Numerical Optimisation of Heat Transfer using Combined Steady and Pulsating Jet Array

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Abstract

Cooling of heated plates finds applications in various fields like cooling of electronic devices. Commonly used method for cooling of electronic devices such as computers is by using fan. With the advent of electronic industry cooling requirements from compact surfaces become the primary focus of research. Jet impingement cooling mechanism with pulsating impinging jet array has proved to be one of the most efficient heat transfer mechanism for cooling applications. The idea of impingement heat transfer is to obtain the higher heat transfer coefficients from a given surface with limited area by means of the high velocity of the jets. Thus, a study is required to optimize the different aspects of the mechanism so as to achieve maximum heat transfer. In this project combined steady and pulsating jet array is used for heat transfer. Various arrangements of jets are considered. Also analysis of different frequencies of jets is done. The best combination for maximum and uniform heat transfer is to be found out. The study is being conducted with the help of CFD simulation package Ansys Fluent.

Keywords- CFD (Computational Fluid Dynamics), Jet Impingement Cooling, Pulsating Jet, Array of Jets, Steady Jet

I. INTRODUCTION

The cooling or heat transfer technology is an inevitable process for many industrial applications. With the advent of electronic industry cooling requirements from compact surfaces become the primary focus of research. Many technologies were developed since the invention of semiconductor devices for faster and better performance. The development of cooling technologies has gone parallel with the electronic advancement to meet the cooling requirements of high performance microprocessor chips and transducers. The demand for better heat transfer from smaller and smaller surfaces is increasing day by day with the exponential growth of electronic industry. Many researchers have come up with different technologies for the cooling challenge throughout recent years, among which cooling with a high velocity fluid jet directly impinging on heat transfer surface become a promising heat transfer method to meet the needs of electronic industry. In this study we focus on jet impingement heat transfer, the growth of the technology throughout these years and its scope of further development in future.

A periodic oscillation induced by pulsation can enhance local heat transfer rates. Pulsating jets thus become a hot research trend as advancement to the traditional steady jet flow. Zumbrunnen and Aziz were the first to report an increased heat transfer rate for pulsating flow problem. The literature about pulsating jet heat transfer is contradictory in several occasions. This is because the pulsed flow shows enhancement in heat transfer only in limited configurations. Some literature shows very high gain in pulsed flow heat transfer.

In the journal 'Heat transfer under composite arrangement of pulsed and steady turbulent submerged multiple jets impinging on a flat surface' by Javad Mohammadpour et al, a composite design consisting of steady as well as intermittent jets in different combinations of four slot jets was simulated. This was done as a two dimensional analysis. The jets were also slotted jets. Also in various research journals, most of composite design simulations are done in two dimensional inline arrangements. Thus here there is a research gap of three dimensional circular jet composite arrangements. In this paper, three dimensional analysis of circular jets with composite staggered arrangement of steady and pulsating ones is done.

II. GEOMETRY AND CONDITIONS

The geometry consists of both air and heating plate domains which constitutes the control volume to be solved with specified boundary conditions. The geometry is symmetric on four sides. The outlet flow takes place in four directions.

