International Journal of Engineering & Technology, 7 (3.17) (2018) 209-214

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Heat Transfer Augmentation Based on Twin Impingement Jet Mechanism

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Abstract

Much of the research interest has now been conferred to jet impingement heat transfer mechanism, particularly in cooling related to electronic equipment and automotive engine since forced convection action generates high heat transfer coefficients. The paper aims to improve the heat transfer rate at radial position at a distant from the stagnation point. This is achieved by determining the local heat transfer coefficients by considering the aluminium plate surface, which employs the twin impingement jet mechanism likewise that allows capturing the distribution associated with heat transfer characteristic near the measured surface because there is not much information regarding this topic. This article presents the experimental studies regarding jet impingement heat transfer as well as associated measurements for local heat transfer coefficient. This subsequently resulted in determining the heat transfer rate associated with the impingement aluminium plate. In this research study, nine models with different parameters has been developed where the distance from nozzle to aluminium Plate (H) equal 10, 60 and 110 mm, while the spacing between nozzles (S) equal 10, 20 and 30 mm. At Reynolds number 10,000, measurements were done, and a heat flux micro-heat sensor installed away from the stagnation point from 0 to 140 mm at radial positions, was employed to measure the heat flux of the steadily heated air jet that impinged on the aluminium surface. The local heat transfer coefficients regarding steady air jet were calculated by measuring the heat flux. Thermal data are recorded, and Graphtec GL820 multichannel data logger was employed to capture distributions of heat transfer. The best heat transfer coefficient was observed through the results from the area enclosed between aluminium plate and nozzles and the closest distance between twin nozzles, particularly in the initial 5 points at the flat, which lowering as we start to move away from the aluminium plate centre. The temperature distribution at the front of aluminium foil Fluke Ti25 was recorded with the help of an infrared thermal imager.

Keywords: *heat transfer enhancement, Twin jets impingement, heat transfer coefficients, stagnation point, heat flux*

1. Introduction

In the industry for cooling and heating purposes, high heat transfer rate can be considered a significant factor that has many applications for impingement jets [1]. In many such tasks, there is a high need to improve fluids' heat transfer rate as well as efficient heat transfer [2, 3]. Much interest has been gained by the jet's impingement heat transfer technique because of high rate of heat transfer generated due to forced convection action. Industrial applications employ jets extensively for a broad range of disciplines and configurations, particularly in industries associated with annealing of metals, drying of textiles, turbine blades cooling, aircraft engine, electronic chip cooling, drying of textiles, tempering of glass, and the food industry, all of which can be produced by employing the jet impingement technology. There have been many research studies that focus on the impacts of applying numerous impinging jets on the characteristics of heat transfer and flow [4]. Many previous studies and articles have discussed how to improve the heat transfer by employing twin and single impingement jets [5-7] In contrast to review articles by Jambunathan et al. [8] which focussed on steady impingement with extensive details, many researchers started to examine the impact of pulsations of flow on heat transfer improvement, both numerically and experimentally.

Sheriff et al. [9] performed an experiment study to determine the impact of flow on cooling efficiency by employing jet arrays. There were coherent structures, but much enhancement was not seen in terms of heat transfer characteristics, while Sopian et al. [10] demonstrated results of the two-part experimental studies regarding jet impingement heat transfer. Three different Reynolds numbers 16,000, 23,300 and 32,000 were employed to perform the measurements. Calculation was done for the Nusselt Number for an air jet that was impinging on a flat by considering the heat flux recorded value. A heat flux sensor was employed to measure the heat flux. As per the results, the local Nusselt number that was calculated was found to be higher for all radial positions at a distant from the stagnation point. As shown with the velocity profile plotted in the experiment's first part, the higher instantaneous velocity could be the reason for the obtained higher Nusselt number at localised radial positions.

