Journal of Engineering Sciences

Vol 11, Issue 7,July/2020

ISSN NO:0377-9254

STUDY ON EFFECT OF DIMPLES ON PULSATING JET IMPINGEMENT COOLING WITH AND WITHOUT EFFUSION

SONY GEORGE NINAN [1] and V. SITARAMIREDDY [2]
1M.Tech Student, 2Assistant Professor Department Of Mechanical Engineering
Newton's institute of science technology,koppunur,macherla,Guntur, Andhra Pradesh

Abstract— Heat transfer from impingement of jets has received attention of many researchers because of its numerous applications in various industries. Its fluid flow properties and heat transfer characteristics are giving interesting results and there is scope for further work. Studies focus on developing various methods for the enhancement of the heat transfer. Jet impingement produces a rapid and uniform cooling or heating on the surface where it impinges. Impingement of a pulsed jet has proved to enhance the heat transfer by the continuous renewal of the boundary layer and the associated effect of turbulence. In the case of normal jet impingement, convex and concave dimples on the target plate has proved to increase the heat transfer due to the increase in turbulence in the flow field. In addition, the effusion holes away from stagnation region have proved to be effective. This study focuses on the effect of dimples and effusion holes in target plate in the enhancement of heat transfer by the pulsed jet and how frequency of the pulsed jet contribute to the change in heat transfer. Numerical investigation was carried out using the finite volume code ANSYS 14.0. The effect of various parameters like type of dimple, dimple geometry, spacing and frequency of jet was studied. Experimental investigation was carried out to verify the numerical results.

I Introduction

Impingement cooling began finding use in the cooling of gas turbine blades and vanes starting in the early 1960's . It has found favour as a means of cooling in regions of high. Heat flux because it is a more effective method of cooling than ordinary convection cooling. The use of singe jets, rows of jets, arrays of jets, single slots, and rows of s lots, particularly impinging on flat surfaces, has been studied by many investigators. Impinging jets provides an effective way to transfer energy or mass in industrial applications.

A flow released against a surface can efficiently transfer large amounts of thermal energy or mass between the surface and the fluid. Heat transfer applications include cooling of turbine components, cooling of machinery structures, Dissipation of heat from small areas is a critical requirement in many engineering applications, such heat treatment of metal parts, thermal management in electronic and photonic devise and many other industrial processes. There are a number of parameters which can affect the heat transfer rate in a jet impingement configuration.

1.2. OBJECTIVES

Main objective of this study is to identify the effect of surface protrusions such as dimples on the heat transfer enhancement of pulsed jet flow regime.

To study the effect of dimples in the target plate for pulsating air jet cooling and for identifying heat transfer characteristics of jet for various types of dimples (concave and convex) using CFD analysis .

Another objective is to conduct numerical investigations on the influence of frequency of the jet and dimple spacing on the heat transfer enhancement.

Conduct numerical studies on the effect of dimple geometry and effusion holes in the target plate in heat transfer enhancement.

To validate the numerical studies using experimental methods and for calculating the errors that might have generated in the numerical studies.

II. Literature Review

Investigation of the topics connected with the heat transfer from the impinging jets can be traced back to about 1951. Freidman and Mueller (1951) conducted jet heat transfer study on a flat plate. Heated air jet was impinged on a plate and the heat transfer was calculated. Since that time, many investigators have appeared who tried both analytical and practical approaches. Researchers have systematically studied the effects of geometrical parameters on the heat transfer characteristics of impinging jets. Many researchers studies the effect of cross flow on jet structure and heat transfer including Kercher and Tabakoff. (1970) and Florschuetz (1984)m Both Florschuetz, and Kercher and Tabakoff developed correlations to predict the effect of cross flow on jet impingement heat transfer for inline and staggered arrays which are still used today in jet impingement research. San and Lai (2001) studied the effect of jet – to – jet spacing on heat transfer in staggered arrays. Bailey and Bunker (2002) studied the effect of sparse and dense arrays for large numbers of jets. Hebert and Ekkad (2004) investigated the effect of a stream wise pressure gradient for an inline array of sparse and dense configurations. Dano et. Al. (2005) researched the effect of nozzle geometry on the flow characteristics and heat transfer performanc Cheong and Ireland (2005) experimental measured local heat transfer coefficients under a impinging jet with low nozzle -to-plate, z/ spacing's Liquid, air, kerosene, other syntheti and even Nano fluids were used as jets. Cooling surface with an impinging liquid jet is attractive technique because of its high efficiency Liquid jet can be easily created using a straight tube or contracting nozzle. John H Lienard (2006) conducted many studies on the heat transfer of liquid jet impingement.

