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Numerical Optimisation of Heat Transfer using Pulsating Jet Array with Phase Shift

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Abstract

The advancement in science had led to highly complicated electronic devices and at the same time the size of such devices is getting reduced day by day. The amount of heat generated by these devices is increasing in par with its complexity. The efficiency of electronics devices decreases with increase in temperature. The cooling of these devices to their normal working temperature is a great challenge since the area available for heat transfer will be very less and there is restricted movement of air. This paper deals with jet impingement cooling, in which high velocity jets are used for removal of heat from a surface. The jets are arranged in the form of a staggered array and are pulsating in nature. To increase the turbulence in the flow domain the jets are pulsated at a phase shift. The study is carried out at different frequencies. The objective of this study is to compare the heat transfer at different combinations of frequencies and angles of phase shift and find the combination at which the heat transfer is maximum. The study is done using computational fluid dynamics software tool ANSYS Fluent version 14.
Keywords- CFD (Computational Fluid Dynamics), Jet Impingement Cooling, Pulsating Jet, Phase Shift Staggered Array of Jets

I. INTRODUCTION

The process of transfer of heat by the bulk movement of fluid is called convection. The flow of fluid may be forced by external processes, or sometimes by buoyancy forces caused when thermal energy expands the fluid. Heating and cooling is very important in everyday industrial process and achieving and maintaining the working temperature for different process is still a challenge. A booming sector of today’s industrial world is the electronics industry, with the devices becoming more and more complicated and faster. In the field of electronics efficiency is very much dependent on the working temperature of the devices. With the increase in speed and complexity of these devices the amount of heat generated by these devices also began to increase, adversely affecting the speed of these devices. The cooling of electronic circuit boards is very challenging because the available heat transfer area is very less and since the space for free circulation of air is less forced convection is the only option. One technique of forced convection is by the usage of fan. Another method is by the use of air jets at high velocity directed on to the surface which is to be cooled.

This study is focused on jet impingement cooling. Many studies have been carried out in this field, and is still an area of active research. Among the most commonly discussed types of jets, this study concentrates on pulsating jets arranged in a staggered arrangement. The jets are grouped into two and each group is fired at a phase shift from the previous jet, in an attempt to increase the turbulence in the fluid domain in the vicinity of the heated plate. Pulsating jets have higher turbulence levels, chaotic mixing and nonlinear dynamic response of the hydrodynamic and thermal boundary layers than steady jets, which increases the heat transfer. Significant enhancement in the heat transfer by intermittent jet flow was first reported by Zumbrunnen and Aziz in 1993[1]. The aim was to study the effect of flow intermittency on convective heat transfer to a planar water jet from a surface. A 2-dimensional numerical study conducted by Peng Xu et al [2] on heat transfer properties of multiple pulsating jets confirmed that intermittent pulsation with phase angle difference will further enhance the heat transfer. In the study conducted by R. Zulkifli et al[3] on the effect of pulsating frequencies on Nusselt number it was reported that local nusselt number obtained is higher in pulsating flow than steady jet at lower pulsating frequencies. In the experimental study conducted by Vadiraj Katti and S.V.Prabhu[4] to study the jet to plate spacing and Reynolds number on heat transfer it was found that increase in Reynolds number increases the heat transfer at all radial locations for a given nozzle to plate distance. Freidman and Mueller [5] investigated the effect of hole spacing and nozzle to plate distance. Results indicate X/D,Y/D ratios from 4 to 6 gives the best heat transfer results. Juan Yan San and Mao-De Lai [6] conducted a study on the optimum jet to jet spacing of heat transfer for staggered arrays. A numerical study has been conducted by considering an array of five jets in a staggered arrangement. The jets are grouped into two and are fired at a phase difference between the two groups. The aim of this study is to optimise the phase shift and frequency for maximum heat transfer.

II. GEOMETRY AND BOUNDARY CONDITIONS

The geometry considered for this study is as shown in figure 1, 2 & 3. It consists of two domains i.e., the fluid domain and the heated plate. The fluid domain consists of five nozzles in which the central nozzle is considered as "inlet 1"and all the outer nozzles are considered as "inlet 2".