Moreover, Zulkifli et al. [11] performed a comparison between pulsating and steady jets of local Nusselt number that had different frequencies, jet Reynolds number as well as radial positions at a distance from the stagnation point. An analysis by

[12] was done on a surface plate's steady-state heating that included a patterned plate down free liquid for jet impingement technique. To the cooled plate, a constant heat flux was applied, and calculations were performed for Reynolds number (Re) that varied from 500 to 1,000 while depths were from 0.000125 to 0.0005 m. It was seen that the local heat transfer coefficient reduced with a rise in the Reynolds number value. As per Kataoka et al. [13], studied the impact of pulsation on the impingement of large-scale structures like vortex rings on the boundary layer, which occurred, results in improved stagnation point heat transfer. Mladin et al. [14] employed a detailed boundary layer model to theoretically evaluate the impact of frequency, amplitude, and pulse shape on time-averaged and instantaneous convective heat transfer applicable to a planar stagnation part. It was reported that a threshold St>0.26, exists, below which there was no significant improvement in the rate of heat transfer. Experimental studies were performed to experimentally investigate heat transfer characteristics [15] for tiny slot jet impingement and high-velocity boiling applied to nanoscale amendment surfaces, in a bid to raise the heat flux as well as examine the quantitative impact and effects mechanism related to surface distinguishing parameters. Moreover, [16] investigated the heat transfer for jet impingement applicable to a concave plate for a wing leading brink: Correlation development and experimental study. With rise in Re and <alpha>, there is an increase in heat transfer achievement at the stagnation point, while a plate distance and optimal nozzle, (H/D) is important to achieve the desirable efficiency of heat transfer rate at the stagnation point, which matches the particular operating parameters.

Wen et al. [17] investigated the heat-transfer characteristics in transient state for a flat surface subjected to circular impingement jet. When the air jet starts its impingement, there is a quick augmentation in the localised of Nusselt number. As the jet impingement continues to cool down, the speed of Nu gradually slows down in the 50-80 s region. Moreover, [18] numerically investigated the heat transfer and fluid flow and associated with slot jet impingement heat transfer for the spacing between nozzle-to-plate by considering a small value, in which a secondary peak could be seen with the Nusselt number. As per the results, in the stagnation region, the mean velocity profile was observed to diverge from that of the standard law of the wall. In contrast, the Nusselt number better as compared to the state with no perturbations, or spotting of large-scale vorticial structures close to the secondary Nusselt number peak's location.

Choo et al. [19] investigated the effect of spacing between nozzle-to-plate caused on heat transfer issues and fluid flow characteristic for submerged impingement jets. As per the results, the segmentation of Nusselt number and pressure is done into three zones. In the zone I, there is a significant rise in the pressure and Nusselt number with decrease in the spacing between nozzle-plate. In part II, the spacing between nozzle-to-plate effect on the pressure and Nusselt number is insignificant. In part III, with rise in the spacing between nozzle-to-plate, there is a diminution in the pressure and Nusselt number monotonically. Wang et al. [20] investigated the characteristics of heat transfer at a high-temperature flat via jet impingement as well as to evaluate the effect of water temperature, jet velocity and initial surface temperature for heat transfer characteristics associated with the many industrial applications. Water temperature, jet velocity, and surface temperature can affect the heat flux maximum.

Furthermore, comprehensive data appearance the impact of steady impingement jets on heat transfer profile is still restricted; and there is a need for further realization and investigation. The purpose of this article is to investigate the twin impingement jet mechanism and characteristics of heat transfer at a high Reynolds number. The distribution of heat transfer characteristics was captured by Fluke Ti25 thermal imager on the surface measured. The focus of the study was on the local heat transfer coefficient in comparison to the local heat transfer coefficient. The radial position on the surface, away from the stagnation point at the Aluminium plate impingement jet heat transfer, was discussed in detail. In this paper, the total heat flux is proportional to the average heat transfer coefficient and the local heat transfer coefficient is assumed to be radially consistent around the stagnation point.

