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Experimental Investigation into Heat Transfer during Swirl Jet Impingement

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Abstract

Augmentation of heat transfer during jet impingement has always been point of interest. For this numerous was are employed of which one way is increasing the turbulence of impinging jet. This can be achieved by using swirl generators. In Author's previous work, numerical simulations were executed to study the effect of heat transfer during Multi-Swirl Jet Impingement (MSJI). In the current work, experimental investigations for evaluating heat transfer during the same are presented. The ducts for this purpose are 3D Printed using PLA. The ducts contain helical swirl generators for generating swirls in impinging jets. 3 different helical swirl generators are experimented. During experimentation, 3X3 swirl jets are impinged on a flat plate. Smoke tests were executed to study the flow pattern. The flow pattern is in agreement with that of simulation results. These are discussed in the article. When experimenting for measuring heat transfer coefficient, Constant heat flux is given as input for which TEC is used. Constant heat flux is a situation that occurs during electronics cooling. Temperatures are measured using 100K Thermistors. These are interfaced to PC using Intel Edison development board. The schematics of the test rig are presented in the paper. Experimentally determined heat transfer coefficient is compared with that of numerically computed value. This is being done so as to validate the authors work published previously.

Keywords: Multi-Swirl Jet Impingement, Thermistor, Intel Edison, Constant heat flux, electronics cooling

INTRODUCTION

A lot of work happened in the field of jet impingement cooling. Some literature was summarized in our previous work [1]. Regarding conventional Jet Impingement, detailed literature survey pertaining to jet impingement cooling and its applications is presented in [2]–[5]. A summary of expressions in conventional jet impingement are given in [6]–[10]. Summary of various experimental investigations are given in [11]–[41].

SWIRL JET IMPINGEMENT COOLING

Augmentation of heat transfer during heat transfer has always been of interest. One way is by increasing the turbulence of the impinging jet. This can be achieved by introducing swirl in the impinging jet. Much work was done with single swirl jet impingement than multi swirl jet impingement. Ortega-Casanova [42], [43] gave expressions relating to heat transfer from a heated plate when subjected to swirl jet impingement. Amini Y, et al [44] practically studied the use of twisted tape inserts in augmenting heat transfer during jet impingement cooling. ZU Ahmed, et al [45] observed the characteristics of incompressible, turbulent, swirling impinging air jet. Zahir U Ahmed, et al [46] used RANS approach with RNG k–ε model is used for investigating the effects of inflow conditions on the transition from free-to-impinging and non-swirling-to-swirling (impinging) jets. Rodriguez, et al [47] compared different methods of modeling helicoloids for generating swirling flow fields. Herrada, et al [48] used axisymmetric CFD simulations to study the effect of a swirl number S and a vortex core length d on the mechanical characteristics of the flow at moderate Reynolds numbers. Kinsella, et al [49] found that the main reason for augmentation of heat transfer in swirling jets is due to increase in turbulence. Sergey, et al [50] employed stereo PIV technique using advanced pre- and post-processing algorithms for studying the turbulent swirling jets. Bakirci, et al [51] & Bilen, et al [52] conducted experiments for flow visualization and study heat transfer in both multi-channel impinging jet (MCIJ), Swirling Impinging Jet (SIJ) and conventional impinging jet (CIJ). Shuja, et al [53] investigated the effect of swirl velocity on various factors like irreversibility, entropy generation, and fluid friction numerically. Erik [54] gave expressions for mathematically modeling swirling flow and evaluating various parameters in the flow. Koichi Ichimiya and Koji Tsukamoto [55] investigated the heat transfer when swirling laminar jet is being impinged on a flat plate. Lamont, et al [56] experimentally studied the effect of a row of swirling jets in heat transfer from a flat plate when being impinged with a row of jets. Ekkad, et al [57] investigated the heat transfer augmentation by inducing swirl in impinging cooling jets by introducing them at an angle during cooling turbine blades

OTHER COOLING AUGMENTATION METHODS

Jia, et al [58] performed numerical simulations to study the effect of upstream and downstream shaped ribs on heat transfer during flow when cooling turbine blades. Xu, et al [59], using numerical simulations, investigated the effect of five different types of vortex generator on heat transfer during flow in a rectangular channel.

