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Heat Transfer Analysis Using Synthetic Jet

M.S.Deokar[1], Harshad S. Pawar[2], Saurabh S. Mahajan[3], Sagar A. Kille[4].
[1]*(Asst.Professor Mechanical Engineering Department,JSPM Narhe Technical Campus,Pune-41104)*
[2,3,4]*(UG Students Mechanical Engineering Department,JSPM Narhe Technical Campus,Pune-41104)*

Abstract: *The focus of this project is to experimentally analyse heat transfer rate of a synthetic jet using different orifice shapes having same hydraulic diameter. We use three different orifice shape to analyse the heat transfer rate by using synthetic jet. In this study we use orifice shape circular, square and oval . The properties of synthetic jet for three different orifice shapes are studied for the constant frequency at different heights. The heat transfer rate depends upon the velocity of synthetic jet which in terms depend upon the frequency of synthetic jet producing device. In this study we found the heat transfer rate for circular, oval and square orifice. The maximum heat transfer rate was found at approximate height 60 mm for all three orifice shapes.After comparing the heat transfer rate of three orifice shape, circular orifice has the maximum heat transfer rate. As the height increases beyond or decreases below optimum height the heat transfer rate decreases.*
Keywords: *Orifice shapes, synthetic jet,*

I. Introduction

In the fast growing technology, due to faster operation of each transistor and an increase in their density on integrated circuits, a large amount of heat needs to be dissipated. Thermal overstressing is one of the major causes of failure of electronic components. This underscores the requirement for proper thermal management which is perhaps the most crucial part of the electronic system design. Effective cooling systems are therefore required which also meet the space and other design constraints. Heat sinks with air as the working fluid, and different fin geometry and fan arrays have been traditionally used for heat removal from electronic systems. However, these traditional forced air cooled heat sinks are facing serious challenges for the cooling of the next generation of electronics o+wing to the additional space constraints and still higher cooling requirements. Due to low cost, availability and reliability, air will continue to be used as the working fluid. In the present work, synthetic jet impingement cooling which can potentially be used for cooling of hot-spots is investigated. Synthetic jets are created as a result of volumetric displacement of a fluid filled cavity due to alternative current electric field acuation of a piezo-electrically,electromagnetic or electrostatically driven diaphragm.As the actuated diaphragm oscillates back and forth it alternately sucks in and blows out the ambient fluid in and out of the orifice on the cavity.Changing parameters such as amplitude,frequency or the orifice,diaphragm and cavity geometry can change property of synthetic jet. Asynthetic jet is commonly formed when the fluid is alternatively sucked into and ejected from a small cavity by the motion of a diaphragm bounding the cavity,so that there is no net mass addition to the system(B.L.Smith,A.Glezer,1998).Effect of square,circular and rectangular shapeof orifice on impingement cooling of heated surface is studied(M.Chaudari,B.Puranik et al.,2010).Impingement improved heat transfer using multiple orifice synthetic jet.The maximum heat transfer coefficient is 30% more as compared to that obtained with a conventional single orifice synthetic jet.9M.Chaudhari,B.Puranik et al.,2010)

What is synthetic jet?

In fluid dynamics, a synthetic jet flow is a type of jet flow, which is made up of the surrounding fluid. Synthetic jets are generally formed by flow moving back and forth through a small opening. Synthetic jets are produced by periodic ejection and suction of fluid from an orifice induced by movement of a diaphragm inside a cavity among other way. A jet flow is a fluid flow in which a stream of one fluid mixes with a surrounding medium. An example is a water jet that forms when you put your thumb over the end of a hose. The water mixes with air to form a jet. If you increase the flow of water or move your thumb to change the diameter of the exit, the jet will change dramatically. Jet flows vary depending on velocity and diameter of the flow and the density and viscosity of the fluid (Reynolds number and Mach number). When the velocities in the jet are greater than the speed of sound, important qualitative changes in the flow occur. One such change is that shock waves form.

Synthetic Jet Producing Devices-

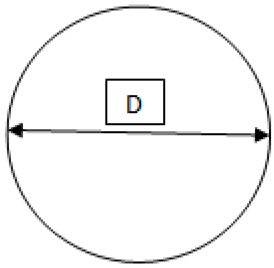
Synthetic jet flow can be developed in a number of ways, such as with an electromagnetic driver (e.g. plasma actuator), a piezoelectric driver, or even a mechanical driver such as a piston. Each moves a membrane or diaphragm up and down hundreds of times per second, sucking the surrounding fluid into a chamber and then expelling it. Although the mechanism is fairly simple, extremely fast cycling requires high-level engineering to produce a device that will last in industrial applications. The tiny synjet module creates jets that can be directed to precise locations for industrial spot cooling.Traditionally,metallic heat sinks conduct heat a way from electronic components and into the air, and then a small fan blows the hot air out. Synjet modules replace or augment cooling fans for such devices as microprocessors, memory chips, graphics chips, batteries, and radio frequency components. Additionally, SynJetic technology has been used for the thermal management of high power LEDs.

