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HEAT TRANSFER ENHANCEMENT THROUGH JET IMPINGEMENT

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Abstract— A comprehensive review on jet impingement heat transfer is presented to consider the state-of the art in this heat transfer field. Recent technological developments in the various field need efficient cooling technique .Generally water jet impingement heat transfer is used for various industrial application. Impingement of liquid jet on a surface to remove heat from the surface is an effective method for high heat flux transfer. There are various parameters that influence the heat transfer in the jet impingement process including the heat flux, flow rate, inlet pressure, nozzle size and working medium properties etc. A significant number of papers dealing with experimental studies on different physical aspects of jet impinging flows are reviewed. This review paper gives various experimental approaches on jet impingement heat transfer process of recent years.

Key Words: (Heat transfer, Free jet impingement, Hydraulic jump phenomenon, Surface flat plate, Experimental approach.)

I. INTRODUCTION

Impinging jets are mostly used in various industrial applications to achieve very high heat transfer rate. impinging jet heat transfer is an interesting flow configuration hence attracted the interest of many heat transfer engineers and researchers. Due to growing demand of heat transfer enhancement in many industrial applications, jet impingements are widely used and studied. These techniques are used wherever high performance cooling, heating or drying of a surface is required. Some important industrial applications are cooling/heating of electrical equipment, drying requirements associated with textile and paper industries, cooling of turbine blades and outer combustor wall, freezing of tissues in cryosurgery, annealing of glass, rapid cooling or heating involved in glass manufacturing and short-take-off/vertical landing (STOVL) aircrafts, etc. Impinging jets offer an effective and flexible approach to transfer energy or mass in many industrial applications by changing the flow and geometric parameters, such as, jet Reynolds number (Re), nozzle geometry/shape, assembly of jet array, nozzle-to-plate spacing, angle of jet impingement, turbulence properties at the exit of the jet, ribbed surfaces and flow pulsation, etc[1].In the present review paper we concentrate on various experimental approaches used in the literature survey for liquid jet impingement heat transfer.

1.1 Flow Pattern

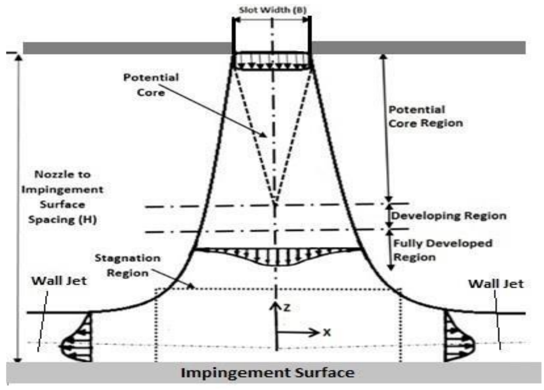

Fig.1.Different region of jet impingement flow pattern[1].

The three regions briefly explained as follows:

1) The free jet region

This region extends from the point where jet subjects to some distance above the solid surface of impingement. A free jet can be defined as a jet entering a large container containing a quiescent fluid. Due to the radial spreading of the jet the axial velocity decreases continuously in the stream flow direction. The region of the jet in which the flow field is not affected by the growing annular shear layer is called the potential core region. The core region is often referred to as the potential core even though the flow is not inviscid.

2) The impingement region

This region, also termed as stagnation point region, is approximately of same dimensions as those of the jet radius. In this region, the static pressure rises above the ambient, and significant pressure gradients are set up, which cause the flow to turn from its initial direction to a direction parallel to the wall. Within this region, the velocity grows rapidly from zero at the stagnation point to an undisturbed state.

3) The wall jet region

In this region, streamlines bend normally, to be oriented in a direction parallel to the solid surface and static pressure drops again to ambient pressure. Within the wall jet the transverse velocity profile shows that the local velocity rises rapidly to a maximum near to the wall and then falls at greater distances from the wall. The last two regions have been further grouped into five sub regions shown in figure 1 , are namely the region of boundary layer type flow, the region of fully developed flow, the region immediately before the hydraulic jump, the region of the hydraulic jump, and the region at downstream of the jump respectively.

