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Experimental Study of Slot Jet Flow on Flat and Curved Surfaces

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ABSTRACT

In the present work experimental setup is planned, designed and fabricated for the study on jet impingement heat transfer on flat and curved surfaces of radius of curvature 0.5, 0.725, 1.3. Experiment was conducted for the varying Reynolds number of 3500, 5500 and 9000. The heat transfer characteristics of a slot jet obtained from nozzle designed is impinged on concave and flat surfaces with constant heat flux have been analyzed experimentally. The effects of surface curvature R/L, the dimensionless nozzle to surface distance and Reynolds number on average Nusselt number of plate is obtained. It is found that Reynolds number has greater influence on heat transfer from the plates as the H/W ratio varies. The findings of the present study can be utilized to investigate the curvature of the blade for which heat transfer is more and to optimize the cooling rates in the surfaces for the better design of the gas turbine blades.

Introduction

Present days gas turbines are used in aircraft propulsion, power generation, fabric industry, sugar industry etc. During 1960's these gas turbines were operated at low temperatures of 600 to 800^{0}C but as the technologies are developed to increase the thermal efficiency of the gas turbines[1], now they are operated at high temperatures of 1500 to 1800^{0}C. Because of this high temperature leading and trailing edges of turbine blades undergo thermal stresses so, for this high accurate and detailed heat transfer data is needed to prevent the blades from failure[2] so as to prevent the blades from this many techniques were developed. In all of those techniques jet impingement technique has shown 20 to 30 % improvement in heat transfer [3]. Higher Reynolds number from 5000-10000 showed better results because of the formation of the vortex and the turbulences over the plates [4], also the inclination angle of jet to the target surface also influences the heat transfer but angle of 90^{0}C is favorable [5], even impingement distance from jet exit to the surface of the target also plays an vital role in optimizing the heat transfer rates [6] and the increase in the impingement distance gives better heat transfer rates but after certain distance heat transfer rates reduces because of the reduction in the flow accelerations [7] so it is mandatory that for increasing the heat transfer rates using jet impingement the parameters like Reynolds number, impingement distance, impingement angles are to be thoroughly studied and to be optimized for the given design of the plates. However much research has been done on jet impingement, but most of the researchers investigate the effect of jet impingement on flat surface, this warrants the investigation on the curved surfaces. So in this present work an attempt is made to understand the behavior of Nusselt number for plates of different radius of curvature and impingement distances with slot jet for different Reynolds numbers.

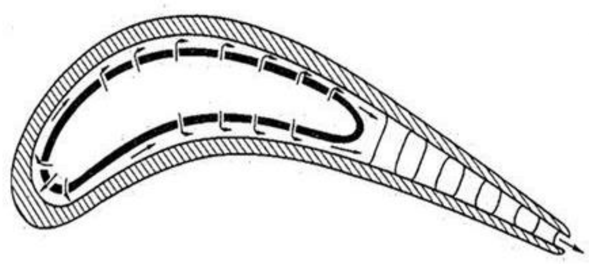

Figure 1. Detailed view of jet impingement cooling of turbine blades.

Experimental setup and procedure-

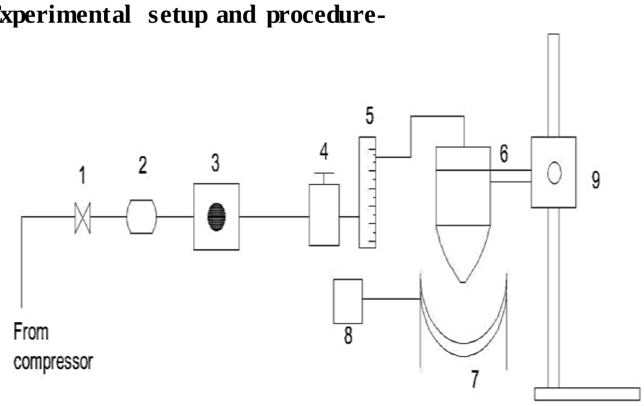

Figure 2. Block diagram of experimental setup

The experimental setup consists of 1.Ball valve 2.Pressure gauge 3.Air filter 4.Pressure regulator 5.Rotameter 6.Nozzle 7.Target plate with heater 8.Temperature controller 9.Traverse.

Target plates were selected as suggested by Ebru Oztekin et.al [8] i.e., R/L is ∞ (flat), 1.3, 0.725, 0.5 and the Nusselt number was calculated for all the plates with varying Reynolds numbers of 3500, 5500 and 9000 and H/W of 6, 8, 10, and 12.