Nomenclature:-

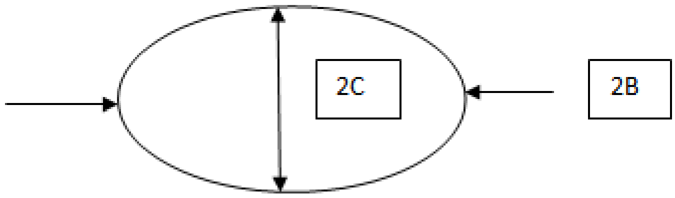
A = Area(m^2)
C_p = Specific heat (J/kg K)
d = Orifice diameter (m)
f = Excitation frequency (Hz)
h = Average heat transfer coefficient(W=m^2 K)
H = Cavity depth (mm)
I = Current (A)
K = Thermal conductivity (W/m K)
l = length of copper block (m)
L = length of orifice plate (m)
L_o = stroke length (m)
Nu = average Nusselt number
Pr = Prandtl number
q_{joule} = imposed ohmic heat flux (W/m2)∂
q_{loss} = total heat loss(W/m2)
Re = Reynolds No.
T_s = Surface temperature (°C)
T_{inf} = ambient temperature (°C)
U_o = average centerline orifice velocity(m/s)
V = Voltage (V)
z = axial distance (m)

II. Problem statement

1.The focus of this project is to study the influence of the synthetic jet on heat transfer characteristic using orifice with different geometry.
2.Compare and validate numerical results of velocity profiles to the experimental data of various tested designs.
3.To study the effect of orifice geometry on the jet flow by comparing three orifice geometrie i)Circular,ii)Square and iii)Oval shape configuration
. A synthetic jet is commonly formed when the fluid is alternately sucked into and ejected from a small cavity by the motion of diaphragm bounding the cavity, so that there is no net mass addition to the system.
1)Circular 2) Square & 3) Oval
For comparison hydraulic diameter is kept same for all the three orifice geometries.
Circle: Dh = D



Oval;: $Dh = \frac{4BC(64-16E^{2})}{(B+C)(64-3E^{4})}$



Square: Dh = B

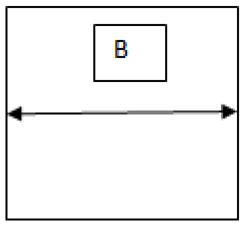


Table I
Summary of literature review and experts Opinion

Main criteria		References
Cavity shape	Effect of cavity shape on synthetic properties of jet	Mark A. Feero et al., 2015, Manu Jain et al. 2011, Udaysinh Bhapkar et al 2015
Numerical modeling Boundary condition	Velocity boundary condition	Qingfeng Xia et al.,Manu Jain et al. 2011
	Moving piston boundary condition	Manu Jain et al. 2011
	Moving Boundary condition of diaphragm	Xiaoyong Ma et al.,2012, Manu Jain et al. 2011, Samir Laouded et al 2012, Poorna Mane et al 2007
Heat transfer	Orifice shape	Mangate et al, 2015
	Distance between orifice and plate z, frequency	Chaudhari et al, 2010, P. Valiorgue et al 2009

III. Methodology

Fig.No.4.1 shows the schematic of the set-up used for the present experiments. The experiments are conducted for different configurations of synthetic jet impinging onaheated surace. The synthetic jet assembly is attached to a 2-*d* traverse stand so that the axial distance between the jet orifice and the heated surface can be controlled easily using a fine pitch traversing mechanism. The heater block is constructed from a copper plate, and has final dimension 50 × 50 × 10 mm. The block is heated by a n i chrome foil heater of the same size attached underneath of the block. The heater is supported by a Bakelite plate to provide proper thermal contact between the heater and the copper block. The copper block is insulated byglass-wool (size 180*180*50 mm3 to minimize the heat loss through the sides and bottom.The heater surface provides a constant heat flux, as the driving power input is constant, and the flexible heater is specifically de- signed to provide a constant heat flux output. The surface temperature is measured with two pre-calibrated K-type thermocouples, which are placed at two sides of the