II. LITERATURE REVIEW

2.1 . Experimental studies on impinging jet flows

T. Iwana , K. Suenaga , K. Shirai , Y. Kameya , M. Motosuke and S. Honami [2] investigated The fluid flow and heat transfer characteristics of an impinging jet with a combined active–passive device. The combined device consisted of triangular tabs and a synthetic jet array that provided periodic disturbance to the jet's shear layer. The heat transfer was governed by the jet's velocity, RMS, and periodic velocity fluctuation. These results indicate that the fluid flow and heat transfer characteristics of an impinging jet could be controlled by optimizing the actuation conditions of the combined active–passive device. Mohamed A. Teamah and Mohamed M. Khairat [3] experimentally investigated The heat transfer and fluid flow between a horizontal heated plate and impinging circular double jets.The parameters investigated are the Reynolds number of each jet and jet-to-jet spacing. Experiments are carried out covering a range for Reynolds number from 7100 to 30,800 for each jet, the dimensionless jet-to-jet spacing from 22.73 to 90.1. During experimental phases, the right jet Reynolds number was higher than the left jet Reynolds number.The results indicated that increasing the Reynolds number of one jet than the other increases both local and average Nusselt numbers. In addition, increasing the jet-to-jet spacing at the same Reynolds number increases the average Nusselt number. M. Wannassi and F. Monnoyer [4] investigated the flow and heat transfer characteristics of a staggered combination of straight and swirling jets. studied the flow field and the heat transfer characteristics for an array of conventional and swirling jets impinging on a flat surface. they evaluated three blade type swirl generators with different swirl angles in comparison with conventional jets. they focused mainly on the dynamic aspect of multiple jets with swirl. Chenglong Wang, Lei Luo, Lei Wang and Bengt Sundén [5] experimentally investigated the effects of vortex generators on the jet impingement heat transfer in cross-flow. In this study, the jet Reynolds number is fixed at 15,000 and the cross-flow Reynolds number varies from 40,000 to 64,000. The nozzle-to-surface distance to jet diameter ratio is 4.0. they concluded a stronger jet impingement is found with the presence of vortex generator pair, due to the reduced cross-flow momentum and secondary flow. Bingxing Wang, Xitao Guo, Qian Xie, Zhaodong Wang and Guodong Wang [6] focused on the heat transfer characteristics during jet impinging on the top or bottom of hot steel plates for industrial application. they studied the heat transfer difference between these two types of cooling processes using the inverse heat conduction method. They indicated that jet velocity is the critical factor to generate higher cooling performance during both impinging processes. This is useful for designing an ultra-fast cooling device and the optimized cooling parameters will enhance the cooling efficiency and cooling uniformity of the industrial ultra-fast cooling equipment.. Kyosung Choo , Brian K. Friedrich, Aspen W. Glaspell and Karen A. Schilling [7] experimentally investigated the heat transfer and fluid flow characteristics of a submerged jet impinging on a flat plate surface. The working fluids are air and water.The effects of a wide range of nozzle-to-plate spacing (H/d = 0.1 - 40) on the Nusselt number decreasing the nozzle-to-plate spacing. In region II, the effect of the nozzle-to-plate spacing is negligible on the Nusselt number and pressure. In region III, the Nusselt number and pressure monotonically decrease with increasing the nozzle-to-plate spacing. Based on the experimental results, new correlations for the normalized stagnation Nusselt number and pressure are developed as a function of the nozzle-to-plate spacing alone. V.I. Terekhov, S.V. Kalinina and K.A. Sharov [8] experimentally investigated the flow and heat transfer in an impinging annular jet. They concluded that the heat transfer intensity of the impinging annular jet is also higher than that of the round jet, and the degree of heat transfer enhancement depends on the annular gap size and distance from the nozzle to the obstacle. In this concluded result it should be noted that an important factor influencing the intensity of heat transfer in the considered conditions is the instability and fluctuations, developing in the annular jet. Bin Sun , Yi Qu , Di Yang [9] investigated the performance of a heat exchanger with an impinging jet cooling system by using nanofluids. Furthermore, they determined heat transfer efficiency by comparing different flow rates, jet heights, and types of nanofluids. they pointed out the use of nanofluids on impinging jet cooling systems significantly improved heat transfer efficiency and that the pressure drop in the system did not change considerably.they also concluded When nanofluids are employed as the working fluid, the convective heat transfer coefficient was higher in circular nozzles than in square nozzles .Carlo Carcasci, Lorenzo