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A REVIEW ON: "HEAT TRANSFER ENHANCEMENT BY JET IMPINGEMENT ON DIMPLED SURFACE"

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Abstract: Experimental data for the rate of heat transfer by jet impingement on dimpled surface have been collated and reviewed from the literature. The geometry considered is of hemispherical shape compared with cusped shape. Also depth of the dimple is varied. The review suggests the correlation with Nusselt number is a function of Reynolds number, jet to plate spacing H/D, r/D. Nozzle geometry, dimple geometry and confinement also affects the heat transfer rate. Turbulence generate after impingement with cross flow scheme also affects the heat transfer rate. A correlation with Nusselt number as a function of Reynolds number, raised to an exponent. This exponent is depend upon the value of jet to plate spacing (H/D) and r/D. The Nusselt number is compare with different values of H/D, Reynolds number, cross flow scheme and different geometry. The H/D is varied from 2-8 nozzle diameter and Reynolds number is varied from 7000-30,000.

Keywords: Jet Impingement, Dimple Surface, Turbulent Flow

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INTRODUCTION

Jet impingement is a cooling technique. It is widely used where high rate of heat transfer are required. In gas turbine, the temperature reaches to 2000°c at the inner wall of leading edge region of blades and outer wall of combustors i.e. for every rise in 55.5°c increase in temperature, the work output increases approximately 10% and it gives 1.5% increase in thermal efficiency. Therefore it is very essential to maintain the high rates of heat transfer for high efficiency and performance. To increase the rate of heat transfer, surfaces are modified with fins, cavities, vortex generators and dimples. Dimples are used on target surface of jet impingement to enhance the heat transfer rate. Dimples have simple geometry, light weight, low maintenance, low pressure penalty and it promotes turbulent mixing due to which the boundary layer get thinned and partially breaks which leads to heat transfer augmentation. The factors which influence the heat transfer by jet impingement includes nozzle geometry, jet to plate distance, jet incidence angle, radial distance from stagnation point, crossflow scheme, Reynolds number (Re) and Nusselt number (Nu).

2. LITERATURE REVIEW

Jet flow characteristics

The flow of air impinging on a plate is divided into four zones :-

1) Initial mixing zone :

In this zone, fluid from the surrounding entered into the jet due to pressure difference and thus reduces the velocity of jet. This mixing surround the core region where velocity U_m is nearly equal to U_n nozzle exit velocity as suggested by K. Jambunathan et al. A core region is the point where $U_m=0.95U_n$.

2) Established jet zone :

Impinging jet being influenced by the the distance of target plate approximately 1.2 nozzle diameter as suggested by the Gardon and Akfirat (1965).

In this region flow is decelerated in axial direction and accelerated in radial direction. The potential core of the jet which strikes the target plate when nozzle to plate distance is smaller than the core length which is 6-8 nozzle diameter long for turbulent jets. At greater jet to plate spacing the jet velocity get reduce and Schlichting (1968) analysis showed that fall of a centreline velocity and the jet half width (jet width at $U=U_m/2$) will be directly proportional to axial distance from the end of potential core.

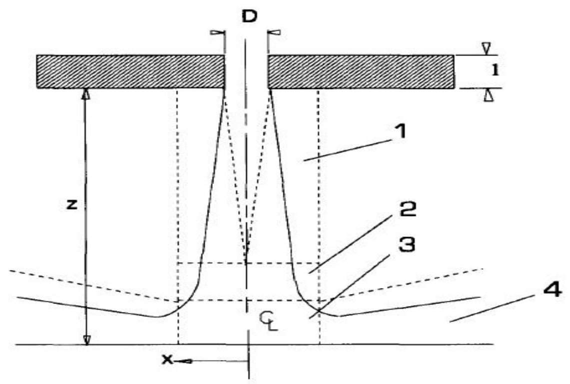

Figure 1 Flow zones in an impinging jet. Zone 1, initial mixing region; zone 2, established jet; zone 3, deflection zone; zone 4, wall jet

3) Deflection zone :

This is the region near the plate surface. There is rapid decrease in the axial jet velocity and corresponding rise in the static pressure. This zone is approximately 2 nozzle diameter from the plate surface as suggested by the Tani and Komatsu (1966).