2. Experimental Procedures and Methodology

Fig 1 below gives a schematic illustration of the experimental setup employed in this current work. The main compressor was used to supply compressed air of 0.275 bar (4 psi). The air reservoir stores the compressed air and a ball valve is used to release air in a controlled manner. A refrigerated air dryer is employed to eliminate moisture from the air that's coming from compressor. Air pressure was controlled with the help of regulator and pressure gauge, which also aid in avoiding fluctuation because of the main compressor's cyclic on/off. A digital air flow meter from CS instruments (Model VA 420) is employed to measure the rated airflow. The air passes through two identical pipelines before entering the twin jets impingement mechanism (TJIM). A ball valve ensures the control of each of the both lines as well as the twin jets' identical flow characteristics.

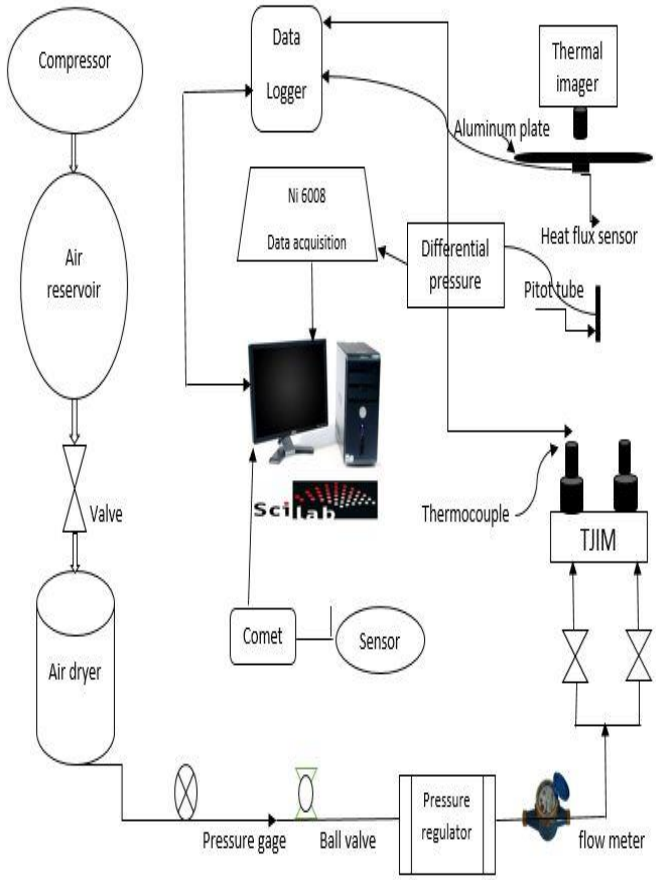

Fig. 1: Schematic of twin impingement jets tests setup

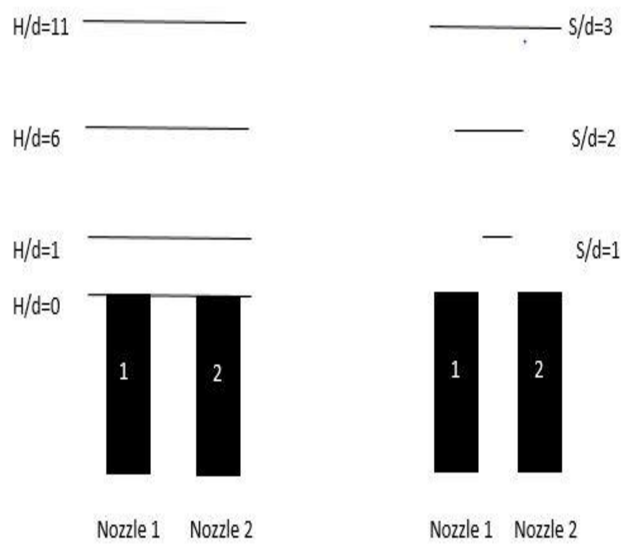

Fig. 2: Arrangement of nozzles for the all models

Figure 2 shows the nozzle arrangement for all nine models. The arrangement is based on the distance between the nozzles and the nozzle- plate distance (as shown in the figure). An Aluminium foil square, with surface dimension and thickness of 300×300×4 mm (as shown in Figure 3 below). The positions of thermocouples and heat flux sensor on the Aluminium flat are also shown in the figure.

