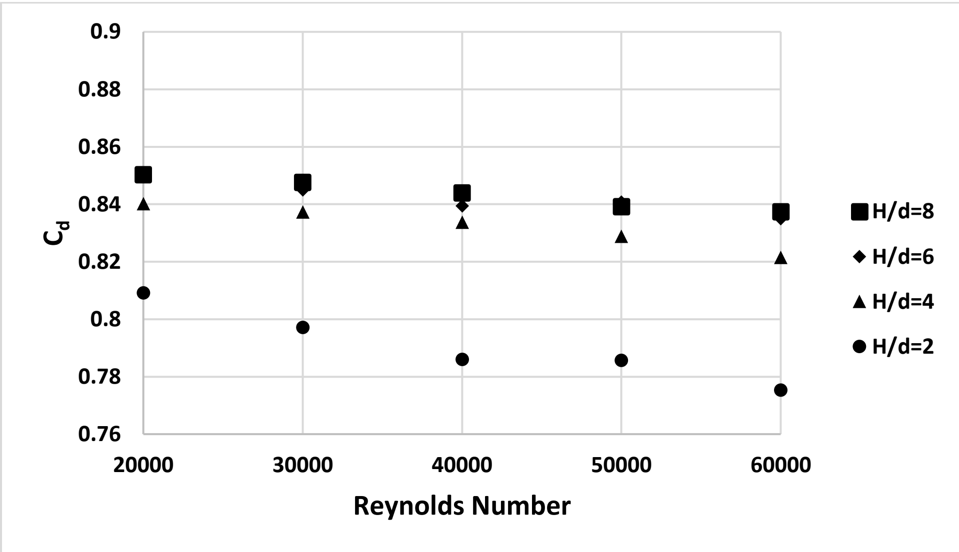

Figure 7 - Discharge coefficient of the reverse target at different jet-to-target spacings

5. CONCLUSIONS

This study focused on the local Nusselt number distribution of a single round jet reverse impingement at different Reynolds numbers over a concave surface. In addition to studying the effect of the target plate shape and the jet-target spacing Reynold's number on the discharge coefficient. Average Nusselt number plots were provided as a function of surface distance from the impingement jet stagnation point, evaluated within a Reynolds number range of 23,000 – 60,000, at H/d = 4, and against a flat plate target geometry. Results show that the reverse impingement geometry provides an increased overall heat transfer compared to a flat plate target, with a proportional relationship to Reynolds number. Evaluation of the discharge coefficient demonstrates that the reverse scheme has a lower recovery than a flat plate, but does show improvement over impingement into a dimple. The relationship between jet-to-target spacing and discharge coefficient shows that there is very little impact between 4 – 8 jet diameters, but when evaluated at 2 jet diameters, showed a severe reduction.

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1. REFERENCES

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