NUMERICAL INVESTIGATION ON JET IMPINGEMENT COOLING AIDED WITH SYNTHETIC JET ON TARGET PLATE

Tigy Varughese, PG Scholar, M.A.College of Engineering
Sabu kurian, Associate professor, M.A.College of Engineering.
Dr. Tide P.S, Professor, School of Engineering, CUSAT

***Abstract**:-The aim of this work is to be done a numerical investigation to determine the heat transfer characteristics of synthetic jet impingement on the target plate.The present problem is analysed at unsteady state condition. It involves analysis of synthetic jet in different frequencies ie.17Hz,50Hz,100Hz The variation of nusslet number and temperature studied for both cases. The model used for solving the problem is SST k-w turbulent model, while the heat flux is fixed to 6000W/m^2. The height to diameter of jet choose as 6 for maximum heat transfer got from previous journal. Here we use a circular shaped orifice for the ejection of synthetic jet. From these studies, we can conclude that the local nusselt number increases on increasing the frequency of operation of synthetic jet . Impinging synthetic jets have excellent potential for energy-efficient local cooling in confined geometries*

Index Terms:- synthetic jet, electronic cooling, unsteady, dynamic mesh.

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 of the surface where it impinges. Jet impingement can be used for cooling, heating and drying. Jet impingement cooling (or heating as well) is a very effective heat transfer mechanism. The main reason is that jet impingement flow forms a very thin boundary layer. 'Impingement' means 'collision' that the coolant flow collides into the target surface and guarantees a thin stagnant boundary layer at the stagnant core for cold coolant contacting the hot surface without damping.In the present study, heat transfer of multiple impinging circular -jets along a rib roughened channel is considered. This can be regarded as a combination of multiple impingement jets cooling and turbulent cooling in a rib-roughened channel. Such heat transfer processes occur in combustor wall cooling, electronic cooling andleading edge cooling of gas turbine blades.

A phenomenon first described as an acoustical streaming around orifices was reported by Ingard and Ising [1] in 1950; this phenomenon has since gone onto be known commonly as the synthetic jet. Still considered to be a relatively new technology the synthetic jet is considered to have great potential in many practical applications and has garnered great interest from numerous modern industries including aeronautics, automotive, manufacturing and electronics, both for purposes of flow manipulation as well as heat transfer enhancement. While this paper reports mostly on the synthetic jet flow evolution prior to impingement upon a horizontal surface, the ultimate interest is with regards to achieving the type of jet impingement most conducive to heat transfer.

The method of using synthetic jets in micro-channels has been suggested by Timchenko et al. [2]. A synthetic jet, similar to a pulsed jet, is formed from the ingestion and expulsion of fluid through an orifice into a fluid-filled space [3]. One unique feature is that the jet is produced entirely by the working fluid of the flow system. It can thus transfer linear momentum to the flow system without net mass injection across the flow boundary. This mechanism is also known as a "zero-net-mass-flux" jet [4]. A number of studies have been performed on synthetic jets in the context of pulsating jet actuators impinging on submerged

surfaces in quiescent fluid media in order to better understand the thermal characteristics for localized cooling. Campbell et al. [5] illustrated the use of synthetic air micro jets for effective cooling of laptop processors while Mahalingam et al. [6,7] established the feasible application of synthetic jets for high power electronic cooling through an integrated active heat sink. Smith and Swift [8] as well as Pavlova and Amitay [9] indicated that heat transfer enhancement increased dramatically

ISSN: 2278 – 7798

through the use of synthetic jets over continuous jets thereby offering better cooling performance.

NUMERICAL PROCEDURE

The jet impingement with synthetic jet on the target plate heat transfer problems is numerically computed with the commercial finite-volume code FLUENT 15 using the time-averaged Navier-Stokes and energy equations with the SST *k-w* turbulent model. The *SST k-w* model is chosen due to its simplicity, computational economy and low Reynolds number value. The circular air jet is assumed to have constant thermo- physical properties such as density, specific heat and thermal conductivity. The 2-D model is created using some modelling tools and User Defined Function for dynamic mesh. The synthetic jet heat transfer seems to be more efficient than other impinging techniques.The finite-volume code FLUENT 15 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 computational domain is given below.