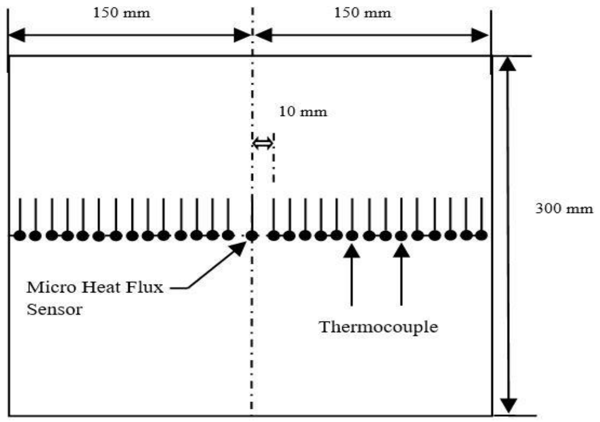

Fig. 3: Positions of sensors on the aluminium flat

A flat impingement surface is maintained by the tightly held aluminium foil. On the aluminium foil's front surface, a heat flux-temperature foil sensor is installed by employing a high conductivity heat sink compound as well as a Kapton tape to mitigate the impact of air gaps between the measured aluminium surface and the sensor. A Graphtec GL820 multichannel data logger was employed to gather the thermal data. At the front of the aluminium foil, the temperature distribution is recorded with the help of a Fluke Ti25 Infrared thermal imager. It was also compatible with various types of thermocouples (i.e., J, T, E, K, S, B and R types) [11]. In our paper, we have employed two K-type thermocouples that were fixed to the aluminium plate and positioned at a distance 120 mm apart for observing the temperature of plate. A comet, model H7331 was employed to gather data related to temperature, room humidity, static pressure (pitot tube), the dew point and atmospheric pressure from all other sensors. [21]

Uniform temperature distribution is maintained due to small thickness of aluminium foil and high thermal conductivity (k) through foil thickness, which ensures measurement of temperature be accurate near the surface [18]. Fig. 4 shows the TJIM with the employed aluminium foil target in this current work.

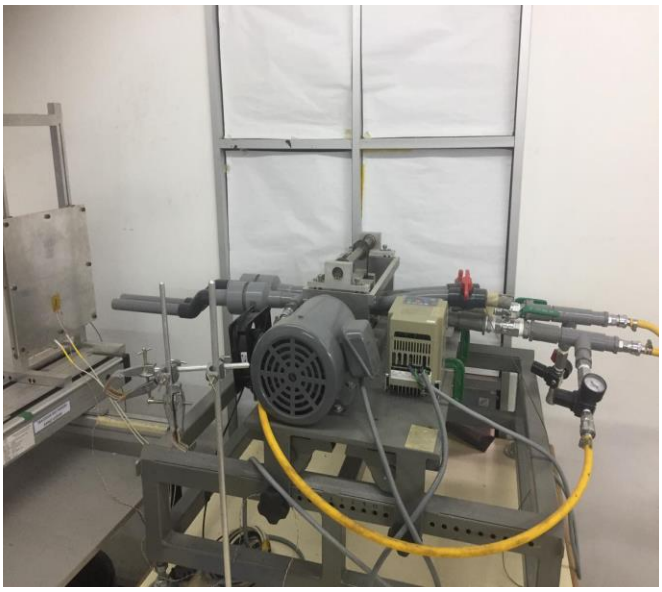

Fig. 4: Twin Impingement jets Mechanism and heat flux microsensor on the Aluminium impingement surface.