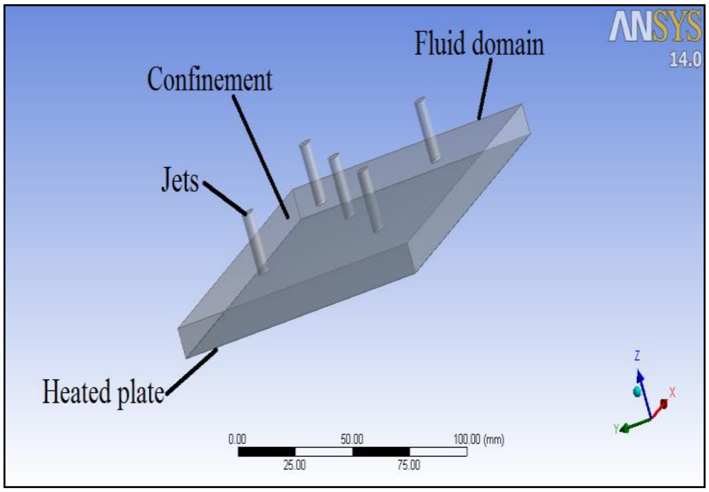


Fig. 1: Geometry

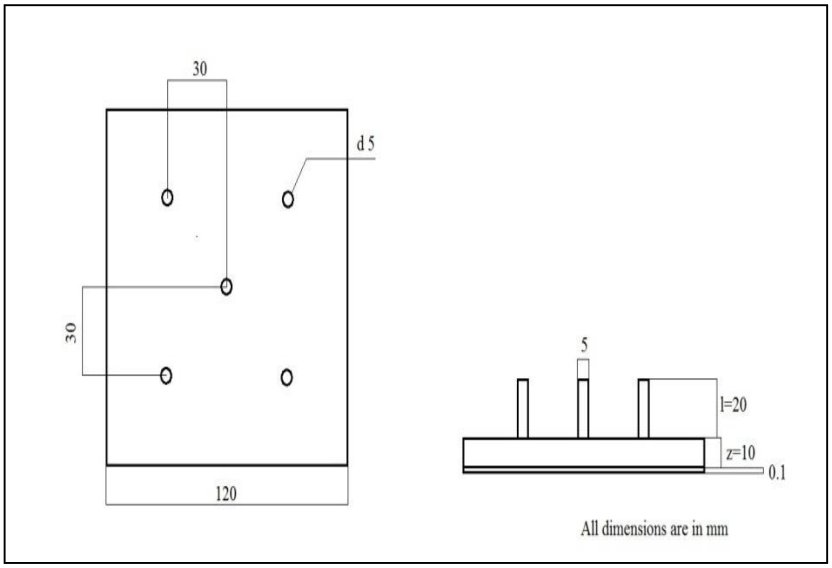


Fig. 2: 2D drawing of the model

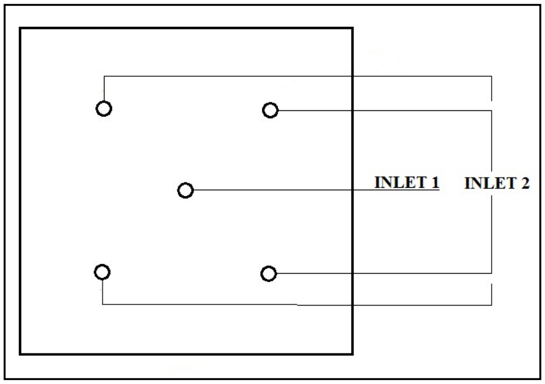


Fig. 3: Figure showing naming of jets

The diameter of each nozzle is taken as 5 mm. The nozzles are positioned above the heated plate at a distance of 10 mm. The heated plate considered is of dimension 120x 120 mm. The model has four flow outlets as shown in figure. The model considered is symmetrical at four quadrants, hence only a single quadrant is considered for the ease of calculation. The fluid considered for this study is air at a temperature of 300K. A constant power input of 120 W is given to the plate which results in the increase of plate temperature. The pressure of air is considered to be 1 bar. The jet flow Reynolds number is assumed to be 32,000. The nozzle "inlet 1" is fired first and is followed by the jets of "inlet 2" after a phase shift. The phase shift results in a lag between the firing of two groups of jets. The firing is continued in the above order for 1 sec. The phase shift angles considered for this study are 0, $\pi/12$, $\pi/6$, $\pi/4$, $\pi/3$, $5\pi/12$, and $\pi/2$.The pulsation and phase shift is achieved with a UDF with different function for inlet 1 and inlet 2. Each case of phase shift is analysed for the frequencies 10 and 20 Hz.