PROBLEM DEFINITION

Keeping the above points in view, it was decided to investigate into the effect of swirl jet impingement both experimentally and numerically. In our previous paper [1], the results of simulations performed in this regard were discussed. Expression derived was also presented in the same which is given as expression (1).

$$Nu = 3.347834\,\mathrm{Re}^{0.8764}\,\mathrm{Pr}^{0.33}\,Si^{0.0364}\,I^{0.04846}\left(z/D\right)^{0.4454} \qquad (1)$$

In the current work, it is planned to verify the above work experimentally. Experimental work and the results of the experimentation are presented in this paper. During fabrication of the test rig, ducts are 3D printed. Smoke tests were performed to study the flow pattern.

3D PRINTING DUCTS

The ducts are modeled using Creo/Parametric. Four different ducts are designed. (i) containing no swirl generator, (ii) containing 90°Helix for generating swirl, (iii) Containing 180° Helix and (iv) Containing 360° Helix. These models are shown in figure 1. The models are 3D Printed using PLA material on Wanhao Duplicator i3 3D Printer. 3D printing tool paths are generated using Cura software. 90°Swirl duct, when being 3D Printed is shown in figure 2. Figure 3 shows the 3D Printed ducts. 3D Printing is done at 205°C with 25mm/s speed.

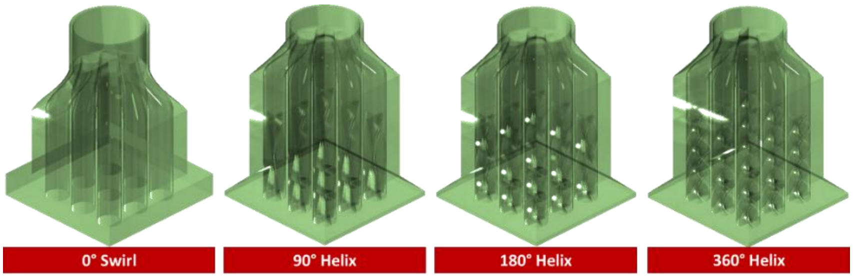


Figure 1: Duct Models 3D Printed

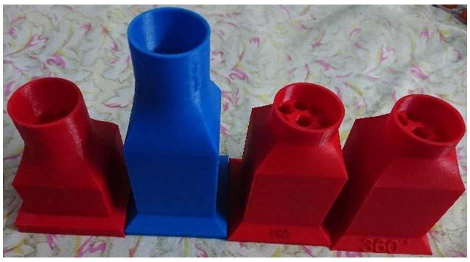


Figure 2: 3D Printed Ducts - 0°, 90°, 180°, 360°

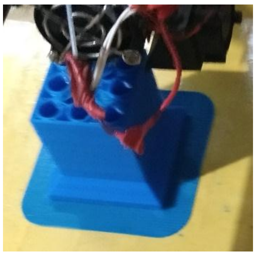


Figure 3: 3D Printing a Duct

SMOKE TESTING THE DUCTS

To understand the flow through the ducts, smoke tests are executed. For this smoke is passed through the ducts. The smoke exiting the ducts is imaged with 120fps camera just as in [55]. The results of the smoke test are shown in figure 4. They demonstrate how the smoke is getting distributed on exit from the nozzle indicating that higher turbulence exists with higher swirl. Jet bending can also be clearly seen during impingement. The flow pattern during swirling impingement when compared with that of simulation result are shown in figure 5 (a), (b) & (c).