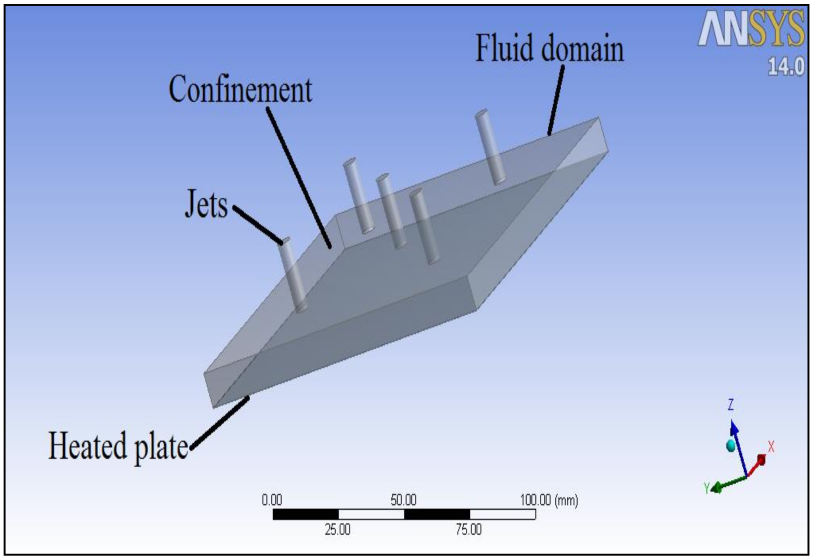

Fig. 1: Geometry

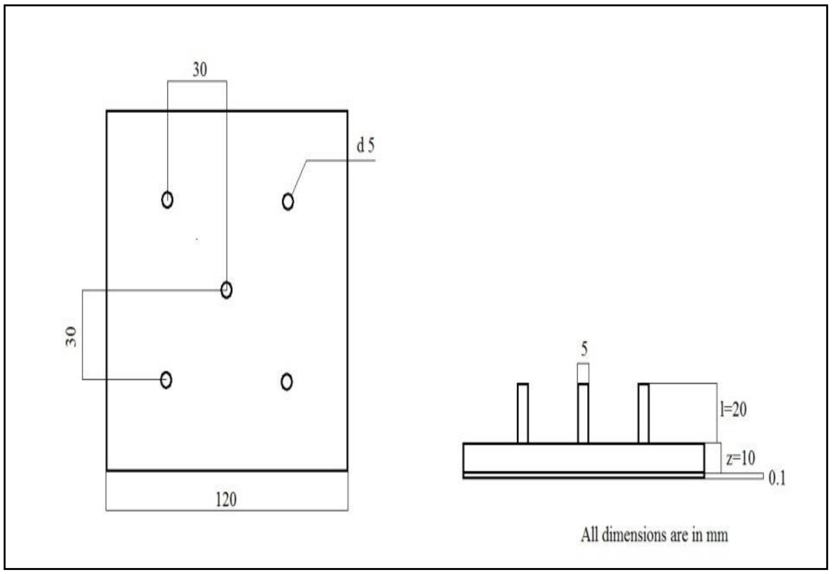

Fig. 2: 2D drawing of the model

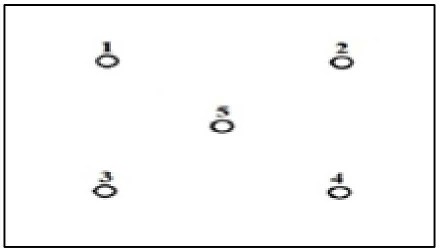

Fig. 3: Figure showing jet numbers

An array of 5 nozzles with circular cross section is placed at a distance of 10 mm above a film of aluminium which receives a constant heat flux from an electronic chip producing 120W heat energy. The heat is to be carried away from the film surface so as to keep the temperature of the chip within tolerable limits.

Convection surface: 120 mm x120mm
Nozzle diameter: d= 5mm
Nozzle length to diameter ratio: l/d =4
Nozzle to plate distance: z/d= 2
Thickness of plate=0.1mm
Inlet hydraulic diameter = 4×Area/ perimeter = 5 mm

Outlet hydraulic diameter = 4×Area/ perimeter = 0.01714 mm
Heat flux = 8333.33W/m^2
Reynolds numbers investigated Re= 16000
Frequencies of pulses f= 10 Hz, 20 Hz, 30 Hz, 40 Hz

Table 1: Jet Arrangement

Jet No→ Cases ↓	*1*	*2*	*3*	*4*	*5*
Case 1	*P*	*P*	*P*	*P*	*P*
Case 2	*S*	*S*	*S*	*S*	*S*
Case 3	*P*	*P*	*P*	*P*	*S*
Case 4	*S*	*S*	*S*	*S*	*P*

III. RESULTS AND DISCUSSION

The various cases of the problem are run and results are obtained. Due to symmetry of the geometry only a quarter section of it is taken for the analysis. This section is indicated as shaded region in the figure below. To show temperature variation, three lines are considered over the plate. These lines are diagonal line, line through centre jet and line through outer jets.

