STUDY ON PULSED JET IMPINGEMENT COOLING

Vipin .R [1], Sabu .Kurian [2], Dr .Tide P. S [3]

***Abstract*—**
The aim of this work is to present the results of a numerical investigation of the effect of pulsating frequencies on the local and average heat transfer characteristic of an impinging air jet. The calculations were done using a commercial software. Temperature plots obtained from the numerical analysis was used to calculate the average and local Nusselt Number for different pulsating frequencies at a Reynolds number of 5000. The pulsating frequencies were between 5Hz - 150 Hz. Results obtained show that the local Nusselt number calculated were higher at all radial position away from the stagnation point. The pulsed jet Nusselt number was higher than the average steady jet Nusselt number for all values of frequencies due to the higher localized heat transfer.

***Index Terms*—C.F.D, Nozzle to plate distance, Pulsating jet, Reynolds Number.**

1. INTRODUCTION

Impingement heat transfer is considered as a promising heat transfer enhancement technique. Among all convection heat transfer enhancement methods, it provides significantly high local heat transfer coefficient. Jet impingement produces a rapid cooling or heating on the surface where it impinges. Study on the effect of pulsating frequencies on the impingement heat transfer has been focused by many researchers in the past. Pulsating flow is widely believed to increase the heat transfer rate. Zumbrunnen and Aziz (1993) were, perhaps the first to study the importance of pulsation frequency and amplitude. They investigated convective heat transfer with a planar impinging water jet on a surface subjected to a constant heat flux. A twofold enhancement of heat transfer was reported.

Sheriff and Zumbrunnen (1998) expanded the study to pulsating array of jets. An array of nine convergent jets in a square matrix was used to cover a Reynolds number range of 2500–10000. Their study focused on jet height to diameter ratio of 2–6, pulse frequency up to 65 Hz, Strouhal number of 0.028 and flow pulsation magnitude up to 60%. It was observed that the increased jet interactions at large magnitude of flow pulsations reduced the jet potential core length by 20%. Also the turbulence intensities were higher by 7–15% than in steady jets. Lance Fisher (2001) conducted a numerical study to investigate the heat transfer to an axisymmetric circular impinging air jet using the k-ε turbulence model. The paper showed that the k- ε model over predicts the turbulent kinetic energy in the stagnation region and also a maximum of turbulent kinetic energy away from the stagnation region. The study reveals that the k- ε model works best in simple shear flows.

N. Zuckerman et al.(2006) deals with the applications, physics of the flow and heat transfer phenomena, available empirical correlations and values they predict, and numerical simulation techniques and results of impinging jet devices for heat transfer.

Peng Xu et.al(2010)has conducted a numerical study for pulsating turbulent slot impinging jet. The jet velocity was varied in an intermittent (on-off) fashion. The effects of the time-mean jet Reynolds number, temperature difference between the jet flow and the impinging surface, nozzle-to-target distance as well as the frequency on heat and mass transfer were examined. Parametric studies show that increase of the mean jet Reynolds number and frequency of pulsation as well as reduced temperature difference enhance the time-averaged local Nusselt number. The on-to-off jet time ratio and nozzle-to-plate distance show significant effects on the heat transfer rates, which can be properly adjusted to achieve optimized performance. Adnan A. Abdul Rasool et.al(2014) has studied the flow structure and heat transfer of air jet normally impinging on a flat plate using numerical and experimental method.

The purpose of this study is to investigate steady and pulsating single circular jet heat transfer characteristics. The focus of the study is given on the effect of flow pulsation frequencies on the average and stagnation Nusselt number. The study is also trying to find out the possibility of controlling the flow structure in pulsating air jet which leads to enhancement in the heat transfer characteristics. Comparisons between steady and pulsed jet heat transfer were discussed in details together with available data in the literature. In this paper the stagnation point Nusselt number of a pulse and steady jet means the time average value at the impingement point of the jet axis. The local Nusselt number of a pulse jet is the time average at a point on the impingement surface. The local Nusselt number is assumed to be radially symmetrical about the stagnation point. The average Nusselt number of a pulse jet is both a time average and an area average over the impingement surface. The total heat flux is proportional to the average Nusselt number. Interaction of flow structures can be influenced by the mixing within the boundary layer and a marked increase in turbulence intensities has been noted with pulse flows. Recent findings on the enhancement of heat transfer due to pulse air jets have encouraged new research in this subject. Comprehensive data showing the effect of pulse frequency on local and average heat transfer profile are still limited and there is need for further investigation