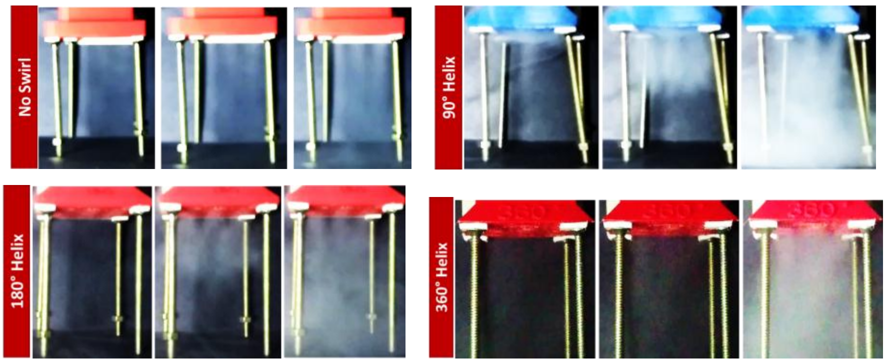
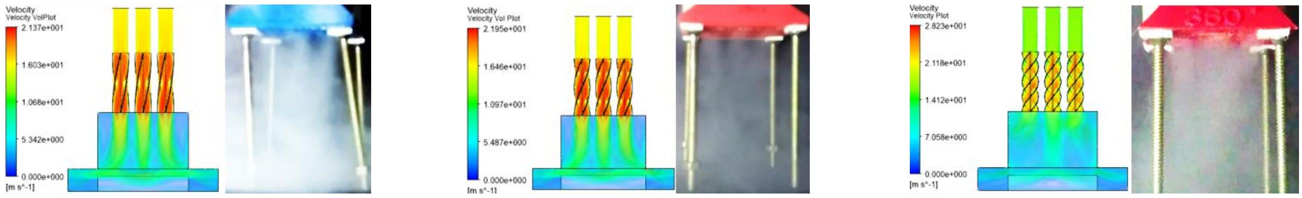


Figure 4: Smoke Test Result



(a) 90° Helix Generator (b) 180° Helix Generator (c) 360° Helix Generator

Figure 5: Smoke Test Results vs Simulation Results

TEST RIG

Using the 3D Printed ducts, test rig was fabricated. 100K Thermistors were used to measure temperature variation. Thermistors were interfaced to PC using Intel Edison board. The schematic of the test rig is shown in figure 6. The temperature measurement equipment is shown in figure 7. The block is having a constant heat input (30W) by using 12706 TEC by controlling Voltage and Current being given as input., in other words constant heat flux wall is experimented.

Experiments are conducted for three swirls at one data point each. During experimentation, temperature is measured at the nozzle exit (T_∞), surface of the block at three points (average Temperature T is then computed), air temperature at the exit of the shroud. Mass flow rate ($\dot{m}$) of air is measured using anemometer at the exit should exit. Heat transferred and the convective heat transfer coefficient are then computed using equations (2) & (3). The experimental results are found to be within 5% variation from the computed values using equation (1).

$$\dot{q} = mc_p\Delta T \qquad (2)$$

$$\dot{q} = h(T - T_\infty) \qquad (3)$$

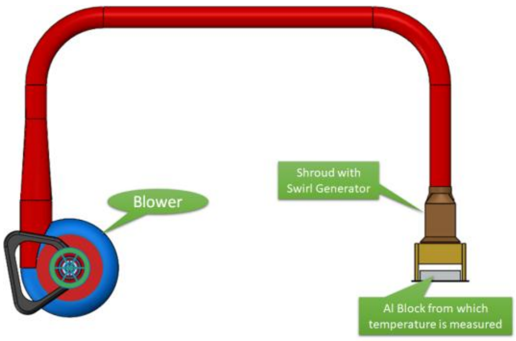


Figure 6: Test Rig Schematic

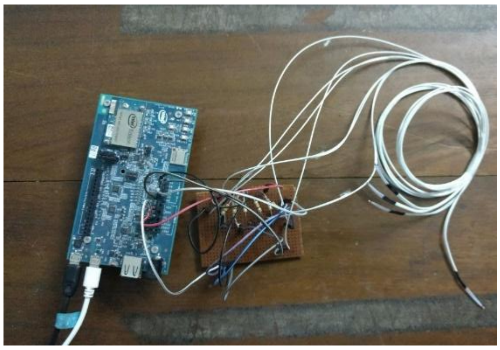


Figure 7: Temperature Measurement Apparatus

CONCLUSION

Experimental investigations are executed to investigate heat transfer from a flat plate subjected to constant wall heat flux. A constant heat input of 30W is given using 12706 TEC. This is achieved by controlling the voltage and current input given to that of TEC. Initially, smoke test was conducted to understand the flow pattern. The flow patterns are in good agreement with that of simulation result. Air flow rate during impingement is measured using Anemometers. The heat carried away is measured by measuring the temperature of air before impingement and after impingement. Heat transfer coefficient is computed using equation (3). The heat transfer coefficients obtained are in good agreement with that of numerically simulated values given in author's previous work validating the same.

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