Cocchi, Bruno Facchini, Daniele Massini [10] studied heat transfer due to a single submerged impinging jet by using different experimental techniques. They pointed out the heat transfer enhancements can be obtained by increasing surface roughness. this is an aspect to be held in consideration for the design of impingement-based cooling systems. C. Quinn , D.B. Murray and T. Persoons [11] experimentally investigated heat transfer characteristics of a dilute impinging air-water mist jet. They determined that the surface liquid morphology varies with mist loading fraction, and that the heat transfer behavior of the mist jet reflects these changes. Three regimes were identified to describe the impingement behaviour of the mist jet in terms of mist loading fraction; these can be described as: 1. Low mist loading fraction regime, characterised by discrete liquid slugs forming without complete surface wetting in the impingement region. 2. Intermediate mist loading fraction regime, with the discrete liquid slugs merging to form localised thin liquid films, though still without complete surface wetting. 3. High mist loading fraction regime, where a continuous film ofliquid has developed in the impingement region that flows outwards under the action of the impinging droplets. Brian K. Friedrich, Tamira D. Ford, Aspen W. Glaspell and Kyosung Choo [12] studied the heat transfer and fluid flow characteristics of the circular hydraulic jump by air-assistant water jet impingement using water and air as the test fluid. The effects of volumetric quality (b = 0–0.9) on the hydraulic jump radius, local Nusselt number, and pressure at the stagnation point were considered under fixed water-flow-rate condition. Their results showed that the dimensionless hydraulic jump radius increased with volumetric quality, attained a maximum value at around 0.8 of the volumetric quality, and then decreased. they developed new correlation for the normalized hydraulic jump radius of the impinging jet as a function of the normalized stagnation pressure alone. Abdullah M. Kuraan, Stefan I. Moldovan, Kyosung Choo [13] experimentally investigated heat transfer and fluid flow characteristics of a free water jet impinging a flat plate surface The effects of low nozzle-to-plate spacing (H/d = 0.08–1) on the normalized stagnation Nusselt number, pressure, and hydraulic jump diameter are considered. they found that the normalized stagnation Nusselt number,pressure, and hydraulic jump diameter are divided into two regions: Region (I) jet deflection region (H/d ≤ 0.4) and Region (II) inertia dominant region (0.4 < H/d ≤ 1). Based on the experimental results, new correlations for the normalized hydraulic jump diameter, stagnation Nusselt number, and pressure are developed as a function of the nozzle-to-plate spacing alone. Taolue Zhang , Jorge L. Alvarado , J.P. Muthusamy , Anoop Kanjirakat , Reza Sadr [14] investigated the hydrodynamics and heat transfer induced by multiple droplet train impingement arrays. they elucidated the effects of droplet impingement parameters, such as droplet Weber number, impact spacing and impingement patterns on droplet-induced hydrodynamics and surface heat transfer on the basis of experimental result. Xiaoming Huang , Wei Yang , Tingzhen Ming , Wenqing Shen , Xiangfei Yu [15] studied The introduction of dimples to heat transfer surface can effectively improve the heat transfer performance of a microchannel heat sink with impinging jets (MIJ).they pointed out that MIJs with convex dimples exhibited the best cooling performance with concave dimples and among all tested cases, MIJs with convex dimples exhibited the best overall performance,followed by MIJs without dimples, with mixed dimples, and with concave dimples. Alexandr S. Nebuchinov, Yuriy A. Lozhkin, Artur V. Bilsky, Dmitriy M. Markovich [16] implemented combination of PLIF and PIV methods for simultaneous measurement of instantaneous fields of temperature and velocity in the near-wall areas of the impinging jet. They pointed out the results of measurements in two different areas of the near-wall region of the impinging jet and for the different distances from the nozzle to the wall. The analysis of instantaneous fields of temperature and velocity demonstrates the presence of coherent structures and flow separations in the stagnation jet area and the associated entrainment of the heated liquid from the wall. R. Jenkins , R. Lupoi , R. Kempers , A.J. Robinson [17] investigated a linear micro-groove and a radial micro-groove surface compared to a flat surface. A jet array consisting of nine 1 mm jets with 5 and pressure at stagnation point are considered. The results indicated that the Nusselt number and pressure are divided into three regions; region (I) jet deflection region (H/d ≤ 0.6), region (II) potential core region (0.6 < H/d ≤7), and region (III) free jet region (7 < H/d ≤40). In region I, the Nusselt number and pressure drastically increase with mm inter-jet spacing and a 2 mm jet to target spacing was employed to cool a 15 mm by 15 mm heated surface. The results show that the