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Table 1.Geometries of target plates[8]

Radius of curvature (R/L)	Trace length (L, mm)	Radius (R, mm)
Flat	150	∞
1.3	150	195
0.725	150	108.75
0.5	150	75

The target plates material was 3mm thick Aluminum plate.

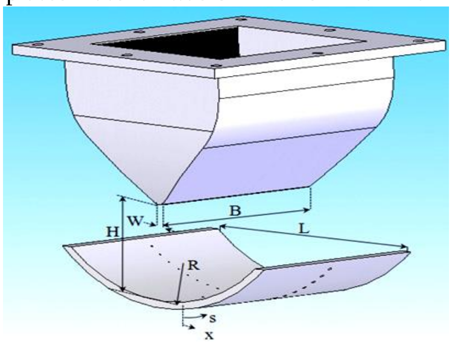

Figure 3. Schematic of testing section [8]

Data reduction-

Using the mass flow rate of air measured by Rotameter Reynolds number (Re) can be calculated by following equation, Re=4m/μP ....(1)

'P' is the perimeter of impinging slot given by,

P=2(W+B) …..........(2)

Where, W=3 mm and B=63 mm.

In jet impingement cooling heat transfer coefficient, average Nusselt numbers are to be defined for the temperature so they are calculated by, $h = (q_{convection}/A)(Tp\text{-}T_j)$ ....(3)
after finding 'h' for all the temperatures of the plate surface on generated grids average of it has to be taken so that it will become 'h_{avr}'. $Nu_{avr}=(h_{avr}D_e)/k_a$ ....(4)

In the equation '$q_{convection}$' is the heat lost due to convection , 'A' is surface area of the target plate, 'Tp' is the temperature of the plate surface which is measured for grid points and 'T_j' is the jet temperature. 'D_e' is the equivalent diameter. It is found by the equation D_e=2WB/(W+B) ....(5)
Heat lost due to convection can be calculated by using,

$q_{convection}= q_{total}- q_{conduction}- q_{radiation}$ ....(6)

in the above equation 'q_{total}' is the total heat supplied to the heater, '$q_{conduction}$' is heat lost due to conduction And '$q_{radiation}$' is the heat lost due to radiation. That can be calculated by the formula, $q_{radiation}= \sigma A(T_p{}^4 - T_a{}^4)$ ....(7)
Where, σ=5.67×10^{-8} W/m^{2}K^4.
Total heat input is calculated using, q_{total}= IV ....(8)
where, 'I' is current and 'V' is voltage.

Results & Discussion-

In this section the results are tabulated in two parts, based on effect of Nu with varying H/W ratio for constant R/L of 0.5, 0.725, 1.3, flat plate and effect of R/L on Nu_{avr} with constant H/W of 6,8,10,12

Effect of Nu with varying H/W ratio for the test plates.

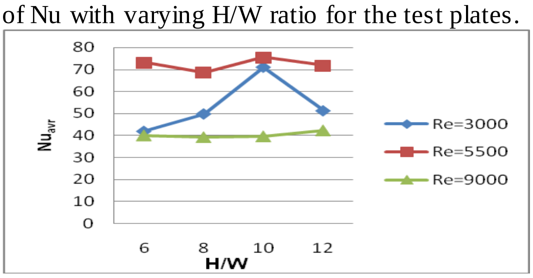

Figure 4. Variation of Nu with H/W for the plate R/L=0.5

For the R/L ratio of 0.5 there is a strong variation in the Nusselt number is observed. For the Reynolds number of 9000 it observed that Nusselt number is constant for all the H/W ratios and Nusselt number is minimum for this particular Reynolds number. And for the Reynolds number of 3000 and 5500 Nusselt number observed for different H/W ratios is different. For Reynolds numbers of 3000 and 5500 maximum convective heat transfer is observed at the H/W ratio of 10. Nusselt number increased from H/D of 6 to 10 for Re of 3000 and 5500 and after that it is decreasing.

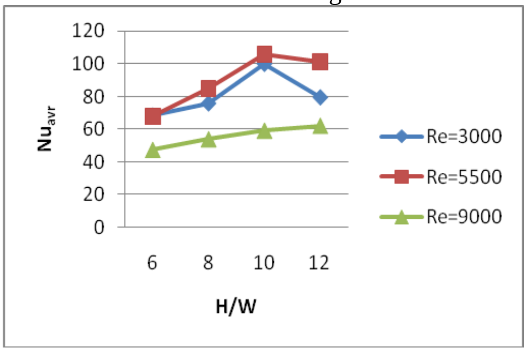

Figure 5. Variation of Nu with H/W for the plate R/L=0.725

For the R/L ratio of 0.725 it is observed that, at Reynolds number of 9000 minimum Nusselt number is observed H/W ratios of 6 to 12. For the Reynolds numbers of 3000 and 5500Nusselt number is increasing with H/W ratio till 10 and after that it is decreasing i.e., it is observed that for Re of 3000 and 5500 maximum heat transfer taking place at H/W ratio of 10.