III. RESULTS AND DISCUSSION

The numerical analysis is done for different cases of phase angles in the above said frequencies. Only a quarter section shown as the shaded region is considered for the analysis. The temperature and Nusselt number variations are plotted along the three lines as shown in figure 4.

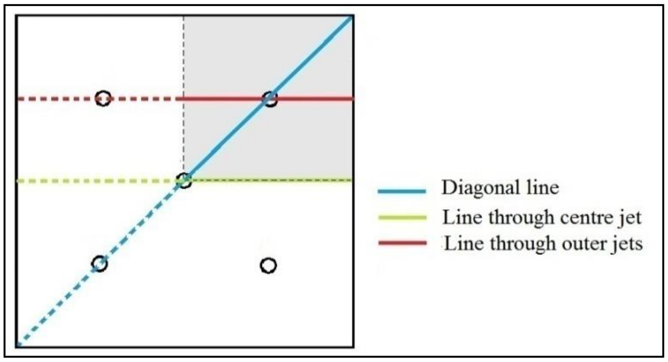
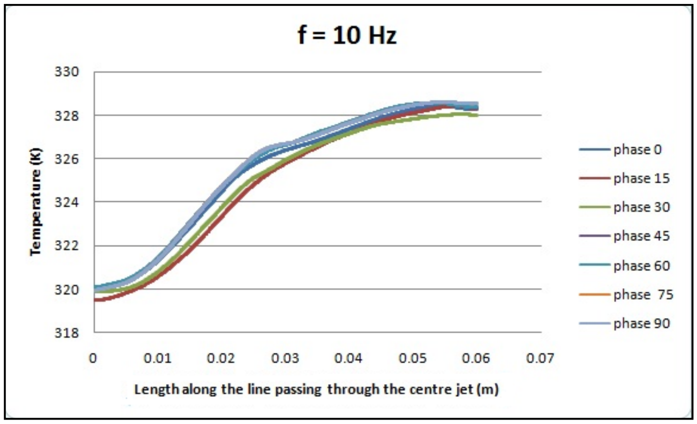


Fig. 4: Figure indicating section and lines of analysis



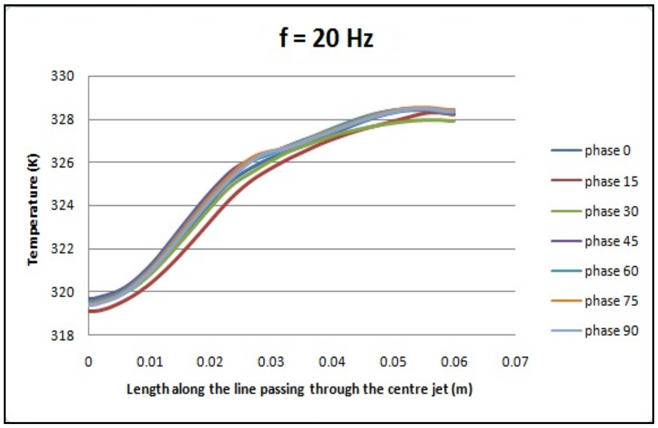
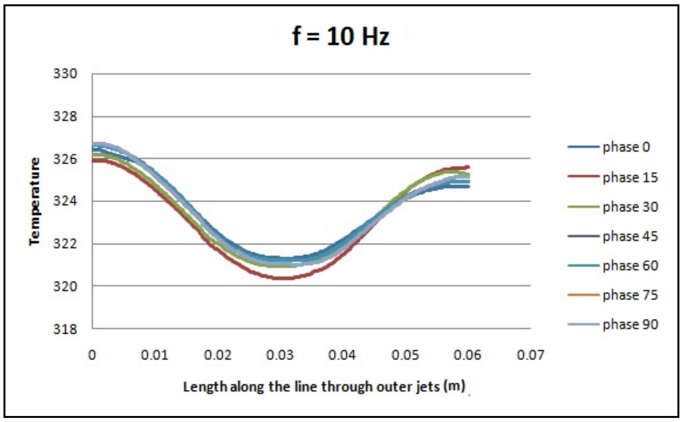


