International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 04 Issue: 10 | Oct -2017 www.irjet.net p-ISSN: 2395-0072

Heat Transfer Enhancement Through Liquid Jet Impingement

Kedar C. Jagtap[1],Nitin B. Kale[2],Vipulraj V. Kale[3],Kiran S. Pawar[4], Prof. Deshmukh S.A[5]

[1,2,3,4] Department of Mechanical Engineering, SBPCOE, Indapur, Maharashtra, India
[5] Professor, Department of Mechanical Engineering, SBPCOE, Indapur, Maharashtra, India

---***---

Abstract - *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. This review paper gives various experimental and numerical approaches on jet impingement heat transfer process of recent years*.

***Key Words*: heat transfer, jet impingement, surface flat plate, experimental approach, numerical approach.**

1.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 paper we lay emphasis on various experimental and computational approaches used in the literature survey for liquid jet impingement heat transfer.

2. 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 flow and heat transfer characteristics of an impinging jet controlled by triangular tabs and synthetic jets. The result indicated that the heat transfer characteristics of an impinging jet may be improved by the combined active–passive device with triangular tabs and synthetic jet actuators. 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. 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 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. 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 analysed the heat transfer difference between these two types of cooling processes using the inverse heat conduction method. 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 surfaceThe effects of a wide range of nozzle-to-plate spacing ($H/d = 0.1 - 40$) on the Nusselt number 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 ($H/d \le 0.6$), region (II) potential core region ($0.6 < H/d \le 7$), and region (III) free jet region ($7 < H/d \le 40$). In region I, the Nusselt number and pressure drastically increase with 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. V.I. Terekhov, S.V. Kalinina and K.A. Sharov [8] experimentally studied the flow and heat transfer in an impinging annular jet.result indicated 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. Bin Sun , Yi Qu , Di Yang [9] investigated the performance of a heat exchanger with an impinging jet cooling system by using 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. 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.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. 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 ($H/d \le 0.4$) and Region (II) inertia dominant region ($0.4 < H/d \le 1$).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. 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] investgated a linear micro-groove and a radial micro-groove surface compared to a flat surface.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 SiO_2-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.result concluded that that the application of nanofluid improves the heat transfer features of single free impingement jet. 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 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. 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.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. 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.result indicated that the surface curvature has opposite effects on heat transfer characteristics.

2.2. Computational approaches on impingement jet flows

G. Nasif ,R.M. Barron and R. Balachandar [23] numerically investigated the thermal effects of an axisymmetric oil jet impinging on a high-speed reciprocating disc subjected to uniform heat flux and bounded by a cylindrical wall. They used the volume of fluid (VOF) method.They concluded that jet impingement onto the moving boundary, the maximum Nusselt number is achieved a short time after the relative velocity between the disc and the jet reaches its maximum.

Lu Qiu, Swapnil Dubey, Fook Hoong Choo and Fei Duan [24] computationally studied the effect of conjugation on jet impingement boiling heat transfer. They observed heating schemes in a jet impingement boiling configuration. the result of this simulation suggested that the experimental data obtained in the different experiments with different heating schemes can be significantly different even if the jet parameters are same.Omidreza Ghaffari, Stephen A. Solovitz and Mehmet Arik [25] investigated flow and heat transfer for a slot impinging synthetic jet. they performed a series of experiments to examine the performance of an impinging slot synthetic jet. they used time averaged and phase-locked PIV to study the flow physics and their effects on heat transfer. M.A. Pakhomov and V.I. Terekhov [26] studied numerically the flow and heat transfer in a turbulent bubbly jet Impingement. They presented the results of modelling of the flow structure and heat transfer enhancement obtained by adding air bubbles into a turbulent liquid (water) impinging jet. Amir Hossein Nobari, Vladan Prodanovic, Matthias Militzer [27] described a strategy to develop a mechanistic heat transfer model for cooling of steel. they investigated the cooling behaviour of stationary steel plates. Md Lokman Hosain, Rebei Bel Fdhila and Anders Daneryd [28] investigated a hot rolling steel run out table case with respect to nozzle diameter, jet-to-jet distance, plate width, impingement angle and water flow rates, and numerically investigated the flow and heat transfer behaviour of single and double jets. they developed new correlation between the radial position of the maximum nusselt number and minimum jet diameter. Fifi N.M. Elwekeel and Antar M.M. Abdala [29] investigated heat transfer characteristics caused by turbulence around impinging jets.they found that the addition of mist has a significant effect on heat transfer produced in the stagnation zones. Bingxing Wang, Dong Lin , Qian Xie, Zhaodong Wang and Guodong Wang [30] numerically investigated the heat transfer characteristics during water jet impingement on a hot plate surface. Christopher Csernyei, Anthony G. Straatman [31] computationally studied forced convective heat transfer on a horizontal circular cylinder due to multiple impinging circular jets.they investigated convective heat transfer on a horizontal cylinder due to a bank of vertically oriented circular jets. J.B.R. Loureiro and A.P. Silva Freire [32] investigated the velocity and temperature profiles, wall shear stress and heat transfer coefficient of turbulent impinging jets.they presented a set of empirical equations that can be used to predict the flow dynamics and the heat transfer properties of impinging jets over a wide range of Reynolds number, nozzle-to-plate spacing and radial position along the impingement plate. Malte Bieber, Reinhold Kneer, Wilko Rohlfs [33] numerically investigated Self-similarity of heat transfer characteristics in laminar submerged and free-surface slot jet impingement. Matthew Searle, Daniel Maynes, Julie Crockett [34] analytically investigated the thermal transport due to a steady, laminar, axisymmetric liquid jet impinging normally on a superhydrophobic (SHPo) surface maintained at constant surface temperature.result indicated the following effects on thermal transport 1) local thermal boundry layer thickness decreses relative to classical scenario2) The local and average Nusselt numbers become less dependent on Re and Pr with increasing temperature jump length .