4) Wall jet zone :

Local velocity increase rapidly, maximum near the wall, and then falls to a greater distance from the wall. This wall jet enhances heat transfer than parallel flow, due to turbulence generated by the shear between wall jet and the ambient air, which is transported to the boundary layer at the heat transfer surface, as suggested by the K. Jambunathan et al.

Obot and Trabold investigated the effect of crossflow scheme on the flat surface heat transfer by jet impingement with minimum, maximum and intermediate crossflow scheme. They found that minimum crossflow scheme is showing the best result compare to maximum and intermediate crossflow schemes. K. Kanokjaruvijit et al. perform an experiment on the flat plate with Reynolds number constant at 11500. They found that minimum crossflow scheme shows higher heat transfer enhancement compare to maximum and intermediate see fig.2. Experiment also performed on dimpled surface for different crossflow schemes. It is found that at jet to plate spacing (H/D) of 2 minimum crossflow scheme shows better heat transfer rate than maximum and intermediate crossflow schmes but there is slight increase in the heat transfer due to presence of dimples compare to the flat plate.

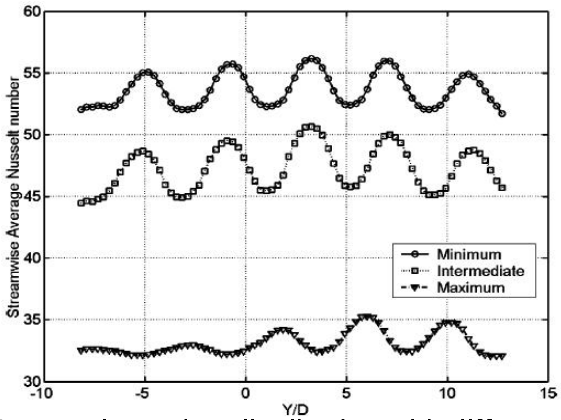

Fig.2: Nusselt number distribution with different flow schemes.

Effect of jet to plate spacing :

Chang shyy woei et al. perform an experiment on convex dimpled surface with different Reynolds number and jet to plate spacing (H/Dj=2 ,4,6,8) with a constant Re=10,000 and compared with distribution of Nusselt number. They found that Nu counter remains unaltered but the Nuc values are reduced with increase in the H/D value. P.M. Nakod et al. investigate the effect of finned surface and vortex generators on the local heat transfer coefficient. They found that, heat transfer rate is maximum at H/D of 0.5 and then it reduces as the value of H/D increases. And it further increases in the vicinity of H/D of 6 and then again reduces at higher H/D. Higher heat transfer at H/D of 6 is due to jet shear layer turbulence is penetrated at the centre which gives higher rate of heat transfer. At H/D of 0.5, high rate of heat transfer is due to the acceleration of the fluid through the gap between target plate and nozzle exit.

C. Nuntadusit et al. compare the multiple swirling impinging jet (M-SIJ) with that of conventional jet (M-CIJ) with four different S/D 2, 4, 6, 8. They have found that, at small jet to jet distance (S/D), the jet flow is strongly confined and interfered. With increase in the S/D, impinging jets moved more freely like a single jet. Also M-SIJ shows higher rate of heat transfer than M-CIJ. For M-CIJ, at S/D of 6, 8, maximum heat transfer rate appear at stagnation point. At small jet to jet distance (S/D=2, 4), Nusselt number decreases along radius for both M-SIJ and M-CIJ. At small S/D, maximum Nusselt number is found at stagnation point and then decreases due to confinement effect of adjacent jets. Yunfei Xing et al. perform an experiment on 9x9 jet array on flat and dimple plate with Reynolds number varying from 15,000 to 35,000. They have found that, at H/D=3, dimple plate shows high rate of heat transfer compare to flat plate at same H/D with cross flow scheme. See fig.3

While H/D=5 shows lower value. For minimum cross flow scheme, flat plate shows nearly same values of heat transfer but there is significant increase in the heat transfer rate on dimpled surface at H/D=3.K. Kanokjaruvijit et al. experiments on 8x8 array of jets with minimum cross flow scheme. It is found that highest Nusselt number is found at H/D=4. They found the distance from nozzle plate to the bottom of the dimple was 45mm, which might be the end of the potential core.