Main steps were employed to conduct the experimental procedures. First, in the steady jet case, Reynolds number of 10,000 for each jet was achieved by setting the air flow through measurement of the velocity for twin jets centre point near the nozzle exit by employing Pitot tube. Second, installation of the digital air flow meter in the TJIM was done for measuring the velocity and flow rate of steady jet flow, by maintaining temperature mode at 100°C as constant. Dantec Dynamic's flow meter anemometer was employed in experimental setup. This flow meter was installed between the TJIM pipes that passes through the twin jets and refrigerated air dryer. On the other hand, the velocity obtained from Pitot tube is employed to carry out the experimental run in the twin impingement jets, where this velocity is confirmed via the flow meter. Then, we obtain the highest Reynolds number, which allows subsequent capturing of the heat transfer (q) per unit time via device of data logger and perform calculation for the heat transfer coefficient (h) based on units ($W/(m^2K)$). Subsequently, for all the 15 points at radial distance far from stagnation point on the measured surface, we calculate the localised heat transfer coefficient. Third, the differential pressure allows us to obtain the pressure difference as an analogue, which can be used as an input for data acquisition (NI 6008), followed by converting to signal and then to value by employing Scilab code that we developed for the results. Setting up this differential pressure between NI 6008 data acquisition and Pitot tube was done. Fourth, installation of aluminium foil was done at a distance of 10, 60, and 110 mm from the nozzle exit to the measured surface as well as the nozzle-nozzle spacing that was 10, 20, and 30 mm indicated that we have constructed nine models at one Reynold number in the tests. This preparation was aimed at measuring surface temperature and heat flux on impingement surface. Fifth, the temperature distribution and thermal images at the surface were simultaneously captured via Fluke Ti25 Infrared thermal imager until heat transfer would reach the steady state. A total of 1,350 samples were recorded to minimise the chances of experimental error during measurement by sensor of heat flux-temperature, in which the average rate was considered. The heat inlet (towards the aluminium foil near the Jets) equals the heat lost due to the impact of natural convection, a steady heat transfer is accomplished. As shown in figure 5.

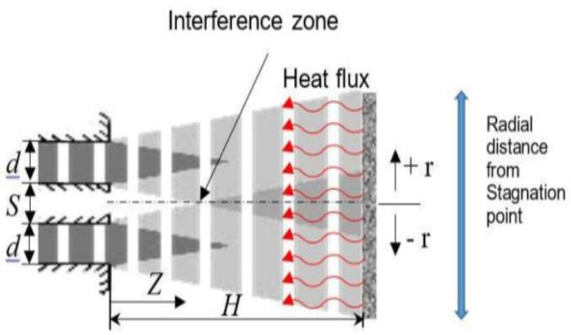

Fig. 5: Twin jets impingement impact

Before beginning the experimental tests, the parameters regarding to the TJIM and thermal imager were kept constant as listed in Table 1 below.

Table 1: Constant value parameters

Constant Parameter	Value
Nozzle to Target distance	1 to 11 cm
Nozzle to Nozzle distance	1 to 3 cm
Reynolds Number	10,000
Ambient Temperature	24 ºC
Aluminium plate temperature	100 ºC
Emissivity of foil Aluminium	0.97
Background Temperature	25 ºC
Transmission	100%

Heat transfer and fluid mechanics need to be considered for the jet impingement problems. Consequently, determination of associated dimensionless numbers also has to be done.

Equation (1) shows computation of the Reynolds number of the air jet associated with the inertial forces because of the fluid's viscous forces [19],

$$Re = \frac{\rho v d}{\mu} \tag{1}$$

out at the spacing of Nozzle-Nozzle, (S) = 20 mm, and nozzle to plate distance (H) = 10 to 110 mm, to obtain heat transfer coefficient results. Steady jets produced different heat transfer coefficients with the three different models used. However, the maximum heat transfer coefficient, of approximately 100, was obtained by TJIM at H = 10 mm, and S = 20 mm, which then reduced gradually until the end of the aluminium flat, until it reached around 30 at the end. Figure 7 below shows the second three models where the distance between the nozzles = 20 mm and the nozzles-aluminium distance was 10, 60 and 110 mm, respectively.