3. CONCLUSIONS

The detailed review of jet impingement heat transfer has been presented. 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. The review includes various experimental and numerical approaches of impingement flows. In the present review paper the effect of different parameters on heat transfer coefficient are studied for maximum heat transfer rate.

ACKNOWLEDGEMENT

We are very thankful to Prof. Deshmukh S A. for guidance and her help in building this review paper on impinging jet heat transfer.

REFERENCES

[1] Anuj K. Shukla, Anupam Dewan, " Flow and thermal characteristics of jet impingement: comprehensive review" Internatinal journal of heat and technology, vol.35,pp.153-166,March 2017.

[2] T. Iwana , K. Suenaga , K. Shirai , Y. Kameya , M. Motosuke , S. Honami, "Heat transfer and fluid flow characteristics of impinging jet using combined device with triangular tabs and synthetic jets" , Experimental Thermal and Fluid Science 68 ,2015,pp. 322–329.

[3] Mohamed A. Teamah, Mohamed M. Khairat, "Heat transfer due to impinging double free circular jet", Alexandria Engineering Journal 54,2015,pp. 281–293.

[4] M. Wannassi a, b, *, F. Monnoyer a, b , "Fluid flow and convective heat transfer of combined swirling and straight impinging jet arrays" , Applied Thermal Engineering 78 ,2015, pp.62-73.

[5] Chenglong Wang, Lei Luo, Lei Wang , Bengt Sundén, "Effects of vortex generators on the jet impingement heat transfer at different cross-flow Reynolds numbers", International Journal of Heat and Mass Transfer 96,2016, pp.278–286.

[6] Bingxing Wang, Xitao Guo, Qian Xie, Zhaodong Wang, Guodong Wang , "Heat transfer characteristic research during jet impinging on top/bottom hot steel plate", International Journal of Heat and Mass Transfer 101 2016,pp. 844–851

[7] Kyosung Choo , Brian K. Friedrich, Aspen W. Glaspell, Karen A. Schilling, "The influence of nozzle-to-plate spacing on heat transfer and fluid flow of submerged jet

impingement", International Journal of Heat and Mass Transfer 97 ,2016,pp. 66–69.

[8] V.I. Terekhov, S.V. Kalinina, K.A. Sharov, "An experimental investigation of flow structure and heat transfer in an impinging annular jet" , International Communications in Heat and Mass Transfer 79,2016,pp. 89–97.

[9] Bin Sun , Yi Qu, Di Yang , "Heat transfer of Single Impinging Jet with Cu Nanofluids" , Applied Thermal Engineering 102 ,2016,pp. 701–707.

[10] Carlo Carcasci, Lorenzo Cocchi , Bruno Facchini, Daniele Massini , "Impingement cooling experimental investigation using different heating elements" , Energy Procedia 101 ,2016,pp. 18 – 25.

[11] C. Quinn , D.B. Murray , T. Persoons, "Heat transfer behaviour of a dilute impinging air-water mist jet at low wall temperatures",International Journal of Heat and Mass Transfer 111 ,2017,pp. 1234–1249.

[12] Brian K. Friedrich, Tamira D. Ford, Aspen W. Glaspell, Kyosung Choo, "Experimental study of the hydrodynamic and heat transfer of air-assistant circular water jet impinging a flat circular disk", International Journal of Heat and Mass Transfer 106 ,2017,pp. 804–809.

[13] Abdullah M. Kuraan, Stefan I. Moldovan, Kyosung Choo, "Heat transfer and hydrodynamics of free water jet impingement at low nozzle-to-plate spacings", International Journal of Heat and Mass Transfer 108, 2017,pp. 2211–2216.

[14] Taolue Zhang , Jorge L. Alvarado , J.P. Muthusamy , Anoop Kanjirakat , Reza Sadr, "Heat transfer characteristics of double, triple and hexagonally-arranged droplet train impingement arrays", International Journal of Heat and Mass Transfer 110 ,2017,pp. 562–575.