Fig. 5: Temperature plots at line passing through the centre jet for different cases



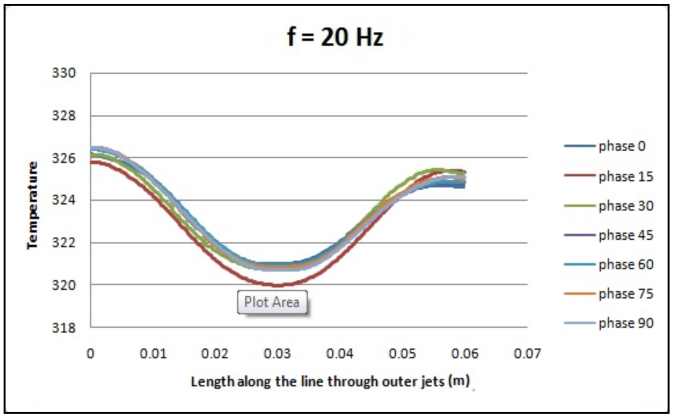


Fig. 6: Temperature plots at line passing through the outer jets

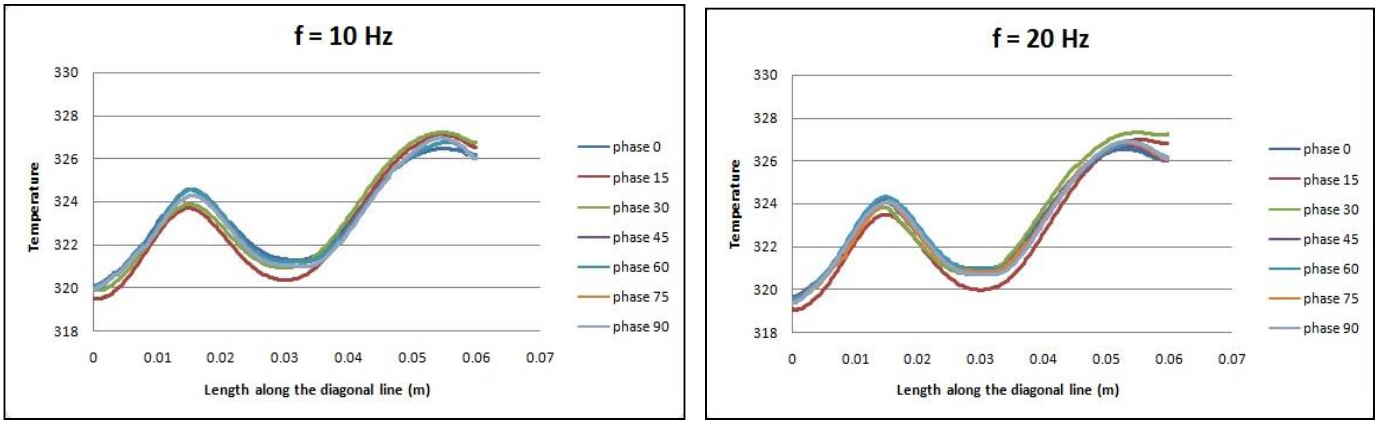


Fig. 7: Temperature plots at diagonal line

From the above figure, it can be seen that in all the cases the temperature variation follows the same pattern. Along the central line the temperature is at its lowest in the stagnation zone, then increases steeply towards the outlet. Along the other tow line the temperature variation follows the same trend i.e, it is at its lowest in the stagnation zone and it increases towards the outlet. As the frequency of pulsation is increasing it can be noticed that the difference in the temperature plot for each phase angle is decreasing. Among the three locations considered along the centre line the maximum temperature is recorded.