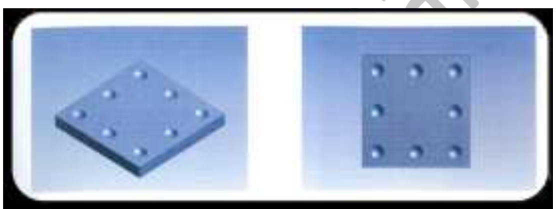
III. METHODOLOGY

Methodology of this thesis involves the following

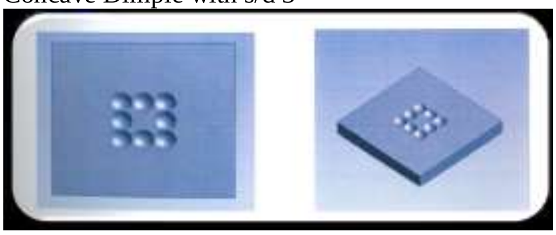
- Conduct literature review on the pulsating air jet impingement cooling and various surface modifications in the target plate.
- Geometry modelling of the models required for numerical studies.
- Meshing of geometry and grid formation using ANSYs ICEM workbench.
- CFD analysis using ANSYs FLUENT software
- Validation of software work using experimental evaluation.
- Results and documentation

GEOMETRY MODELING

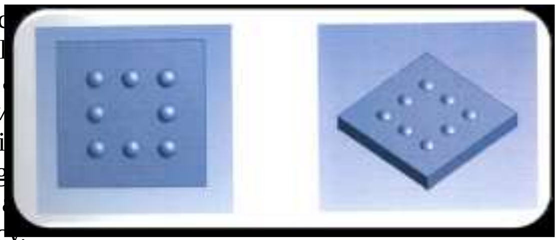
All 3D CAD geometries were pre pared using Solid works software. Solid target plates were first modelled and a reverse geometry is assembled to it as the fluid model. A simple convex and concave dimpled target plates are shown below. Dimple geometries were drawn for analysis. The spacing has been kept uniform from the center stagnation region since the most important significance of jet impingement cooling is the uniformity in the cooling rate and it has a direct impact on the hot spot formation undesired heat transfer losses.



Concave Dimple with s/d 3



Concave Dimple with s/d 1



Convex Dimple with s/d 2

Various geometries were created for various dimple spacing and geometry. A 10 cm x 10 cm x 10 mm mild steel plate is used as the target plate for the given jet diameter 12 mm. These are the standard dimensions used for a 12 mm diameter jet. The reverse fluid geometry was drawn and assembled to the target plate geometry and the nozzle to plate distance is kept a constant.

In the case of pulsating jet, it is not possible to determine the potential core length of the jet. Thus, we assume a jet to target spacing Z of three times the jet diameter.

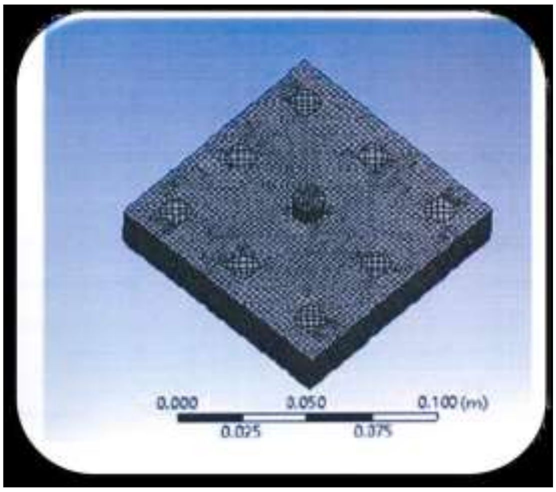
Assembled view of fluid and target plate is shown in the figure. The four ends of fluid geometry is made the fluid outlet. The inlet and plate is kept at a constant distance of 3 D throughout the analysis. Heat flux is provided from the bottom of the plate. Fluid jet is made to impinge on the central stagnation region of the jet. A height of two times the diameter is used for the jet flow region from the target plate. From the previous studies, the heat flux is kept at a constant value of 1000 W/m2.