[15] Xiaoming Huang , Wei Yang , Tingzhen Ming , Wenqing Shen , Xiangfei Yu, "Heat transfer enhancement on a microchannel heat sink with impinging jets and dimples", International Journal of Heat and Mass Transfer 112,2017, pp.113–124.

[16] Alexandr S. Nebuchinov, Yuriy A. Lozhkin, Artur V. Bilsky, Dmitriy M. Markovich, "Combination of PIV and PLIF methods to study convective heat transfer in an impinging jet", Experimental Thermal and Fluid Science 80 ,2017,pp. 139–146.

[17] R. Jenkins , R. Lupoi , R. Kempers , A.J. Robinson, "Heat transfer performance of boiling jet array impingement on micro-grooved surfaces", Experimental Thermal and Fluid Science 80 ,2017,pp. 293–304.

[18] Jizu Lv , Chengzhi Hu , Minli Bai , Ke Zeng , Shengnan Chang , Dongdong Gao , "Experimental investigation of free single jet impingement using SiO2-water nanofluid" ,Experimental Thermal and Fluid Science 84 ,2017,pp. 39–46.

[19] C. de Brún,R. Jenkins,T.L. Lupton , R. Lupoi, R. Kempers , A.J. Robinson, "Confined jet array impingement boiling", Experimental Thermal and Fluid Science 86 ,2017,pp. 224–234.

[20] Saroj Suresh Kumar , Vijaykumar Hindasageri , S.V. Prabhu, "Local heat transfer distribution on a flat plate impinged by a swirling jet generated by a twisted tape", International Journal of Thermal Sciences 111, 2017,pp. 351-368.

[21] X. Ai, Z.G. Xu, C.Y. Zhao, "Experimental study on heat transfer of jet impingement with a moving nozzle", Applied Thermal Engineering 115,2017,pp. 682–691.

[22] Zhou Ying , Lin Guiping , Bu Xueqin , Bai Lizhan , Wen Dongsheng, "Experimental study of curvature effects on jet impingement heat transfer on concave surfaces", Chinese Journal of Aeronautics, 2017.

[23] G. Nasif ,R.M. Barron, R. Balachandar, "Simulation of jet impingement heat transfer onto a moving disc", International Journal of Heat and Mass Transfer 80, 2015, pp.539–550.

[24] Lu Qiu, Swapnil Dubey, Fook Hoong Choo , Fei Duan, "Effect of conjugation on jet impingement boiling heat transfer", International Journal of Heat and Mass Transfer 91,2015,pp. 584–593.

[25] Omidreza Ghaffari, Stephen A. Solovitz , Mehmet Arik , "An investigation into flow and heat transfer for a slot impinging synthetic jet", International Journal of Heat and Mass Transfer 100 ,2016,pp. 634–645.

[26] M.A. Pakhomov , V.I. Terekhov, "Numerical study of the flow and heat transfer in a turbulent bubbly jet Impingement", International Journal of Heat and Mass Transfer 92 ,2016,pp. 689–699.

[27] Amir Hossein Nobari, Vladan Prodanovic, Matthias Militzer, "Heat transfer of a stationary steel plate during water jet impingement cooling", International Journal of Heat and Mass Transfer 101,2016,pp. 1138–1150.

[28] Md Lokman Hosain, Rebei Bel Fdhila, Anders Daneryd , "Heat transfer by liquid jets impinging on a hot flat surface" Applied Energy 164 ,2016,pp. 934–943.

[29] Fifi N.M. Elwekeel, Antar M.M. Abdala , Effects of mist and jet cross-section on heat transfer for a confined air jet impinging on a flat plate, International Journal of Thermal Sciences 108 ,2016, pp.174-184.

[30] Bingxing Wang, Dong Lin , Qian Xie, Zhaodong Wang, Guodong Wang, "Heat transfer characteristics during jet impingement on a high-temperature plate surface",Applied Thermal Engineering 100 ,2016,pp. 902–910.

[31] Christopher Csernyei, Anthony G. Straatman, "Forced convective heat transfer on a horizontal circular cylinder due to multiple impinging circular jets", Applied Thermal Engineering 105, 2016,pp. 290–303.

[32] J.B.R. Loureiro, A.P. Silva Freire, "Velocity and temperature profiles, wall shear stress and heat transfer coefficient of turbulent impinging jets", International Journal of Heat and Mass Transfer 107 ,2017,pp. 846–861.

[33] Malte Bieber, Reinhold Kneer, Wilko Rohlfs, " Self-similarity of heat transfer characteristics in laminar submerged and free-surface slot jet impingement", International Journal of Heat and Mass Transfer 104 ,2017,pp. 1341–1352.

[34] Matthew Searle, Daniel Maynes, Julie Crockett, "Thermal transport due to liquid jet impingement on super hydrophobic surfaces with isotropic slip", International Journal of Heat and Mass Transfer 110,2017,pp- 680–691.