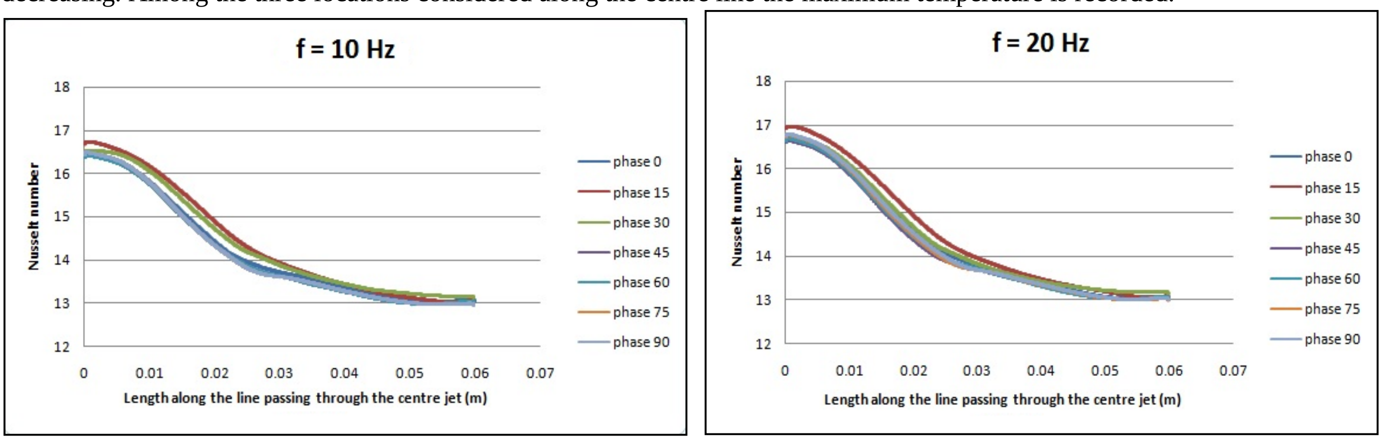


Fig. 8: Nusselt number plot at line passing through centre jet

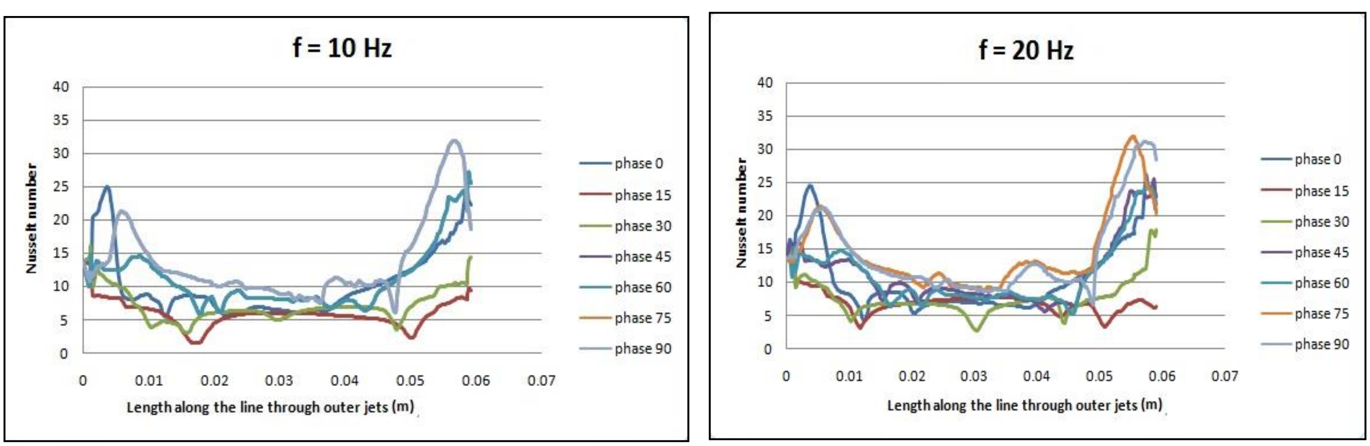


Fig. 9: Nusselt number plot at line passing through the outer jets

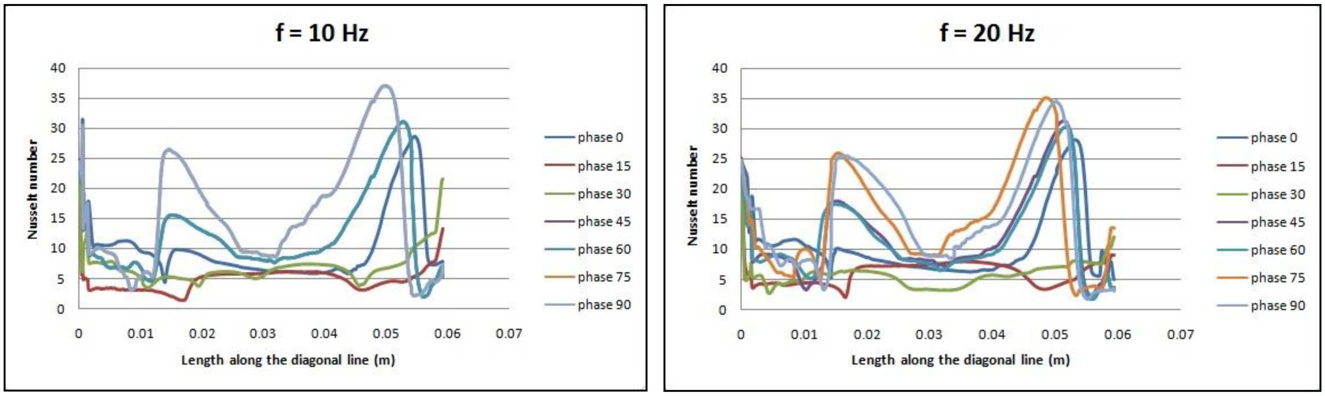


Fig. 10: Nusselt number plot at diagonal line