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11. NUMERICAL PROCEDURE

The pulsated impinging jet heat transfer problem is numerically computed with the commercial finite-volume code using the time-averaged Navier-Stokes and energy equations with the standard k- ε turbulence model. The k- ε model is chosen due to its simplicity, computational economy and wide acceptability. The circular air jet is assumed to have constant thermo-physical properties such as density, specific heat and thermal conductivity. Hence, the geometric boundaries and physical conditions are symmetric about the axis of the jet; a 2-D axisymmetric model is constructed. It neglects gravitational effect during the impinging jet. The finite-volume code ANSYS 14.0 is used to solve the thermal and flow fields using the standard turbulence model. Diffusion terms of all the governing equations are discretized using the central difference scheme. Convective terms of the momentum and energy equations are discretized using the third order QUICK interpolation scheme and convective terms of the turbulent kinetic energy and turbulent dissipation rate equations are discretized using a second-order upwind differencing scheme. Pressure-velocity coupling is handled using the SIMPLEC algorithm. The axi-symmetric domain is shown in Fig. 2.1

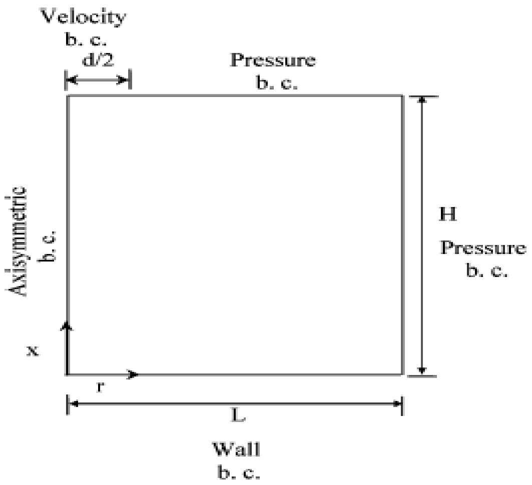

Fig.2.1 Computational Domain

Successful computation of the turbulent model requires some consideration during the mesh generation. Since turbulence plays a dominant role in the solution of transport equations, it must be ensured that turbulence quantities are properly resolved. It is therefore proposed to use fine meshes as shown in Fig.2.2 to resolve the near-wall region sufficiently. Computational domain contains around 40000 elements. Edge sizing for jet axis and wall region was set at an appropriate value for relevance. Relevance centre was set as fine and smoothing is high.

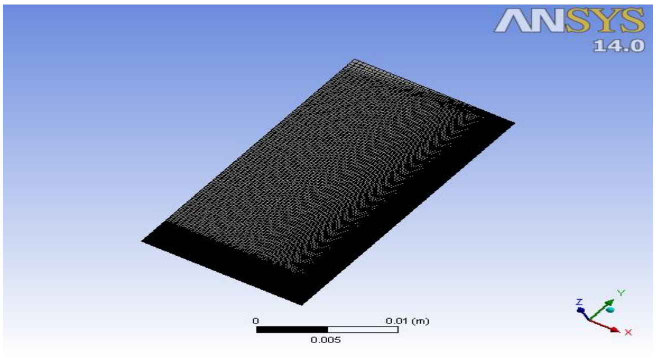

Fig. 2.2 Two Domain with mesh

111. GRID INDEPENDENT STUDY

The average Nusselt number shows much variation from the accurate value with the grid size. The accuracy of the result increases with the element size and it reaches an optimum value, above which the variation is insignificant (Fig. 3.1).

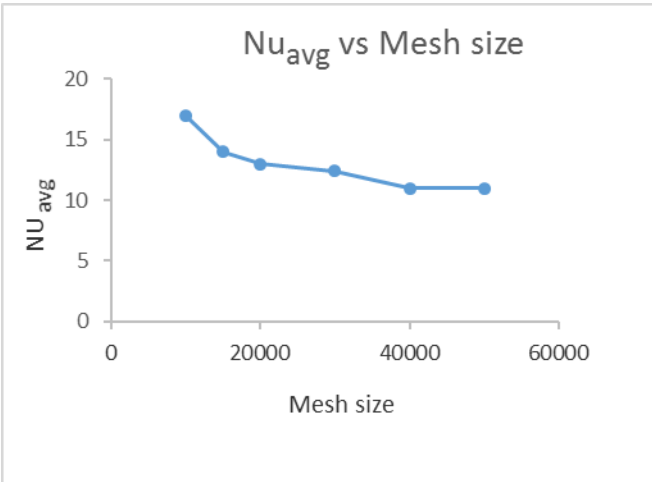

Fig.3.1 Variation of average Nusselt number with number of elements

1V. RESULTS AND DISCUSSIONS

In this chapter the numerical results are presented for the heat transfer characteristics of an un-confined jet impingement. The local Nusselt number corresponding to the stagnation point and the average Nusselt number are considered for the evaluation of the performance of the jet impingement. The jet impingement heat transfer rates of circular (D=5mm), un-confined jets were evaluated at Reynolds number of 5000. The dimensionless nozzle-to-plate distance (Z/D) is kept at 3.The effect of pulsation frequency variation on the heat transfer rate and the pressure distribution was to be studied from a frequency range of 5Hz to 150Hz .The thermal and fluid flow characteristics of the present problem were numerically simulated by computational fluid dynamics (CFD) technique. Commercial package ANSYS 14.5 is used for the present