1. COMPUTATIONAL DOMAIN

The present problem is analyzed at unsteady state condition. The unsteady state analysis were carried out in 3 frequency values(17Hz,50Hz,100Hz).

1. Design parameters

- Size of nozzle - 1mm
- Size of target plate - 6mm
- Diameter of jet - 1mm
- h/d - 6
- Heat flux - 6000 W/m^2
- Air inlet temperature - 300k

2. Unsteady State Analysis

The SIMPLEC (Semi-Implicit Method for Pressure-Linked EquationsConsistant) algorithm is used as the solution method. This algorithm is essentially a guess-and-correct procedure for the calculation of pressure on the staggered grid arrangement.

To initiate the SIMPLE calculation process a pressure field is guessed and the discretized momentum equations are solved using the guessed pressure field to yield the velocity components. The correct pressure is obtained by adding a pressure correction to the guessed pressure field. To avoid the divergence problem a suitable under relaxation factor is considered during the iterative process. The assigned values of under relaxation factors are:

Pressure= 0.3

Momentum=0.7

Energy=1

Turbulent kinetic energy=0.8

Turbulent Dissipation rate=0.8

For the analysis, the flow is assumed to be at unsteady state, the fluid physical properties are constant and the effect of gravity is neglected. For this numerical simulation flow is assumed to be incompressible, turbulent with constant fluid properties. The computational domain is shown below.

3. Modelling

Jet impingement cooling with synthetic jet only

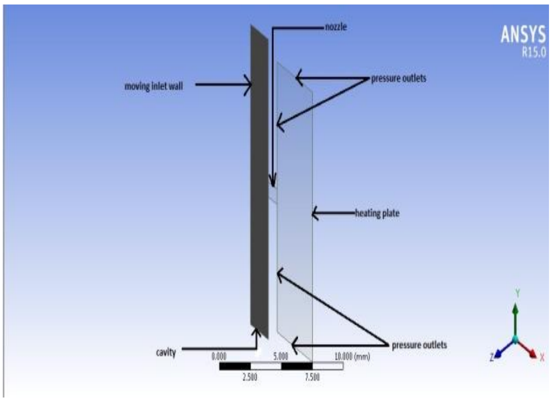

Fig 1:- computational domain

This computational domain consists of single nozzles and one moving inlet and four pressure outlets. At the heating plate, the heat source applied. Around 6000 watts applied at the plate..

ISSN: 2278 – 7798

The pressure based solver is used ,because it take pressure and momentum as the primary variables. The second order differential equation is used to solve this for the accurate results.

4. Meshing

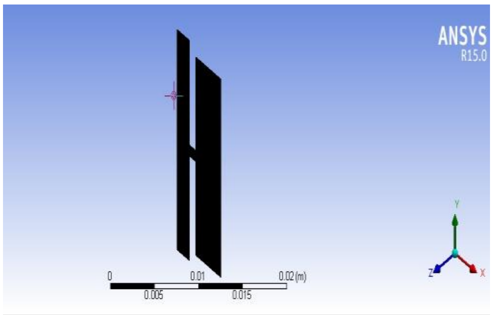

Fig2:-Mesh domain

Computational domain contains around 46001elements & 45122 nodes. Relevance centre is set as fine and smoothing is high and 60 is given because after that value there is no remarkable change in temperature.All other settings are to be done as default.

2. Element based Study

I. Element based study with varying relevance values

Relevance	Nodes	Elements	Temperature(K)(100Hz)	Temperature (K)(50Hz)	Temperature(K)(17Hz)
10	38614	39855	313.2	315.7	313.9
20	39261	40032	312.3	315.5	313.3
30	40176	41031	311.8	315.3	312.7
40	42392	43747	310.8	314.7	312.5
50	43704	44818	310.6	314.1	312.4
60	45122	46001	310.5	313.9	312.4

The maximum temperature of the plate is varied according to the number of elements. When the number of elements increases the accuracy of the result increases ,when the elements in the meshing are low which results in lowering the accuracy. The number of elements increases the precision and accuracy of the results increases .which is shown in the above modelling. The accuracy of the result increases with the element size and it reaches an optimum value, above which the variation is insignificant.