The nusselt number plot at the diagonal line and at the line through the outer jets clearly indicate that the turbulence at these locations is high compared to that at cental line. The plots also shows a high nusselt number at the wall jet region.

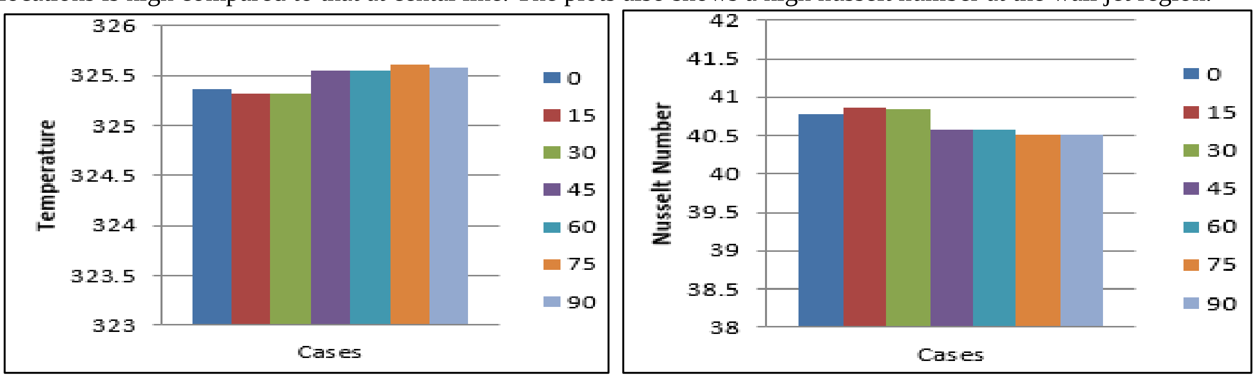


Fig. 11: Comparison of temperature and nusselt number for various phase angles at f=10 Hz