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numerical study. In this comparative study the effects of buoyancy and gravity are neglected. No slip flow condition is assumed above the target surface.

4. VALIDATION OF NUMERICAL RESULTS

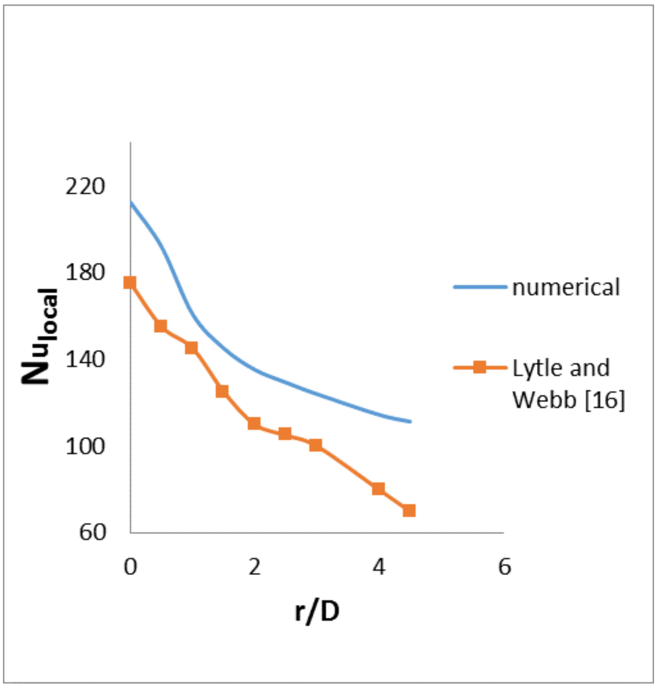

Fig.4.Variation of Local Nusselt number with radial distance for Re=23000, Z/D=6

The local Nusselt number at a given Reynolds number of 23000 and Z/D of 6 is compared with those of the earlier published data as .It compare good with the results of Lytle and Webb [11].The results from present experiments and numerical analysis show that the Nusselt number depend on distance from stagnation point in the stagnation region and heat transfer coefficients decrease from the stagnation point till the edge of stagnation region. This may be because of small increase in boundary layer thickness in the radial direction. The flow from stagnation region to wall jet region occurs through the transition where the boundary layer changes from laminar to turbulent. The numerical result is higher than experimental due to the character of the selected turbulence model and boundary conditions. The selected k-ϵ model over-predicts the value of Nusselt number in the stagnation region than the wall jet region.

4.1.EFFECT OF PULSE JET FREQUENCY

Variation of average Nusselt number corresponding to different frequencies is shown in Fig. 4.1

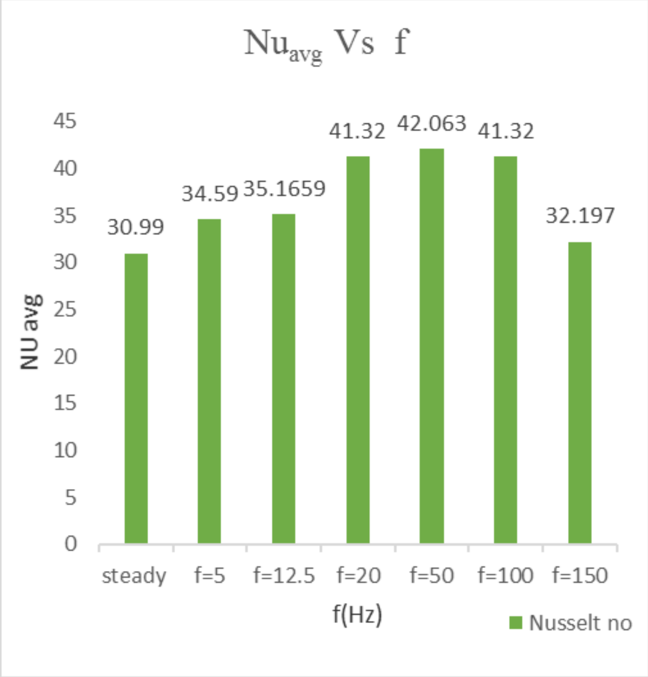

Fig.4.1Variation of average Nusselt number for steady and pulsed jet with different frequencies at Re=5000 and Z/D=3