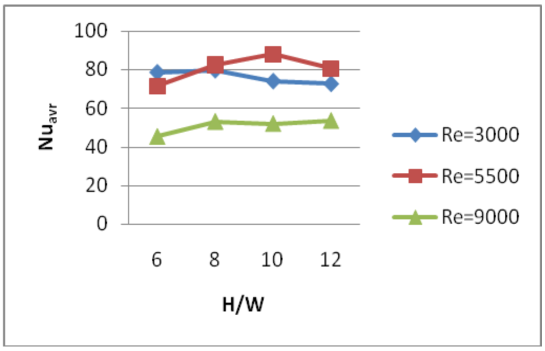

Figure 6. Variation of Nu with H/W for the plate R/L=1.3

For the plate of R/L ratio 1.3 is been observed that, for the given Reynolds number with the variation in H/W ratio from 6 to 12 decrease in the Nusselt number is observed. And the maximum convective heat transfer observed was at H/W ratio of 10 for the Reynolds number of 5500.

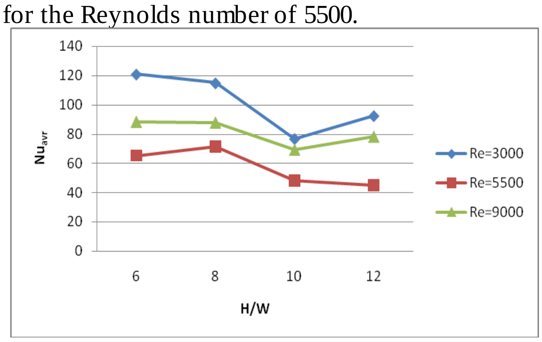

Figure 7. Variation of Nu with H/W for flat plate

For the flat plate it is observed that for the given Reynolds number Nusselt number is decreasing till the H/D ratio of 10 after that a slight increase is observed. And maximum Nusselt number is observed for Re of 3000 at H/W ratio of 6.

Effect of R/L on Nu_{avr} with constant H/W of 6,8,10,12

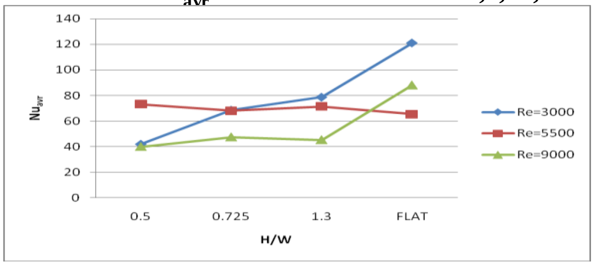

Figure 8. Effect of R/L on Nu_{avr} for H/W of 6

When the H/D ratio is 6 for all the plates minimum Nusselt number observed at Reynolds number of 3000 and 9000 for the R/L ratio of 0.5. Although it is same at Re of 3000 and 9000 for R/L of 0.5 Nusselt number gets deviated for other R/L ratios. Maximum heat transfer is observed for flat plate at Reynolds number of 3000 and for Reynolds number of 5500 heat transfer is minimum for all the plates at H/W ratio of 6.

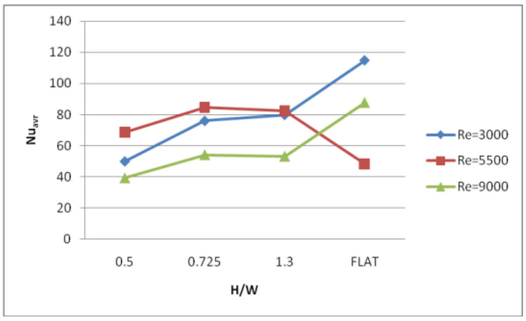

Figure 9. Effect of R/L on Nu_{avr} for H/W of 8

When the H/W ratio was 8 there is a maximum heat transfer for flat plate at both Reynolds number of 3000 and 9000 and the minimum heat transfer observed at Re of 5500 for flat plate. The graphs plotted clearly shows that increase in the R/L ratio increases the heat transfer for particular Reynolds numbers.