MESH GENERATION

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 figure to resolve the near – wall region sufficiently. Computational domain contains above 100000 elements. Edge sizing for jet axis and wall region was set at an appropriate value for relevance. Relevance center was set as fine and smoothing is high .Hexahedral meshes were used to obtain maximum quality. In the case of dimples with ID spacing, the tetrahedral meshes were used to obtain more physically relevant meshes and mesh quality was maximum.

Vol 11, Issue 7,July/2020

ISSN NO:0377-9254



Computational Mesh Domain

NUMERICAL ANALYSIS

The pulsated impinging jet heat transfer problem is numerically computed with the commercial finite – volume code using the time average 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 3D 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 central difference scheme. Convective terms of the momentum and energy equations are discretized using the third order QUICK interpolation scheme ad 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.

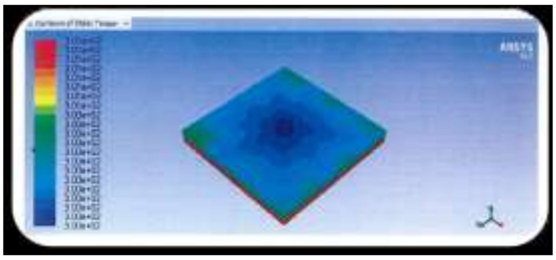
EXPERIMENTAL ANALYSIS

A Schematic diagram of the experimental set up is shown in the figure. A reciprocating compressor is used to create the necessary air jet at required velocity. A controlling valve used to control the airflow to rotameter. An acrylic a rotameter is used to measure the velocity of the air jet. Pul generating module (PGM) is used to generate the pulse required frequency. Pulse generating module is created using 24 V solenoid valve, which has been used to make the pul using a relay circuit. K type thermocouples were used measure the temperature with a temperature indicator. Pla type heater was used to provide the heat flux. Heat flux is controlled using an autotransformer.

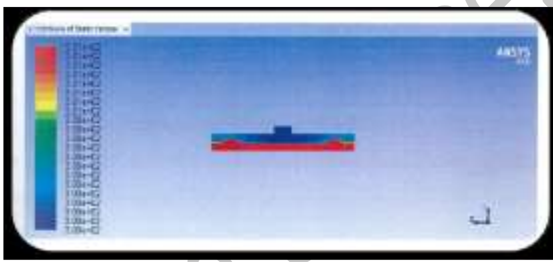
RESULT AND DISCUSSION

EFFECT OF DIMPLE SPACING, TYPE AND FREQUENCY

Numerical studies were conducted at various dimple spacing's from s/d 1-3 and also for random spacing at frequencies from 5 Hz – 150 Hz.