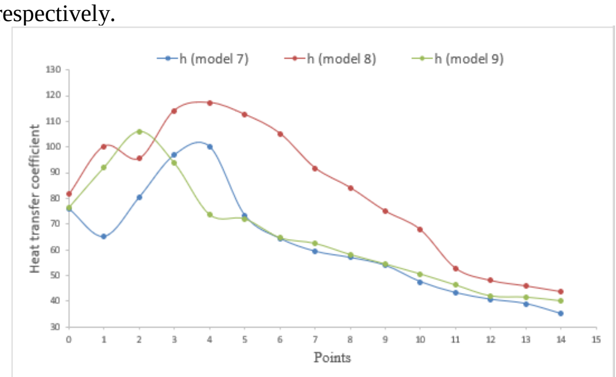

Fig. 7: Heat transfer coefficient values when S = 20 mm, and H = 10, 60, and 110 mm

Enhancement of heat transfer tests (Figure 8) at nozzle-plate distance (H) = 10 to 110 mm and nozzle-nozzle spacing (S) = 30 mm, in order to obtain heat transfer coefficient results. Steady jets produced different heat transfer coefficients with the three different models used. However, the difference here is that the maximum heat transfer coefficient of around 120 was obtained by TJIM at H = 60 mm and S = 30 mm in the initial 5 points at a radial spacing away from the stagnation point, which reduced gradually until the end of the aluminium flat, until it reached around 20, obtained by TJIM at H = 10 mm, and S = 30 mm at the end. In summary, these results discuss the behaviour of heat transfer coefficient qualitatively and quantitatively, and twin jets impingement of hot surface at the centreline of the interference zone. Figure 8 below presents the last three models, where the Nozzle-Nozzle distance = 30 mm and the nozzles-Aluminium flat spacing equals 10, 60, and 110 mm, respectively.

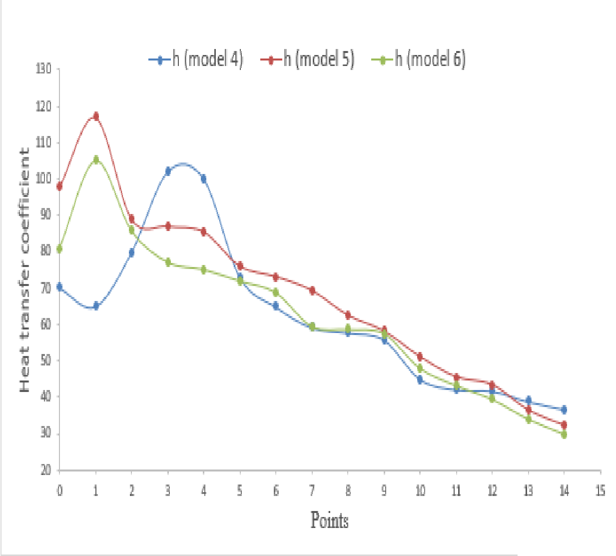

Fig. 8: Heat transfer coefficient values when S = 30 mm, H = 10, 60, and 110 mm

This part shows the results from the experimental test as discussed. Figs. 9, 10 and 11 present the Twin jets impingement mechanism (TJIM) impact on the flat temperature as measured during heat flux-temperature sensor installed on the front surface as well as from the thermal image of the Aluminium flat. At the first 5 points on the plate surface, there is a rise in the surface temperature, followed by regression post the 5 points distances near the aluminium flat. It is vital to show how TJIM can have an effect on the heat transfer coefficient near the centre or midpoint between the twin jets that pass towards the end of the interference region near the aluminium plate surface's end. Figs. 6, 7 and 8 demonstrate these effects for heat transfer coefficient according to micro foil sensor measurements. Recording of high heat transfer coefficient was done, which decreased as we move away from the aluminium plate surface's centre towards the end of the flat (from the centre of the surface, low rates at distant points). This result is logical since there is heat transfer in the present article, where there is an increase in the rate of heat transfer as long as the twin jets are in proximity to the surface and in the case when the heat flux sensor is under the direct effect from twin impingement jets air flow on the aluminium plates, which gradually decreases when moving away from the interference region's centre.