Fig. 4.1 shows the variation of the average heat transfer coefficients along the impinging surface for different pulse jet frequencies. Here, a jet with square wave form is used as the impinging jet, with different frequencies, for the analysis of heat transfer rate from the impinging plate. The analysis was studied under steady state and then compared with jets of different frequencies. The pulse jet shows the higher heat transfer rate than steady jet at different frequencies. The average heat transfer coefficient increases for the frequency range of 5Hz to 50 Hz. However, the average heat transfer coefficient value is less for 100Hz and 150 Hz when compared with low frequency values such as 5 Hz, 12.5 Hz, 20 Hz and 50 Hz. An enhanced heat transfer coefficient is observed when compared with steady jet.

The effect of pulse jet under different frequencies on the stagnation region is shown in Fig. 4.2. For higher frequency; the Nusselt number in the stagnation region of the pulse jet is even larger than that in the steady case. Stagnation point Nusselt number increases with increase in frequency for the pulsed jet, reaches an optimum value and then decreases. At very high frequencies the pulse jet behaves like as steady jet and thus a reduction in Nusselt number occurs in the stagnation region.

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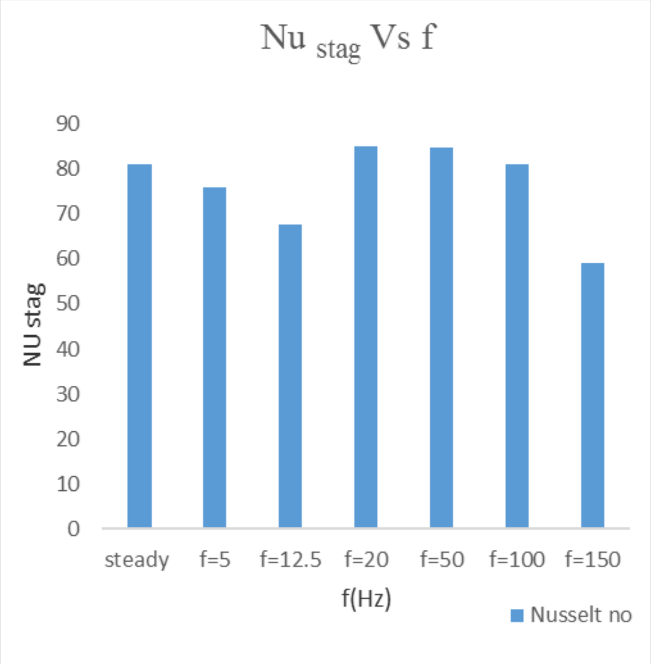

Fig. 4.2 Variation of stagnation Nusselt number for steady and pulsed jet with frequency at Re=5000 and Z/D=3

At higher *Z/D* ratios, the jet becomes shorter and broadens its velocity profile. This reduces the length for which the potential core persists and degrades the mean velocity of the jet at the core. However, the distance is not large enough to allow the increased mixing provided by the pulsating jet to impact the potential core of the jet. Pulsed jets generate large-scale eddy patterns around the exit nozzle, resulting in unsteady boundary layers (thermal & hydrodynamic) on the target that may produce higher heat transfer rate with frequency. The unsteady disturbances of the boundary layer can cause the increased rate of heat transfer rate with frequency. As with a pulsed jet, the variation in local fluid velocity over the target prevents the development of a steady boundary layer. This effect was counteracted by an increased tendency of the precessing jet to mix with the surrounding fluid at higher *Z/D* ratios, loose energy and reach the target at lower velocities than would be found with a stationary jet.

The effect of pulse jet frequency on the local Nusselt numbers is shown in the Fig. 4.3.The enhancement of heat transfer by intermittent pulsation in the wall jet region is clear from the figure. Compared with the steady impinging jet of the same mean Reynolds number, the decrease of local Nusselt number along distance from the stagnation region slows down in the wall jet region for the pulsed case. The relatively strong vortex is believed to increase flow entrainment and mixing, and contribute to the predicted heat transfer.