RESULT AND DISCUSSION

In this project the study is done as 3 different cases .They are, synthetic jet with a frequency of 17Hz, 50Hz, and 100Hz without altering the geometry.There is a comparison done in each case regarding the nusslet number

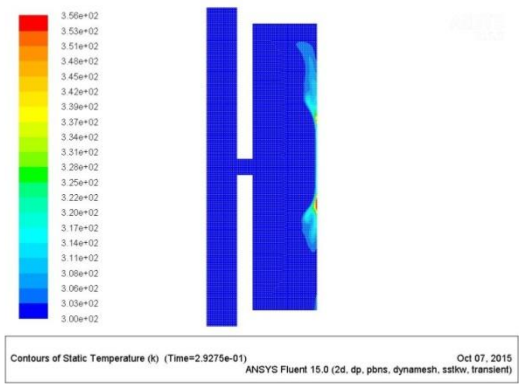

Fig 3:- Temperature contour for 100Hz

This is the temperature contour of 100Hz synthetic jet. The blue line indicates where the temperature is low and nusselt number is high and when goes to the bottom the color changes to red that indicates that temperature increases due to the decrease in nusselt number it happens because of heating of air. At the starting the nusselt number in the range of 9 and at the end it falls to 5.2.

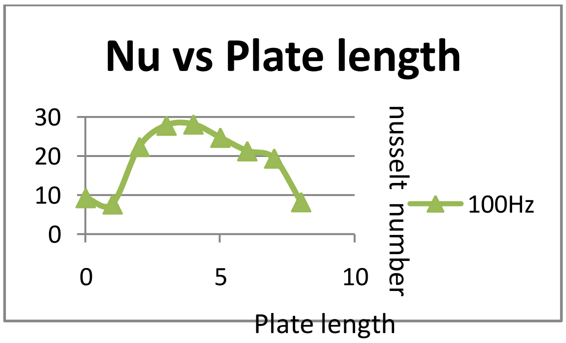

Fig 4:- Nusselt number variation vs plate length at 100Hz

ISSN: 2278 – 7798

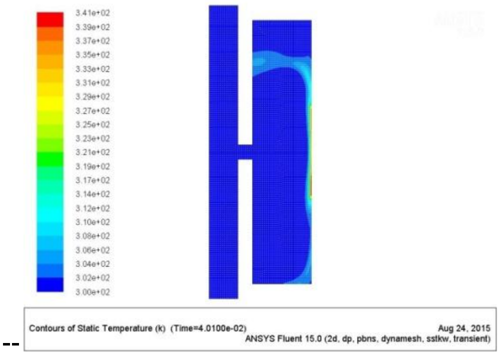

Fig 5:- Temperature contour of 50Hz frequency.

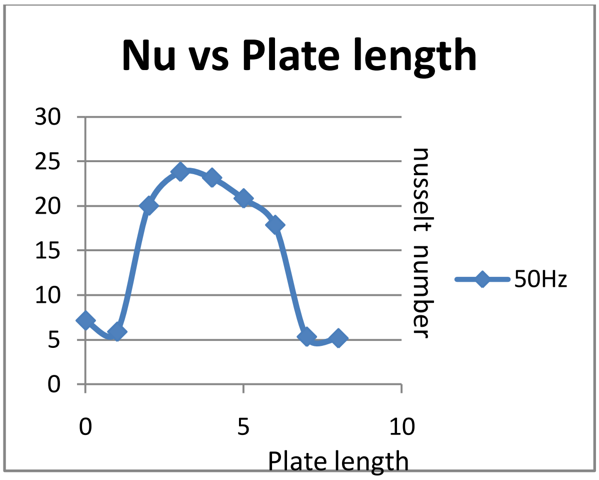

Fig 6:-Nusselt number variation vs plate length at 50Hz.