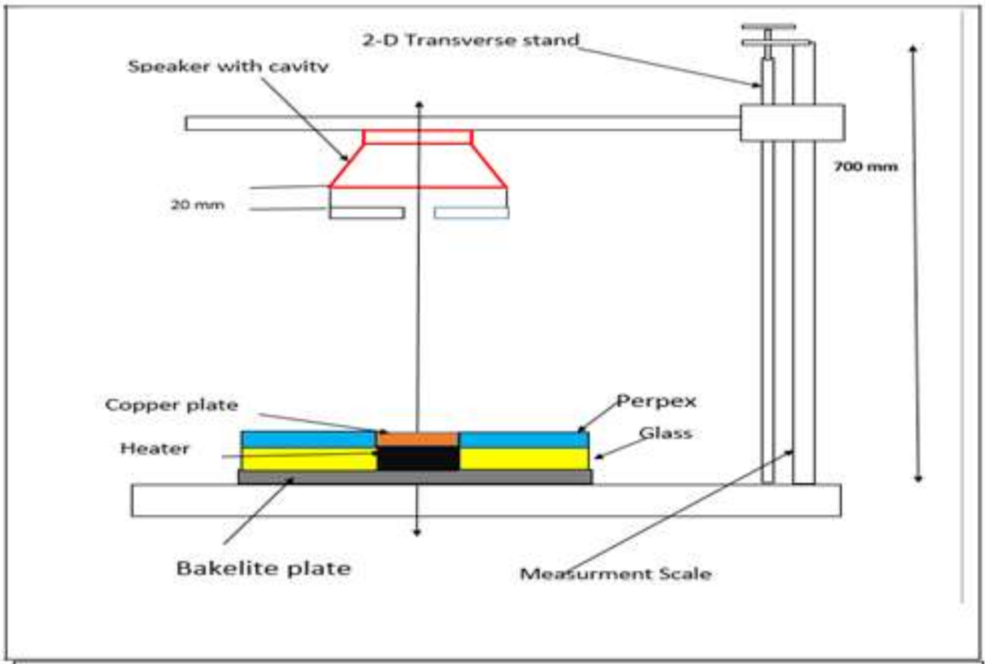


Fig.1 Experimental setup

An identical thermo- couple is used away from the heated surface for ambient air temperature measurement. The power supplied to the heater is measured with a multi-meter and is controlled by a rheostat. A synthetic jet is synthesized at the edge of an orifice by a periodic motion of a diaphragm mounted on one side of a sealed cavity. Air is the working fluid in the present experiments.

From the literature it is noticed that a number of researchers use a piezo-actuated membrane as the oscillating diaphragm for the creation of a synthetic jet. A piezoelectric actuator requires relatively high voltage (Vrms =90 V) as compared to that required for an electromagnetic actuator. Furthermore, a piezo-actuator operates at certain discrete input frequencies. For these reasons, piezo-actuators have not been used here. In the present study, an electromagnetic actuator (acoustic speaker) of diameter 50 mm and operating at an input voltage (Vrms) of 4 V is employed. The experiments are conducted for different orifice diameters, length of orifices, and cavity depths (see Table 1). The input voltage to the actuator is maintained constant and the frequency of excitation is controlled by a signal generator and monitored by an oscilloscope.

$20\text{mm} < z < 100$ mm

$t = 1.5$ mm

$1000 < Re < 4300$

Thickness of plate (t) =1.5 mm

Frequency Range-100 Hz

The jet issuing from the orifice impinges normally onto the plate at a distance of z from the orifice (Fig. (b)). The distance between the orifice surface and the copper plate is varied with the help of a traverse stand. The effects of the synthetic jet impingement cooling are investigated by measuring the surface and ambient temperatures for different operating frequencies and other geometric parameters for a known power supplied to the heater. The results are presented in terms of the average Nusselt number as a function of normalized axial distance z=d.

The heat loss is calculated by supplying different input powers to the heater, and measuring the surface temperature of the heated copper block along with the ambient temperature, while insulating the top surface of the heated block. The losses are taken in to account for calculation of heat transfer coefficient as per Eq6.The losses from the sides and the bottom of the test section are found to be typically 22% of the input power. Due to low temperatures involved in this experiments, the heat loss from the surface due to radiation transfer is neglected, as it is calculated to be less than 1% of the power input. The temperature difference between the copper surface and the ambient is maintained above 15 C for all the experimental results.