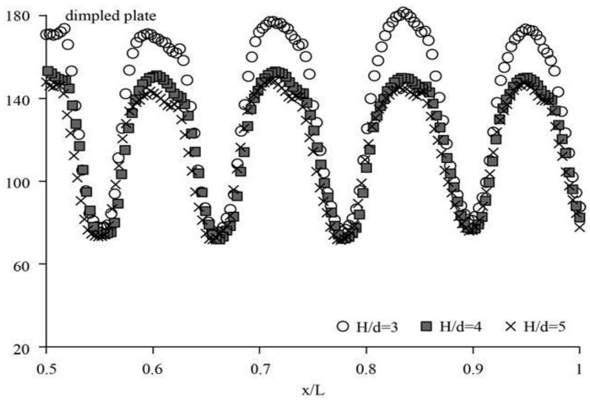

Fig.3: Nusselt number variation with H/D=3, 4, 5.

Effect of Reynolds number:

Increase in Reynolds number increases the velocity of impinging jet and thus increases the heat transfer rate. P.M. Nakod et al. suggested that increase in Reynolds number increases the heat transfer rate at all radial locations but it is higher at the stagnation point compare to the radial distance. They found that at Re=7000-12500, the Nusselt number increases by 74% at stagnation point, whereas at radial location it is only 48% at r/D of 6.8. This is the proof that heat transfer at stagnation point is stronger than the radial locations. See fig.4

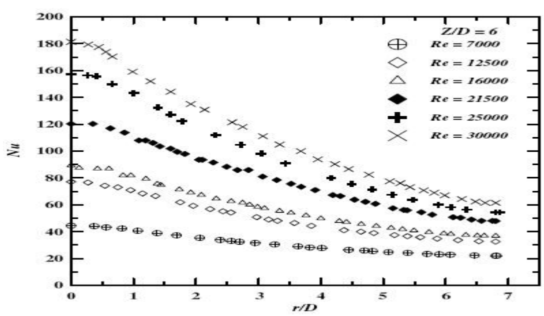

Fig.4: Nusselt number variation with different Re.

K. Kanokjaruvijit et al. shows the similar results, with Re=11,500 the heat transfer rate was 51% higher on dimple plate than the flat plate. Whereas, at Re=8000 and 5000, the heat transfer rate led to the improvement of 38% and 22% respectively. According to the flow visualization reported by Cornero et al. the impacting jet formed the vortices which are oscillates at stagnation point. This cause acceleration and break down of boundary layer. At higher Re, the velocity of spent air also increases and more vigorous vortices are formed which leads to the higher heat transfer rate. Y. Xing et al. also suggests that the increase in Re increases the heat transfer rate. To normalize the heat transfer value, Nu= Re0.8Pr1/3 this relation is referred. That means the heat transfer values can be correlate with Re0.8 for turbulent boundary layer.

Effect of dimple geometry :

K. Kanokjaruvijit et al. (2010) perform an experiment on shallow dimple with (d/Dd=0.15) and with (d/Dd=0.25), it is found that shallow dimples show greater heat transfer rate than the deep one.

It is due to, the deep dimple causes higher recirculation of vortices radially inside the indentation which reduces the poorer heat transfer rate; whereas in shallow dimple, the vortices can easily go out from the cavity which enhances the heat transfer rate. K. Kanokjaruvijit et al.(2005) also perform an experiment to compare the Nusselt number distribution with cusped shape dimple and hemispherical dimple. It found that, at all values of (H/D=2, 4, 6, 8); the hemispherical dimple shows better heat transfer rate than cusped (fig.5)

Effect of nozzle geometry :

Obot et al. shows that variation in nozzle geometry shows different heat transfer rate due to variation in turbulence level.