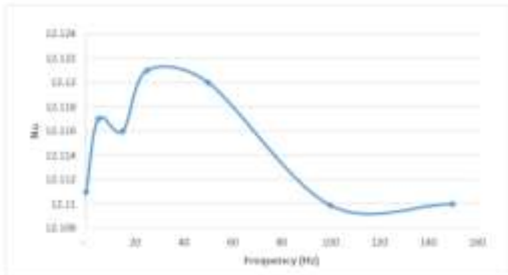


Temperature Contour of Convex Plate s/d 3

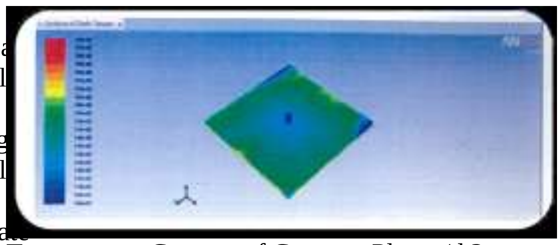


Temperature Contour of Cut Section View

Velocity Contour of Convex Plate s/d 3

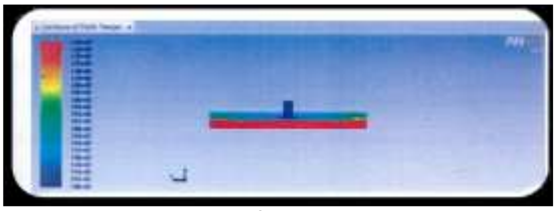


Nusselt Number Vs Frequency for Concave Plate s/d 3

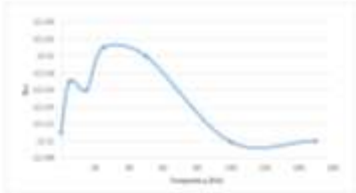


Temperature Contour of Concave Plate s/d 3

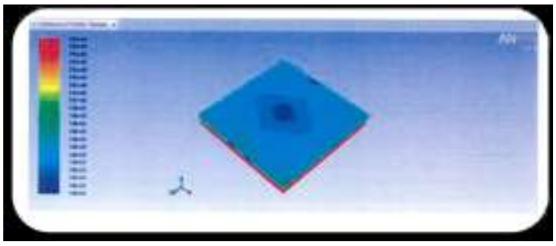
Journal of Engineering Sciences
Vol 11, Issue 7,July/2020
ISSN NO:0377-9254



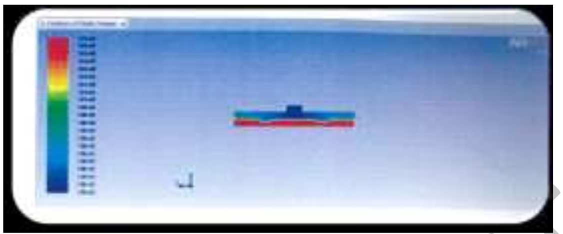
Temperature Contour of Cut Section View



Nusselt Number Vs Frequency for Concave Plate s/d 3

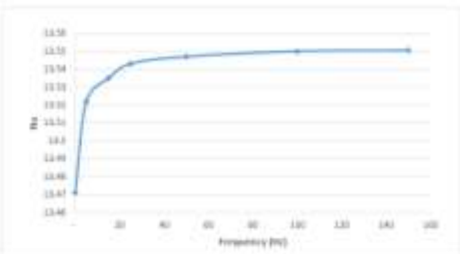


Temperature Contour Concave s/d 2

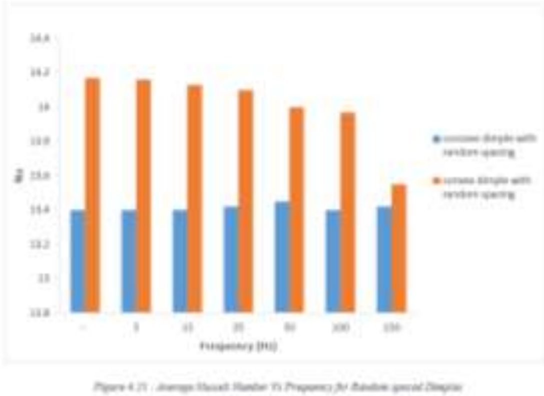


Cut Section View Concave s/d 2

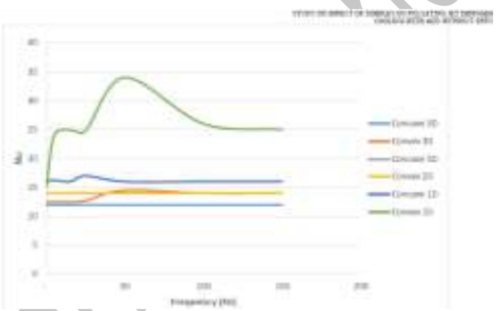
Velocity Contour Concave s/d 2



Nusselt Number Vs Frequency for Concave Plate s/d 2



Average Nusselt Number Vs Frequency for Random spaced Dimples



EFFECT OF DIMPLE GEOMETRY

Dimple height and diameter have influence in the turbulence generated in the flow field. Heat transfer characteristics of various dimple geometries were studied. Usually dimple height is 3 mm and dimple diameter is 12mm.

ght , mm	nber , Nu	meter, mm	nber , Nu

EFFECT OF EFFUSION

es	sselt No.