4.1 Analytical/ Numerical Method

Analytical Method;-

The Reynolds number is calculated using the procedure given by Smith and Glezer [1]

Re = UoD/v ..... (1)

Where 'D' is the orifice diameter,

'v' is the kinematic viscosity, and

'Uo' is the average orifice velocity during the ejection part of the cycle at the exit and center line of the orifice. This last parameter is calculated as

Uo = Lof ..... (2)

where 'f' is the excitation frequency (or inverse of time period s) and

'Lo' is the stroke length calculated over the ejection part of the total cycle as

$$L_0 = \int_0^{\tau/2} u(t)\,dt.$$

The average velocity is between 3.1 and 8.5 m/s and the maximum instantaneous velocity ranges between 10 and 25 m/s for the present set of experiments. The Reynolds number is greater than 4000 for the present experiments. The procedure for calculation of the Average Nusselt number for simple force convection is given by

Nu={(f/8)(Re-1000)Pr}/{1+12.7(f/8)^0.5(Pr^0.67-1)} …..(4)

where Pr= uCp/K

Put 'Nu' calculated from eq.(4) in

Nuavg = havg*d/k ..... (5)

Eq.(7) gives 'havg'.Put these value in below eq.

qconv = havg (Ts -Tinf) …..(6)

Ts -Tinf) is the temperature difference between the surface Ts and the ambient Tinf, and qconv is the net heat flux supplied. The net heat flux is the difference in the supplied heat flux (qjoule) and heat lost (qloss), i.e.

qjoule =VI/A ..... (7)

qloss = qjoule -qconvection ..... (8)

IV. Result And Discussion

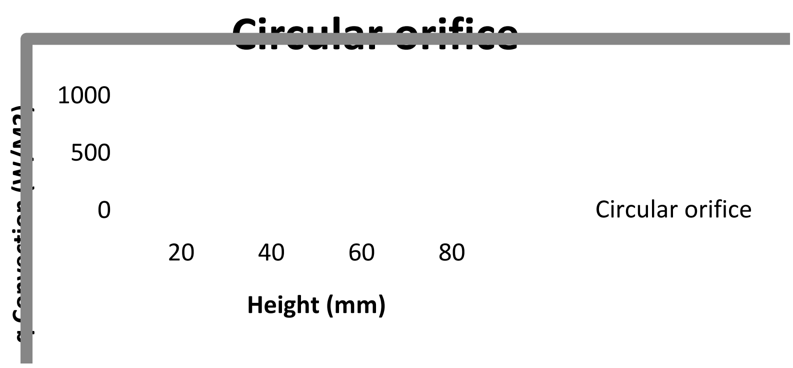


Fig.2 Graph of qconvection v/s Height(Circular Orifice)

Fig. shows heat flux convection variation for different height of the synthetic jet between the source(diaphragm) to the copper plate surface.The graph shows that we get maximum heat transfer rate at approximate height of 60mm.As the distance increases upto 60 mm the heat transfer rate increases linearly and beyond 60 mm the heat transfer rate starts decreasing.

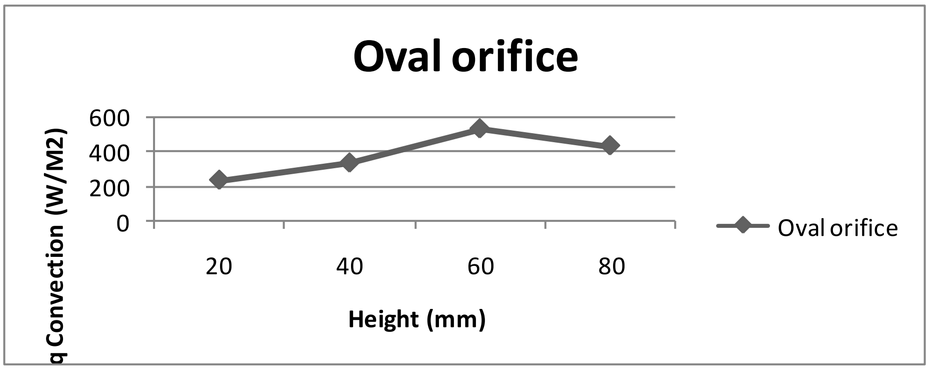


Fig. 3 Graph of qconvection v/s Height(Oval Orifice)

Fig. shows heat flux convection variation for different height of the synthetic jet between the source(diaphragm) to the copper plate surface.The graph shows that we get maximum heat transfer rate at approximate height of 60mm.As the distance increases upto 60 mm the heat transfer rate increases linearly and beyond 60 mm the heat transfer rate starts decreasing.