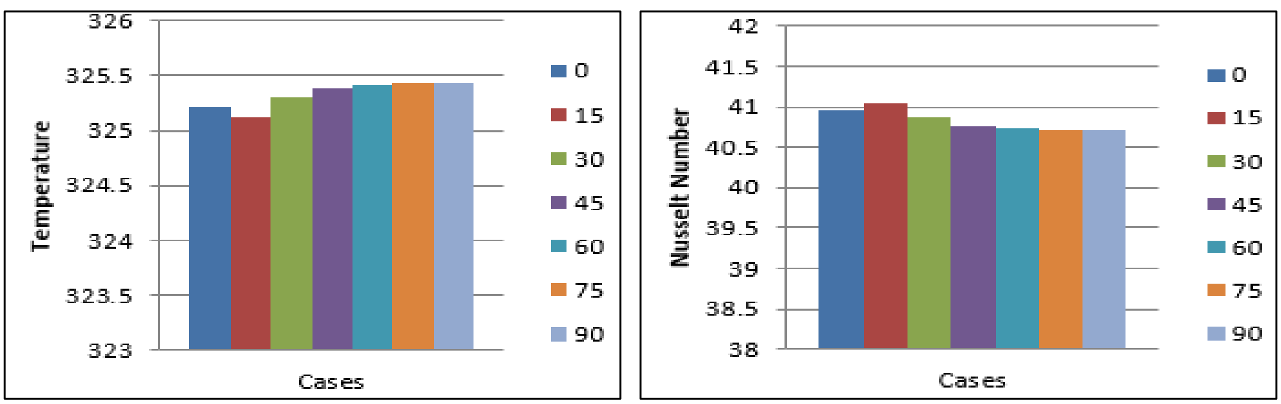


Fig. 12: Comparison of temperature and nusselt number for various phase angles at f=20 Hz

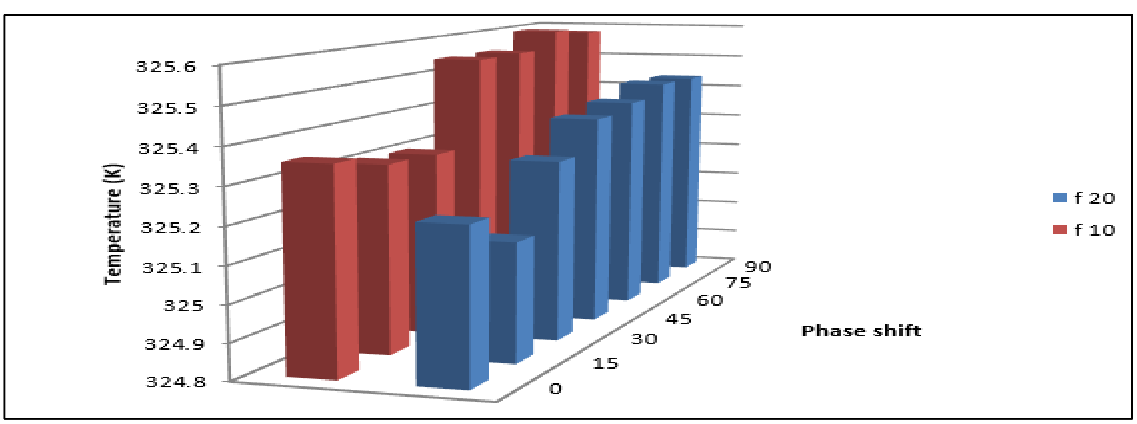


Fig. 13: Overall comparison of average temperature

From the overall comparison of average temperature it is found that the minimum temperature is achieved at phase shift angle of 15° at 20 Hz. The pulsating jet without phase shift shows better heat transfer than pulsating jets with phase shift angles 45°, 60°, 75° and 90°.

IV. CONCLUSION

The heat transfer by pulsating jet without phase shift is better than the heat transfer by the pulsating jets with phase shift angles 45°, 60°and 75°. The heat transfer for the pulsating jet without phase shift increases with increase in frequency. The maximum heat transfer among all the cases was obtained for 15° phase angle at 20 hz. From the study it is inferred that the combined firing period of jets, the velocity at which the jets interact plays a key role in the heat transfer. The heat transfer is increased with the increasing frequency of pulsation, and can be further increased by introducing phase shift in the jets pulsating flow.

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