Figs. 9, 10 and 11 show the captured images via thermal imager (Fluke Ti25). These thermo-images signify the impact and distributions of twin jet on the impinged target's surface. In the pictures, labelling of the centre of temperature values was done. The figures below showcase the steady jet cases for the nine models, after which three pictures for every model were captured (centre of interference zone, middle and end of the aluminium plate). In these images, few surveillances can be recognised. First, the hottest spots are the ones to be seen clearly because of the effect of twin jets impingement. Also, after the midlevel point of temperature, an elliptical temperature distribution can be spotted.

Furthermore, higher heat transfer coefficients were achieved by the steady jet state because of the jets' high flow rate. In contrast, because of its duty principles, supplying of the lower flow rate in the TJIM was done. Furthermore, the higher temperature of 90.8°C in centre, as presented in Fig. 8, was generated by the first model when S=10 and H=10 mm. Moreover, because of the high sensitivity of thermal imager to minimal temperature changes between both jets, exchange of their superiority in possession of the highest temperature by twin jets occurs.

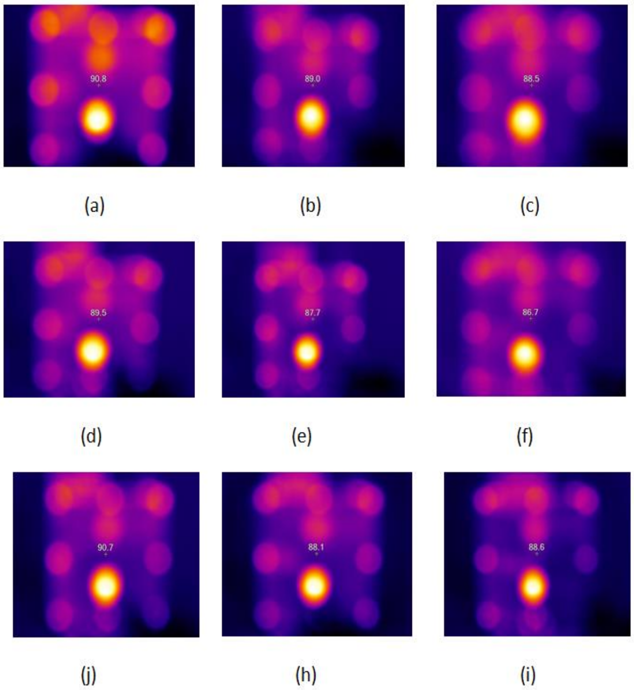

Fig. 9: Thermographic temperature distribution of Aluminium Foil Models 1, 2 and 3, (a) to (i)

The steady jet case is presented in Figure 9 for the three models, respectively. Three pictures were captured for each model (centre of interference zone, middle, and end of the aluminium plate). Some monitoring can be generally recognized in these pictures. First of all, the hottest spots can be seen immediately, which is because of the impact of twin impingement jets. Also, an elliptical temperature allocation can be seen after the midlevel point of temperature, Higher heat transfer coefficient were accomplished in the steady jet case because of jets' high flow rate. In contrast, in TJIM, supply of a lower flow rate was done due of its duty principles. Moreover, as presented in Fig. 9, the fifth model gave a higher centre temperature of 91.5 C when S= 20 and H= 60 mm.

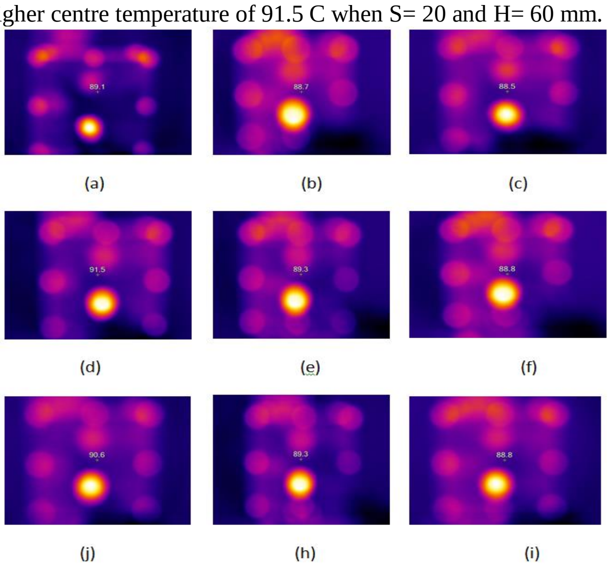

Fig. 10: Thermographic temperature distribution of Aluminium Foils Model 4, 5 and 6, (a) to (i)