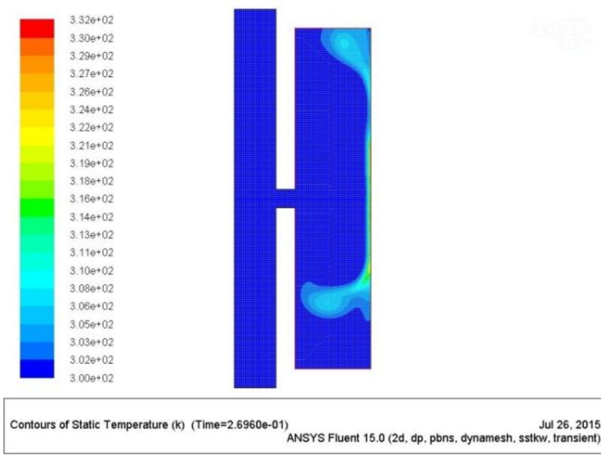

Fig 7: Temperature contour of 17Hz frequency.

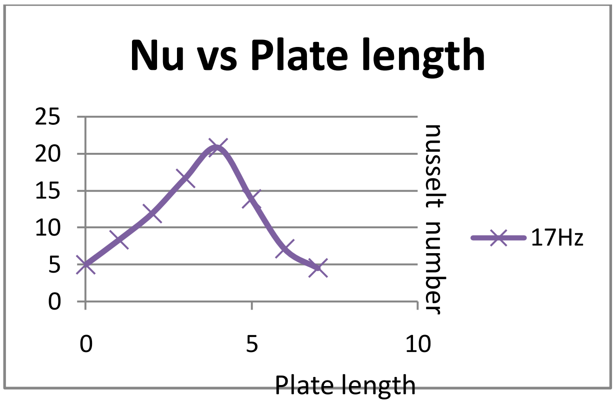

Fig 8:- Nusselt number variation vs plate length at 17Hz .

.COMPARISON OF NUSSLET NUMBER AND TEMPERATURE

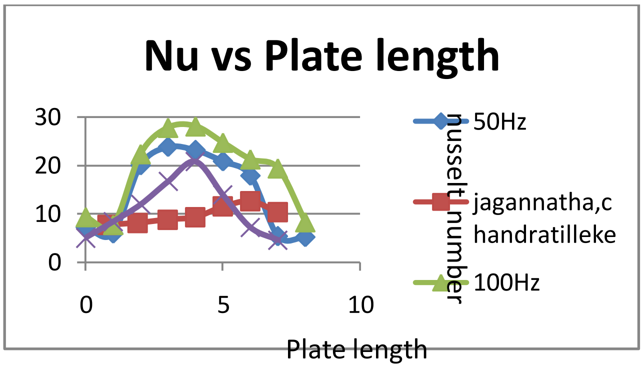

Fig 9:- Comparison of Nusselt number

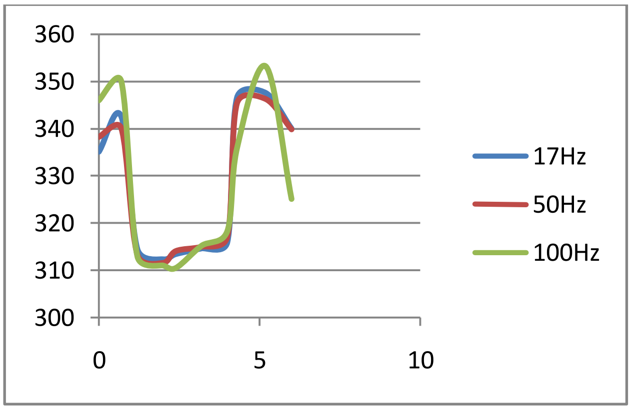

Fig 10:-Variation of temperature along the length of plate for different frequency values such as 17Hz,50Hz & 100Hz.

CONCLUSIONS

The present study is done with the help of is SST k-w turbulent model which give most accurate result with minimum complexity in calculations. The following results are obtained.

ISSN: 2278 – 7798

- In this project synthetic jet cooling at three different frequency values are studied. They are 17Hz,50Hz & 100Hz frequencies.
- These synthetic jets were created in Ansys Fluent package Workbench 15 with the help of a User Defined Function programmed in PYTHON language.
- The 100Hz frequency jet seems to be more efficient as compared to 50Hz & 17Hz jets.
- The maximum Nusselt number obtained for 17Hz,50Hz, 100Hz frequency jets are 20.83,24.8,29.17 respectively.
- The minimum temperature attained by the heating plate on impinging of synthetic jets at different frequencies such as 17Hz,50Hz &100Hz are 312.4,311.6 & 310.5 respectively.
- There is vorticity generation nearer to the heating plate which enhances the heat transfer and results in proper cooling of the plate.