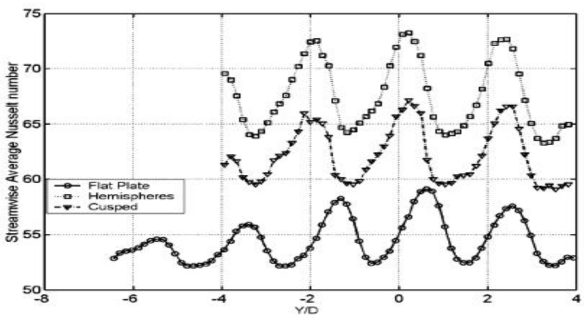

Fig.5 : Nusselt number variation with Flat, Hemispherical and Cusped shape dimple plate at H/D=4.

They showed the result, for a nozzle with sharp-edge inlet with l/d ratio of 1, (Re=29,485), the maximum point Nusselt number is 155,which occurs at H/D=4. With countered inlet, Nu=125 at H/D=8. Popiel et al. shows the similar results, the heat transfer rate with countered nozzle is 25% less than the sharp edged orifice at H/D=4 with Re=20,000. Gundappa et al. also shows the similar comparison between orifice jet and and the jet from pipe (l/D=10). The axial velocity decay more slowly in case of jet from pipe which led to the higher values of Nusselt number at all radial position with H/D=7.8. K.jambunathan et al. suggests that the nozzle geometry affects the velocity profile at the nozzle exit which affects the toroidal vortices formed near the jet circumference and the turbulent layer generated in the shear layer. The turbulent intensity would affects the mixing of the jet with ambient air and so the rate of velocity decay which also affects the heat transfer rate.

Effect of small-scale turbulence :

The turbulence at nozzle exit affects the heat transfer rate at stagnation point, as suggested by Hoogendoorn et al. An increase of 0.5-3.2% in axial turbulence intensity (Re=6000, H/D=2) resulted an increase of Nusselt number from 180-215. However, Gardon et al. suggests that turbulence at nozzle exit affects less at

H/D=6 because the turbulence generate in the shear layer predominates.

Effect of Confinement :

Obot et al. shows that the confined jet causes the decrease in the heat transfer rate and it further decreases with increase in the flow rate. Their experiment showed the results as, at H/D=6 and r/D=6, the heat transfer rate was reduced by 4% at Re=29,673 and it reduces further by 10% at Re=50,367.

Correlations :

Results of the experiment were correlated with the dimensionless parameters like Reynolds number, nusslet number, H/D, r/D. K. Kanokjaruvijit et al. suggested the correlation for the for impingement on dimple and on flat plate as

Nudimple=0.1770(ReDj)0.61(H/Dj)-0.23

(d/Dd)0.60(Dj/Dd)0.85

R2=0.8563

For impingement on flat portion,

Nu=0.3472(ReDj)0.50(H/Dj)-0.16(d/Dd)-0.64

(Dj/Dd)0.31

R2=0.7837

V. Katti et al. suggested from his experiment a correlation, at r/D=1.5 as

Nu=0.33Re0.65(H/D)-0.08

DISCUSSION:

Many papers are available which considers the effects of Reynolds number, Nusselt number, jet to plate spacing (H/D), r/D, nozzle geometry, dimple geometry and confinement. Many authors suggests that the rate of heat transfer is increases with the use of dimple surface. Increase in Reynolds number increases the velocity which leads to the high rate of heat transfer. The rate of heat transfer is also depend upon the jet to plate spacing. The heat transfer rate is also depend upon the dimple geometry. Cusped shape dimple shows less heat transfer rate while the hemispherical one shows higher rate of heat transfer. Depth of dimple also play a role in heat transfer rate. Deep dimple is less effective than the shallow one. It is due to the deep dimple causes higher recirculation of vortices radially inside the indentation which reduces the poorer heat transfer rate; whereas in shallow dimple, the vortices can easily go out from the cavity which enhances the heat transfer rate. Nozzle geometry and confinement also affects the heat transfer rate. Orifice can increase the rate of heat transfer upto H/D=10 than the contoured nozzle. At larger H/D, the use of pipe shows higher rate of heat transfer than the contoured one.

CONCLUSIONS

A review of empirical results shows that the rate of heat transfer i.e. Nusselt number is a function of Reynolds number, jet to plate spacing H/D, r/D. But these correlation will not take an account for the nozzle geometry, confinement and the turbulence generated after the impingement. This correlation gives as the Nusselt number is a function of Reynolds number raised to an exponent. This exponent is depend upon the value of jet to plate spacing (H/D) and r/D. It is suggested that further work in developing the correlation should follow a similar approach.