heat transfer performance of the impinging jet is insensitive to Reynolds number for fully developed boiling. they concluded that the radial micro-groove surface provided the highest heat transfer performance of all the surfaces tested. A maximum heat transfer coefficient of 230 W/m2 K was achieved at a heat flux of 380 W/cm2 achieving an enhancement of 2.3-fold over that of the flat surface. In comparison, the linear micro-grooved surface achieved an enhancement of 2-fold over the flat surface. Jizu Lv , Chengzhi Hu , Minli Bai , Ke Zeng , Shengnan Chang , Dongdong Gao[18] experimentally investigated heat transfer performance of free single jet impingement using SiO2-water nanofluids with various volume fractions (1%, 2% and 3%).they discussed the effect varying nanoparticles volume fractions, Reynolds number, nozzle-to-plate distance, and the impact angle on the heat transfer performances of the jet impingement. They also analyzed the heat transfer performances along the radial direction.they concluded that the convective heat transfer coefficient of nanofluid increases with the volume fraction of nanoparticles and Reynolds number. Heat transfer coefficient decreases along the radial direction. result concluded that that the application of nanofluid improves the heat transfer features of single free impingement jet.they also proposed heat transfer correlation of nanofluids for the free single jet impingement by taking the effects of the suspended nanoparticles and the condition of impinging jet into consideration. C. de Brún,R. Jenkins,T.L. Lupton , R. Lupoi, R. Kempers , A.J. Robinson [19] experimentally investigated confined jet array impingement boiling heat transfer. They used three jet configurations consisting of 2 × 2, 3 × 3 and 5 × 5 arrays of 1.0 mm diameter jets were tested for a jet-to-target spacing of 2 mm. A 15 mm ×15 mm plane copper surface was used as the heat transfer surface which formed a confined channel with the upper jet orifice plate. For a Reynolds number (Re) range of 900 ≤ Re ≤ 11,800, tests were performed by fixing the flow rate and progressively increasing the heat flux until the Critical Heat Flux (CHF) was reached. The results show that the single phase heat transfer coefficient increases with increasing Re and is reasonably predicted by a recent jet array heat transfer correlation. they pointed out with many earlier studies, the single phase heat transfer depends on flow velocity and jet geometric parameters. Saroj Suresh Kumar , Vijaykumar Hindasageri , S.V. Prabhu [20] conducted the experiment to study the local heat transfer distribution on a flat surface normally impinged by a swirling air jet. Twisted tapes of twist ratios equal to 2, 3.2, 4.5 and 7.5 (corresponding swirl numbers S ¼ 0.79, 0.49, 0.35, 0.21) are inserted in a circular tube to generate swirling effect. Experiments conducted out for Reynolds number varying from 500 to 3000 for jet to plate spacing varying from 1 to 4. they concluded the heat transfer rate for swirling jet is found to increase with increase in Re and the uniformity of heat transfer rate improves with increase in z/d for swirling jets. X. Ai, Z.G. Xu, C.Y. Zhao [21] investigated the heat transfer characteristics of a water jet impinging a surface with a moving nozzle impinging a surface using a stepping motor to control the nozzle.they investigated The effect of nozzle velocity on the heat transfer rates at different heat fluxes and flow rates. they pointed out mainly that moving nozzle enhances the heat transfer uniformity, which leads to a more uniform temperature distribution, with increased uniformity as the nozzle velocity increases. they also pointed out a moving nozzle enhances the heat transfer in the convection by more than forty percent. Zhou Ying , Lin Guiping , Bu Xueqin , Bai Lizhan , Wen Dongsheng [22] studied local and average heat transfer characteristics of a single round jet impinging on the concave surfaces. The experiments were conducted by employing a piccolo tube with one single jet hole over a wide range of parameters: jet Reynolds number from 27,000 to 130,000, relative nozzle to surface distance from 3.3 to 30, and relative surface curvature from 0.005 to 0.030. Result indicated that the surface curvature has opposite effects on heat transfer characteristics.they contributed to a better understanding of the curvature effects on heat transfer of a round jet impingement on concave surfaces, which is of high importance to the design of the aircraft anti-icing system.

CONCLUSIONS

The comprehensive review of jet impingement heat transfer has been presented. Jet impinging heat transfer is widely studied experimentally by many researchers. Review include different experimental approaches. Data presented in this review provides support for designing liquid jet impingement as an efficient cooling technique for various industrial as well as in electronic equipment. In the present review paper the effect of different parameters on heat transfer are studied for maximum heat transfer rate.

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