During 50Hz and 100Hz frequency synthetic jets, the increment in nusselt number as compared to 17Hz jet are 19.05% & 40.03% respectively.

References

[1] A. Pavlova, M. Amitay, **Electronic cooling with synthetic jet impingement, Journal of Heat Transfer** 128 (2006) 897–907.

[2] J. Garg, M. Arik, S. Weaver, T. Wetzel, S. Saddoughi, **Meso scale pulsating jets for electronics cooling, Journal of Electronic Packaging** 127 (2005) 503-511.

[3] R. Malingham, A. Glezer, **Design and thermal characteristics of a synthetic jet ejector heat sink, Journal of Electronic Packaging** 127 (2005) 172–177.

[4] Y. Utturkar, M. Arik, T. Icoz, **Thermal characteristics of a synthetic jet integrated heat sink design for air-cooled electronics**, in: ASME Interpack Conference, IPACK 89109, San Francisco, CA, 2009.

[5] M.B. Gillespie, W.Z. Black, C. Rinehart, A. Glezer, **Local convective heat transfer from a constant heat flux flat plate cooled by synthetic air jets**, Journal of Heat Transfer 128 (2006) 990–1000.

[6] J. Zhang, X. Tan, **Experimental study on flow and heat transfer characteristics of synthetic jet driven by piezoelectric actuator**, Journal of Science in China Series E: Technological Sciences 50 (2007) 221–229.

[7] R. Holman, Y. Utturkar, R. Mittal, B.L. Smith, L. Cattafesta, **Formation criterion for synthetic jets**, AIAA J. 43 (2005) 2110–2117.

[8] Y. Utturkar, R. Holman, R. Mittal, B. Carroll, M. Sheplak, L. Cattafesta, et al., **A jet formation criterion for synthetic jet actuators**, in: 41st Aerospace Sciences Meeting & Exhibit, Reno, NV, AIAA Paper 2003-0636, 6–9 January, 2003.

[9] A. Glezer, M. Amitay, **Synthetic jets**, Ann. Rev. Fluid Mech. 34 (2002) 503e529.

[10] J.S. Campbell, W.Z. Black, A. Glezer, **Thermal management of a laptop computer with synthetic air microjets** InterSociety Conference on Thermal Phenomena, IEEE (1998) 43e40.

[11]R. Mahalingam, N. Rumigny, Thermal **management using synthetic jet ejectors**,IEEE 27 (2004) 439e444.

[12] M. Amitay, D.R. Smith, V. Kibens, D.E. Parekh, A. Glezer, **Aerodynamic flow control over an unconventional airfoil using synthetic jet actuators**, AIAA J. 39 (2001) 361–370.

[13] M. Amitay, B.L. Smith, A. Glezer, **Aerodynamic flow control using synthetic jet technology**, in: 36th AIAA Aerospace Sciences Meeting and Exhibit, 1998

[14] Jagannatha.D and Chandratilleke.T and Narayanaswamy.R.2010. **Interactive flow behaviour and heat transfer enhancement in a microchannel with cross flow synthetic jet**. International Journal of Emerging Multidisciplinary Fluid Sciences2(1); 27-43

[15] M. Li, S. Zhong, **Heat transfer and flow characteristics of impinging synthetic jets**, in: 9th UK National Heat Transfer Conference, 2005.

Appendix

List of figures:

ISSN: 2278 – 7798

Fig 7: Temperature contour of 17Hz frequency

Fig 8:- Nusselt number variation vs plate length at 17Hz

Fig 9:- Comparison of Nusselt number

Fig 10:-Variation of temperature along the length of plate for different frequency values such as 17Hz,50Hz & 100Hz.

List of tables:-

I. Element based study with varying relevance values

Name of authors:-

1.

Tigy Varughese

PG Scholar

MTech-Thermal Power Engineering

M.A.College of Engineering,

Kothamangalam

2.

Sabu Kurian

Associate Professor

M.A.College of Engineering,

Kothamangalam

3.

Dr.Tide P.S

Professor in Mechanical Engineering

School of Engineering

CUSAT

ISSN: 2278 – 7798