Nomenclature

D - diameter of nozzle exit (m)

H - height of the fin (m)

Nu - Nusselt no. (hL/k)

Nuc - Nu at centreline jet region

R - radial distance from stagnation point (m)

Re - Reynolds no. (ρvD/μ) Um - centreline velocity m/s Un - nozzle exit velocity

U - velocity

Dj - jet diameter

M-SIJ - multiple swirling impinging jet

M-CIJ-multiple conventional impinging jet

S/D - jet to jet spacing

REFERENCE:

1. Koonlaya Kanokjaruvijit, Ricardo F. Martinez-botas " Jet impingement on adimpled surface with different crossflow schemes", "IJHMT",48(2005)161-170.

2. Srinath Ekkad, David Kontrovitz "Jet impingement heat transfer on dimpled target surfaces", "IJHFF", 23(2002)22-28.

3. Sidy Ndao, Yoav Peles, Michael K. Jensen, " Experimental investigation of flow boiling heat transfer of jet impingement on smooth and micro structured surfaces", "IJHMT", 55(2012)5093-5101.

4. Koonlaya Kanokjaruvijit, Ricardo F. Martinez-botas, "Heat transfer correlations of perpendicularly impinging jets on a hemispherical dimpled surface.", "IJHMT", 53(2010)3045-3056.

5. Yunfei Xing, Berhard Weigand, " Experimental investigation of impinging heat transfer on a flat and dimpled plate with different crossflow schemes", "IJHMT", 53(2010)3874-3886.

6. W. M. Yan, H.C. Liu, C.Y. Soong, W.J. Yang " Experimental study of impinging heat transfer along rib roughnedwalls by using transient liquid crystal technique", "IJHMT",48(2005)2420-2428.

7. Lei Wang, Bengt Sunden, Andreas Borg, Hans Abrahamsson, " Control of jet impingementheat transfer in crossflow by using a rib", "IJHMT", 54(2011)4157-4166.

8. Chang Shyy Woei, Jan Yih Jena, Chang Shuen,Fei, " Heat transfer of impinging jet array over convex dimple surface", "IJHMT",(2006)3045-3059.

9. C. Nuntadusit, M. Wae-hayee, A. Bunyajitradulya, S. Eiamsa-ard, " Heat transfer enhancement by multiple swirling impinging jets with twisted-tape swirl generators, "ICHMT", 39(2012)102-107.

10. P. M. Nakod, S. V. Prabhu, R. P. Vedula, " Heat transfer augmentation between impinging circular air jet and flat plate using finned surfaces and vortex generators", "ETFS",32(2008),1168-1187.

11. Eun Yeong Choi, Yong Duck Choi, Won Suk Lee, Jin Teak Chung, Jae Su Kwak, " Heat transfer augmentation using rib-dimple compound cooling technique, "ATE", 51(2013)435-441.

12. Mohammad A. Elyaan, Danesh K. Tafti, A novel split-dimple interrupted fin configuration for heat transfer augmentation", "IJHMT",52(2009)1561-1572.

13. Gilberto Moreno, Sreekant Narumanchi, Travis Venson, Kevin Bennion, " Microstructured surfaces for single-phase jet impingement heat transfer enhancement", "JTSEA(ASME)",Sept 2013, Vol.5/031004-1.

14. Vadiraj Katti, S. V. Prabhu, "Heat transfer enhancement on a flat surface with axisymmetric detached ribs by normal impingement of circular air jet", "IJHFF",29(2008)1279-1294.

15. Yonghui Xie, Ping Li, Jibing Lan, Di Zhang, "Flow and heat transfer characteristics of single jet impinging on dimpledsurface","JHT(ASME)",May2013,Vol.135/0522011

16. K. Jambunathan, E. Lai, M. A. Moss and B. L. Button "A review of heat transfer data for single circular jet impingement ""IJHFF" Vol.13 No.2 June1992.

17. S. V. Garimella, B. Nenaydykh, " Nozzle-geometry effects in liquid jet impingement heat transfer", "IJHMT", Vol. 39 No.14 pp. 2915-2923, 1996.