Figure 11 shows the steady jet case for the last three models, respectively. Three pictures were captured for each model (centre of interference zone, middle, and end of the aluminium plate). Some monitoring can be recognized from these pictures. First, the hottest spots caused by the impact of twin jet impingement (TJIM) can clearly be shown. Distribution of elliptical temperature, after the midlevel temperature point, can be spotted. Also, the steady jet state accomplished higher temperature rates because the high flow rate of the jets. In contrast, the lower flow rates were provided in twin jets due to its duty principles. Furthermore, the higher centre temperature of 91.8oC (see Figure 10) was produced by the seventh and eighth models, where H = 10 and 60 mm, and S = 30 mm.

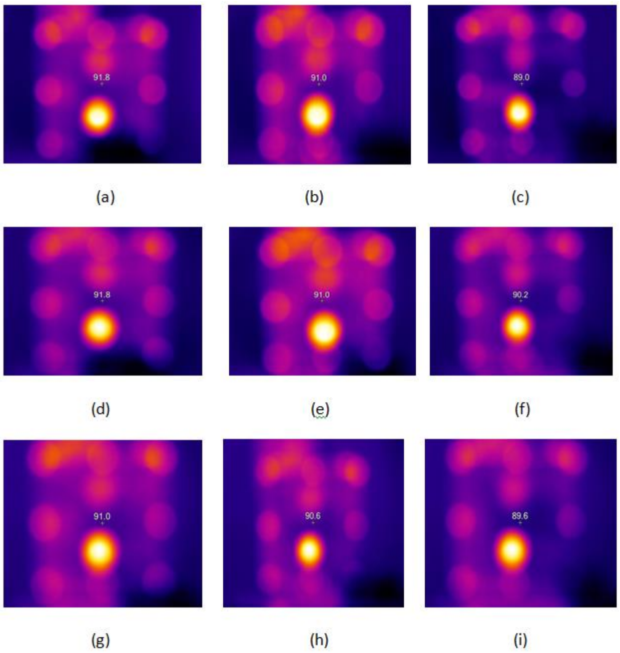

Fig. 11: Thermographic temperature distribution of Aluminium Foil Models 7, 8 and 9, (a) to (i)

3. Conclusions

This experimental study was conducted for twin jet impingement mechanism (TJIM) to improve heat transfer rate. The current study involved IR infrared thermal imaging (Fluke Ti25) as well as heat flux-temperature micro foil sensor measurements. Based on the results, there was a noticeable and substantial improvement in the localised heat transfer coefficient regarding the steady flow at radial distance positions on the measured aluminium surface of 10-50 mm with a Reynolds number of 10,000 as presented in the above figures as well as gradual decrease when moving away subsequently from the interference area's centre. The surface of aluminium was used for the thermography capturing process, while the nine models on the impinged flat of the target were employed for the collection of heat flux-temperature data (centre of interference zone, middle and towards the end of aluminium plate). The results presented logical behaviour encompassing all parameters that were under consideration. The performance of twin jets system is confirmed with the identical effect of twin jets, which was developed to produce identical two jets. In addition, for the optimum condition to establish the higher heat transfer rates regarding the current problem, we can consider the distance between nozzles as well as the spacing between nozzles and the jet. To conclude, the different results presented could define the impact of the selected nine models in different arranging on heat transfer characteristics associated with the twin jet impingement mechanism, which could also contribute towards the enhancement of performance for electronic chips cooling, internal combustion engines and numerous applications.

Acknowledgements

We would like to thank the financial support provided by UKM Arus Perdana AP-2015-003 and Prof Dr. Faris Abdullah Al-Janaby.

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