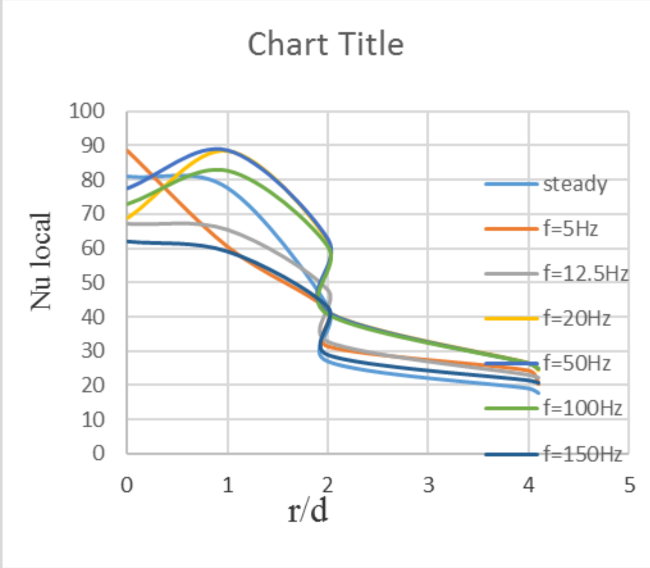

Fig. 4.3 Variation of average Nusselt number for steady and pulsed jet with different frequencies at Re=5000 and Z/D=3

V.CONCLUSIONS

The heat transfer enhancement in pulsed jet impingement cooling at different frequencies was studied and the following conclusions made.

For all frequencies under study (5 Hz, 12.5 Hz, 20 Hz, 50 Hz.100 Hz, 150 Hz) for pulsed jet it is observed that there is a considerable increase in average Nusselt number. Significant enhancement of heat transfer at the target surface by the intermittent pulsation in a turbulent impinging jet is observed. At 20 Hz and 50 Hz the stagnation and local nusselt number of the pulsed impinging jet is larger than that in the steady jet. For a frequency of 100 Hz, there is a significant enhancement of local Nusselt number, where as Nusselt number at stagnation region remains same.For a Reynolds value of 5000 and a nozzle to target plate distance (z/d) of 3, the optimum pulsed frequency is observed to be 50 Hz. The stagnation and local Nusselt number at this frequency is higher, that ensures a higher value of heat transfer coefficent over the target plate.

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REFERENCES

[1]D. A. Zumbrunnen and M. Aziz, “Convective heat transfer enhancement due to intermittency in an impinging jet,” Trans. ASME, J. Heat Transf., vol. 115, pp. 91–98, 1993.

[2]H. S. Sheriff and D. A. Zumbrunnen, “Means to improve the heat transfer performance of air jet arrays where supply pressure is limiting,” Trans. ASME, J. Heat Transf., vol. 120, pp. 787–789, 1998.

[3]Lance Fisher, 2001, A Numerical Investigation of Jet Impingement on a Heated Flat Plate, ME 513, pp.3-20

[4]N. Zuckerman, N. Lior, 2006, Jet Impingement Heat Transfer: Physics, Correlations, and Numerical Modelling, Advances in Heat Transfer, Vol-39, pp. 565-631.

[5]Peng Xu, Boming Yu, Shuxia Qju, Hee Joo Poh, Arun S. Mujumdar, 2010, Turbulent impinging jet heat transfer enhancement due to intermittent pulsation, International of Thermal Sciences, Vol.49, pp. 1247-1252.

[6]Adnan A. Abdul Rasool, Jirunthanin V, F. A. Hamad, 2014, Numerical and Experimental Study of Flow Structure and Cooling Behaviour of Air Impingement on a Target Plate, Int. J. of Thermal and Environmental Engineering, Vol. 8, No.1, pp. 33-43.

[7] Robert Gardon, J. Cahit Akfirat, 1965, The Role Turbulence in Determining the Heat Transfer Characteristics of Impinging Jets, Int.J.Heat Mass Transfer, Vol.8.pp.1261-1272

[8] N.K.Chougule, G.V.Parishwad, C.M.Sewatkar, 2012, Numerical Analysis of Pin Fin Heat Sink with a Single and Multi Air Jet Impingement Condition, International Journal of Engineering and Innovative Technology, Vol.1, Issue 3, pp.44-50

[9] M.K.Isman, E.Pulat, A.B.Etemoglu, M.Can,2008, Numerical Investigation of Turbulent Impinging Jet Cooling of a Constant Heat Flux Surface, Numerical Heat Transfer, Part A,53: pp.1109-1132

[10] 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, Vol.2,Issue 5, pp.160-170

[11]D. Lytle, B.W.Webb, 1994, Air Jet Impingement Heat Transfer at Low Nozzle-Plate Spacing’s, Int.J.Heat Mass Transfer, Vol.37, No.12, pp.1687-1697

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