Jet Impingement Heat Transfer – A Review

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Abstract - *Cooling of heated plates finds applications in various fields like electronic devices, gas turbines, aerospace, textiles etc. Commonly used method for cooling of electronic devices such as computers is by using fan. With the advent of electronic industry cooling requirements from compact surfaces become the primary focus and jet impingement become one of the best methods for heat transfer. Numerous researchers has been done this field and is been going . The review studies different jet impingement cases having different geometry, cross flow, frequency effects etc.*

Key Words: **jet impingement, convective heat transfer, single jet, multiple jets, jet Reynolds number, turbulence models.**

1. INTRODUCTION

The performance of electronic devices decreases with increase of temperature so it is necessary to dissipate the heat develop in such plates, in the most effective way, for enhancing their performance. There are limitations for cooling by natural convection. Jet of air impingement provides significantly high local heat transfer coefficient among all convective methods. Jets can be single or multiple according to the cooling rate. There are numerous applications in various engineering industries for fluid jets impinging normally to plane solid surfaces. Impinging single, as well as multiple jets, is used in applications where high convective heat transfer rate is required. The local heat transfer coefficient is high in the jet impingement region as well as the adjoined wall jet region. Impinging jets are used to cool, heat and dry the surfaces in a number of industrial applications. Some applications of jet impingement are cooling to maintain the temperatures of turbine blades below metallurgical allowed limits in gas turbines, annealing of plastic sheets, anti-icing of aircraft wings, tempering of glass, drying of continuous sheets like papers, photographic films, textiles, and plywood etc. it is also used for cooling of microelectronic components where intense cooling is required. The low Reynolds number jets are preferred in order to avoid the high pressure in the impingement region.

2. LITRATURE REVIEW

Sinan Caliskan et al.(1) investigated the geometry effects on multiple impinging air jets. They used elliptical and rectangular jets over a smooth surface with a Reynolds number ranging from 2000 to 10000. They concluded that elliptical jets provide better heat transfer coefficient than rectangular jets. P. M Nakod et al. (2) investigated the heat transfer between impinging circular air jet and flat plate using finned surface and vortex generators. Fins are used in the form of cubes. Vortex generators are in the form of the equilateral triangle of sides 4mm. They inferred that surface with vortex generators are effective in heat transfer than the finned surface for steady jets. M F Koseglu and S. Baskaya (3) investigated experimentally and numerically the role of jet inlet geometry in impinging jet heat transfer. The heat transfer is more for elliptical and rectangular jets. Harekrishna Yadav et al.(4) investigated the mixing and entrainment characteristics of a pulse jet and found that length of fully developed zone depends upon the magnitude of pulsation and frequency of pulsation jet. Jung-Yang san and Jenq-Jye Chen (5) studied the nusselt number distribution for five confined circular air jets vertically impinging on a flat surface. Junsik Lee et al.(6) conducted an experiment for finding new impingement heat transfer data on the combined effects of jets to target plate distance and jet hole spacing.

Impingement electronics cooling was investigated by Hollworth and Durbin [7]. Jet impingement heat transfer on the inside of a vehicle windscreen was investigated by Roy et al. [8] Jet impingement for the cooling of a grinding process was investigated by Babic et al. [9] the methods of controlling the vortex flow of a free jet were reported by Hussain and Zaman [10], Ho and Huang [11]. Liu and Sullivan [12] have proved that when the jet is excited acoustically at certain frequencies, the heat transfer to the jet can be enhanced. Different methods to control the vortex roll-up in the jet flow was investigated by Hwang et al. [13]. The heat generation and dissipation in the arc of cut of a grinding process were investigated numerically by Lavine and Jen [14], [15], Jen and Lavine [16], [17] and Liao et al. [18] and proposed a new model. Smoke wire technique was employed by Fleischer et al. [19] to visualize the initiation and development of vortices in an impinging jet flow. Jet to surface spacing on the vortex initiation distance and vortex breakup distance and effect of Reynolds number were investigated.