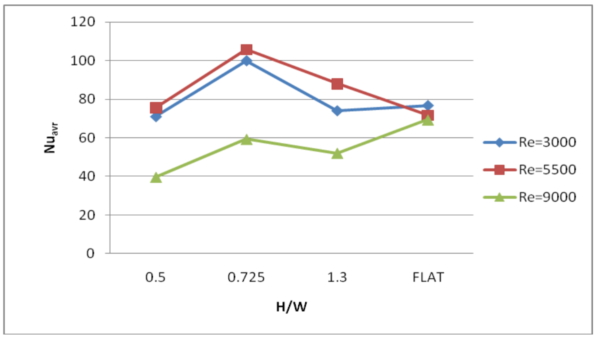

Figure 10. Effect of R/L on Nu_{avr} for H/W of 10

When H/W ratio was 10 maximum heat transfer is obtained for the plate with R/L ratio of 0.725 for the given Reynolds numbers and for the remaining plates Nusselt is less at H/W ratio of 10 for given Reynolds numbers when compared to R/L ratio of 0.725.

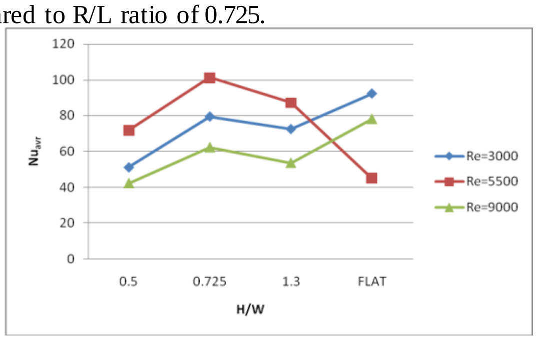

Figure 11. Effect of R/L on Nu_{avr} for H/W of 10

For the H/W ratio of 12 for the given Reynolds numbers best heat transfer is obtained for the plate of R/L 0.725. Heat transfer was less at R/L of 0.5 and is increased at 0.725 and again it is decreasing for 1.3 and flat plate only at Reynolds number of 5500. And for the Reynolds numbers of 3000 and 9000 the heat transfer is increasing for R/L of 0.725 and slightly decreased for 1.3 and again it is increased for flat plate.

Conclusion

From the research work conducted, it is found that Reynolds number has greater influence on heat transfer from the plates as the H/W ratio varies. Maximum heat transfer is observed for R/L ratio of 0.725 at Reynolds number of 5500 and less heat transfer is observed for plate of R/L ratio of 0.5 at Reynolds number of 9000. It is also observed that the heat transfer is increased till the H/W ratio of 10 after that heat transfer is reduced, this was happening because of the accelerating flow of air and the turbulence but after H/W of 10 flow accelerations were reduced. The findings of the present study can be utilized to investigate the curvature of the blade for which heat transfer is more and to optimize the cooling rates in the surfaces for the better design of the gas turbine blades.

References

[1] Je-Chin Han. “Fundamental gas turbine heat transfer”, journal of thermal science and engineering applications.june 2013,vol 5/021007 1-15.

[2] Je-Chin Han. “Recent studies in turbine blade cooling”, international journal of rotating machinery oct-2002 443-456.

[3] Chitranjan Agarwal, J. K. Maherchandani, , Mukesh Sahi “Effect of Nozzle Exit to Surface Spacing on the Cooling of Electrically Heated Surface with Jet Impingement”.International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering Vol. 1, Issue 2, August 2012.ISSN 2278 – 8875.

[4]Vadiraj katti, S V Prabhu “Heat transfer enhancement on a flat surface with axisymmetric detached ribs by normal impingement of circular air jet”. Dept of mechanical engineering,IIT, Bombay,Powai,India.

[5]Jimmy Wayne Crafton (2004)“The impingement of sonic and sub-sonic jets onto a flat plate at inclined angles”. A Thesis Submitted to the Faculty of Purdue University
December 2004

[6]V.M.Jeevanlal, B.C. Anil Kumar (2014) “Experimental Investigation of Heat Transfer from a Flat and Surface Indented Plate Impinged with Cold Air Jet- Using Circular Nozzle” ,International Journal of Emerging Engineering Research and Technology Volume 2, Issue 5, August 2014, PP 160-170 ISSN 2349-4395 (Print) & ISSN 2349-4409.

[7]Yue-Tzu Yang, Tzu-Chieh Wei, Yi-Hsien Wang “Numerical study of turbulent slot jet impingement cooling on a semi circular concave surface”. International journal of heat and mass transfer 54(2011) 482-489.

[8]Ebru Oztekin, Orhan Aydin, Mete Avci “heat transfer in a turbulent slot jet flow impinging on curved surfaces”. International communications in heat and mass transfer 44(2013) 77-88.