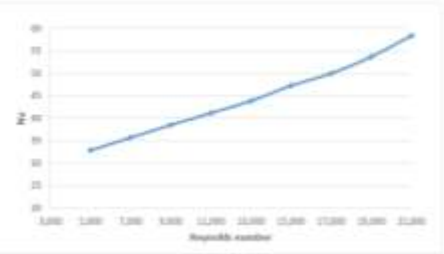
EFFECT OF REYNOLDS NUMBER

Heat transfer has shown to improve with improve in Reynolds number at constant jet frequency 50 Hz. The increase in the heat transfer is steady this might be due to the narrowing of boundary layer with increase in velocity.

JES Journal of Engineering Sciences

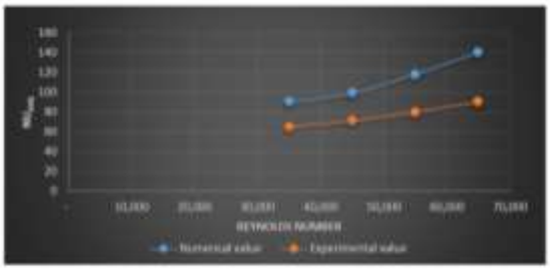
Vol 11, Issue 7,July/2020

ISSN NO:0377-9254



EXPERIMENTAL VALIDATION

Experiments were conducted to validate the numerical result. Dimple spacing of s/d 1 and a constant frequency of 50 Hz was used in the study. 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.



CONCLUSION

- Maximum heat transfer was obtained for convex dimples at 1 d spacing.
- Heat transfer was maximum at 50 Hz frequency. At higher frequencies heat transfer was comparatively low which may be due to the steady state behaviour of jet at higher frequencies.
- Random spacing reduces the heat transfer. This might be due to the non - uniform cooling.
- 21 - 30 % decrease in the surface Nusselt number was observed with effusion holes which might be due to the thick boundary layers.
- A dimple height of 4 mm provided maximum heat transfer
- Heat transfer rate increased almost steadily with Reynolds number this might be due to the further reduction of boundary layer thickness,
- Experimental result agrees with the result obtained from numerical analysis.
- 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.

REFERENCES

1. Freodman. S.J. and Mueller A/C (1957) “Heat Transfer to Flat Surfaces”, Proc. Gen. Dis c.on Heat Transfer Institution of Mech. Engineers.

2. Kercher, D.M and W. Tabakoff (1970) “ Heat Transfer by a Square Array of Round Air jets impinging Perpendicular to a Flat Surface including the effect of Spent Air” ASME Journal of Engineering and Power VOl. 92 , 1970 : 73 – 82.

3. Florschuetz, D.E Metzger, and C.C Su (1984) “Heat Transfer Chracteristics for Jet Arry Impingement with Initial Crossflow” . Journal of Heat Transfer Vol . 106. 1984 : 34 – 40.

4. San, Jung – Yang and Mao – De Lai (2001) “ Optimum jet -to – jet spacing of heat transfer for staggered arrays of impingings airjets. “ International journal of H eat and Mass Transfer Vol. 44, 2001 : 3997 – 4007

5. Bailey,J.C and R.S Bunker (2002) Local Heat Transfer and flow Distributons for impinging Jet Arrays of Dense and Sparse Extent. Proc. Of the ASME Turbo Expo, June 2002, Amsterdam : Netherlands.

AUTHOR DETAILS

SONY GEORGE NINAN [1] pursuing M.Tech in thermal engineering from Newton’s institute of science technology, koppunur, macherla, Guntur, Andhra Pradesh

V. SITARAMIREDDY [2]working as Assistant Professor Department Of Mechanical Engineering Newton’s institute of science technology,koppunur,macherla,Guntur, Andhra Pradesh