2.1 IMPINGING JET FLOWS

Sparrow and Wong (20) employed naphthalene sublimation technique to analyze mass transfer coefficients due to an impinging slot jet in the laminar region. A mass-heat transfer analogy was used to convert mass transfer results into heat transfer results. Miyazaki and Silberman (21) analyzed theoretically the two-dimensional laminar jet impinging on a flat plate. They evaluated the local friction factor and Nusselt numbers. Masliyah and Nguyen (22) studied the problem using the holographic technique. Al-Sanea (23) presented numerical results for laminar slot jet impinging on an isothermal surface for three cases namely, free-jet impingement, semi-confined-jet impingement, and semi-confined-jet impingement through a cross flow. It was found that cross flow degrades the nominal heat transfer rate. Seyedein et al (24) presented the numerically simulated results of two-dimensional flow field and heat transfer due to laminar heated multiple slot jets discharging normally into a converging confined channel. The parameters studied were the jet Reynolds number ($600 < Re < 1000$), and the angle of inclination of the upper surface ($0° < \theta < 20°$). The inclination of the confined surface so as to accelerate the exhaust flow was found to level the Nusselt number distribution on the impingement surface. Fitzgerald and Garimella (25) experimentally studied the flow field of an axi-symmetric, confined, submerged, turbulent jet impinging normally on a flat plate. Reynolds number range of 8500-23000 was considered. A recirculation zone was observed moving radially outward from stagnation zone, with an increase in both Reynolds number and nozzle-to plate spacing.

2. 2 CONJUGATE HEAT TRANSFER

Ruocco (26) discussed the conjugate heat transfer from a finite thickness plate to a laminar confined, impinging planar jet in order to determine the solid-fluid coupling characteristics that minimize the rate of entropy generation. Lallave et al. (27) studied the conjugate heat transfer for a confined liquid jet impinging on a rotating and uniformly heated solid disk of finite thickness and radius. It was found that plate materials with higher thermal conductivity maintained a more uniform temperature distribution at the solid-fluid interface. A higher Reynolds number increased the local heat transfer coefficient reducing the wall to fluid temperature difference over the entire interface. The rotational rate also increased local heat transfer coefficient under most conditions. Rahman and Lallave (2007) studied the convective heat transfer of a free liquid jet impinging on a rotating and uniformly heated solid disk of finite thickness and radius and proposed a generalized correlation for the average Nusselt number

2.3 IMPINGING SLOT JET FLOWS THROUGH POROUS MEDIUM

The jet impingement cooling through the horizontal porous layer is important from theoretical as well as application points of view. The buoyancy driven phenomena in porous media has attracted researchers interests due to number of technical applications, such as, fluid flow in geothermal reservoirs, insulation of buildings, separation processes in chemical industries, dispersion of chemical contaminants through water-saturated soil, solidification of casting, migration of moisture in grain storage system, crude oil production, solar collectors, electronic components cooling. Teamah and Farahat [28,29] studied the heat transfer and flow due to the impingement of a circular jet on a horizontal heated surface numerically and experimentally for single jet and experimentally only for multi jets of four arrangements, double jets, three in line, L-shaped and full cluster, in order to study the effect of the interaction between the jets on heat transfer. The water volume flow rates 1, 5 and 8 l/min per jet are used for multi-jets. It was found for multi jets that the interaction between the jets leads to reduce the mean velocity of the fluid film, which in turn leads to reduce both the local and the average local Nusselt number compared to a single jet. The overall average Nusselt number for multi-jet is higher than a single jet of one jet of the multi-jets. Many investigators [30,31,32] have examined the jet impingement heat transfer with crossflow effects, which potentially degrade the favourable heat transfer performance of impinging jet and the Nusselt number is lower than its absence. The heat transfer performance of a laminar annular jet impinging on a surface was compared with that of a standard circular jet having the same mass and momentum effluxes at the nozzle exit by Chattopadhyay [33]. Numerical analysis and optimization of staggered dimple channels by using two surrogates, namely the response surface approximation and the Kriging models, were performed by Husain et al. [34]. The Kriging model [35] was employed to approximate the objective function, i.e., the thermal resistance, to reduce the computation time for the optimization. Zumbrunnen and Aziz [36] firstly reported substantial heat transfer enhancements by the unsubmerged intermittent jet flow, numerous experimental and numerical investigations have been conducted to study the effect of flow pulsations on the local heat transfer rates of the impinging jet.

Sheriff and Zumbrunnen [37] tested the cooling performance of a pulsing water impinging jet associated with both sinusoidal and square-pulse waveforms and indicated that the reduction of local heat transfer by the sinusoidal pulsation decreases markedly from the stagnation point, while the square-wave pulsation can increase the time-averaged Nusselt number by up to 33%.

Bejera et al. numerical results [38] show that the sinusoidal pulsed impinging jet shows some enhancement over a steady impinging jet of the same Reynolds number only at large pulsation amplitude, however, they reported that the time-averaged Nusselt number increases up to 12% in the stagnation zone and 35% in the wall jet zone for the corresponding intermittent pulsed impinging jet.

3. CONCLUSION

Different characteristics which influence the heat transfer in Jet impingement have been studied. Multiple jets having elliptical nozzle is showing better heat transfer when compared to circular as well as rectangular nozzle jets.

Many more studies can be done in this field. The best combination of height to nozzle spacing and jet Reynolds number depends on the amount of heat transfer rate.

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