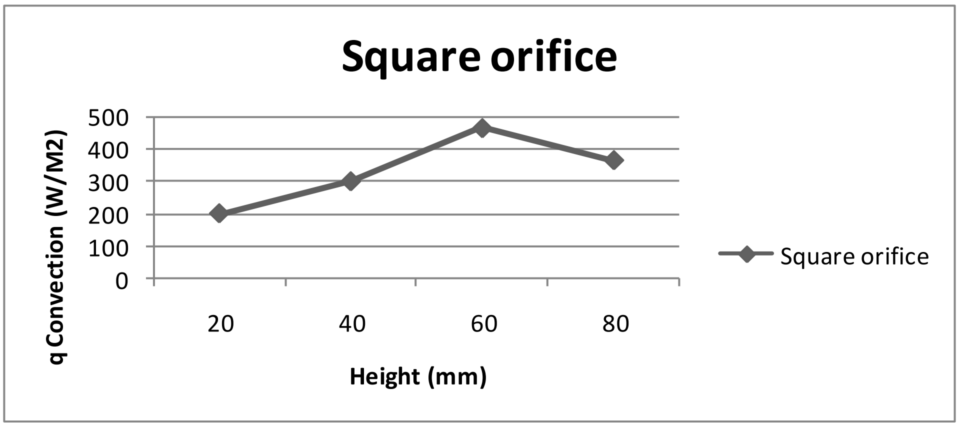


Fig.No.4.3. Graph of qconvection v/s Height(Square Orifice)

Fig. shows heat flux convection variation for different height of the synthetic jet between the source(diaphragm) to the copper plate surface.The graph shows that we get maximum heat transfer rate at approximate height of 60mm.As the distance increases upto 60 mm the heat transfer rate increases linearly and beyond 60 mm the heat transfer rate starts decreasing.

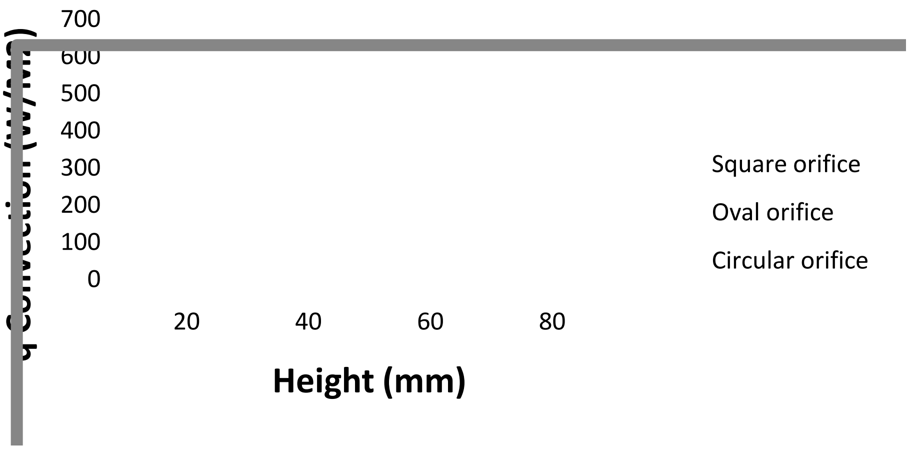


Fig.No.4. Graph of qconvection v/s Height(Different orifice)

Fig. shows heat flux convection variation for different height of the synthetic jet between the source(diaphragm) to the copper plate surface with different shape of orifice.The graph shows that we get maximum heat transfer rate at approximate height of 60mm.As the distance increases upto 60 mm the heat transfer rate increases linearly and beyond 60 mm the heat transfer rate starts decreasing.

The figure shows maximum heat transfer rate occure through the circular orifice and minimum heat transfer occure through the square shape orifice.

V. Conclusion

In this study analytical calculation of synthetic jet with three different orifice shape is done.Orifice shapes :-1)Circular 2)Square and 3)Oval.The analytical calculation utilizes the different temperatures(i.e.atmospheric temperature,constant heated copper plate temperature and temperature of copper plate after impinging synthetic jet on it).The validated numerical calculation is used to study the synthetic jet characteristics coming out from different orifice shapes.For the study Circular,Oval and Square orifice were compared to obtained the effective orifice shape.Hydraulic diameter is kept same for all three orifice shapes.

At the maximum cavity volume step which is at the end of ingestion cyclethe air is coming inside the cavity which causes vortex generation inside the cavity.The incoming jet hits the diaphragm causing high pressure at the centre of the diaphragm.Maximum expulsion and maximum ingestion steps shows similarities with eachother but in reverse direction.As the frequency goes on increasing the velocity of jet also increases.For the range of 50 Hz to 100 Hz the peak velocity for all the jets increases linearly, however increase in peak jet velocity is more rapid in case of circular orifice followed by oval orifice jet and lastly square orifice jet.

The maximum velocity obtained in synthetic jet is directly related to heat transfer rate obtained by the jet at given frequency.

Recently studies shows that multiple orifice synthetic jet gives more heat transfer rate as compared to single orifice sunthetic jet.

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