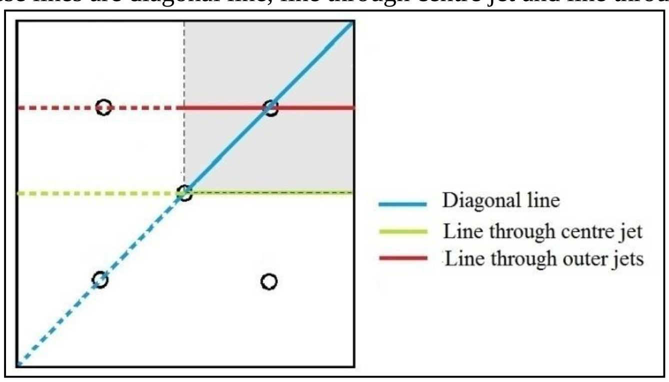

Fig. 4: Figure indicating section and lines of analysis

A. Temperature Contours

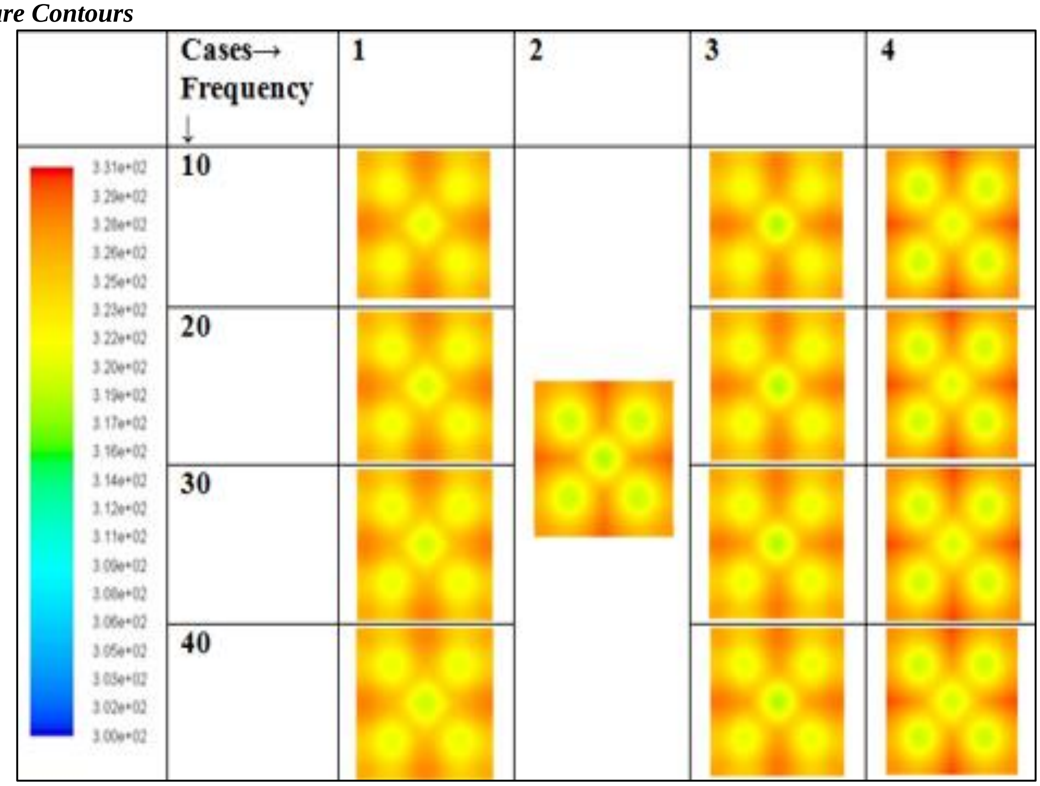

Fig. 5: Temperature contour of heated plate for all the cases

B. Temperature Plots

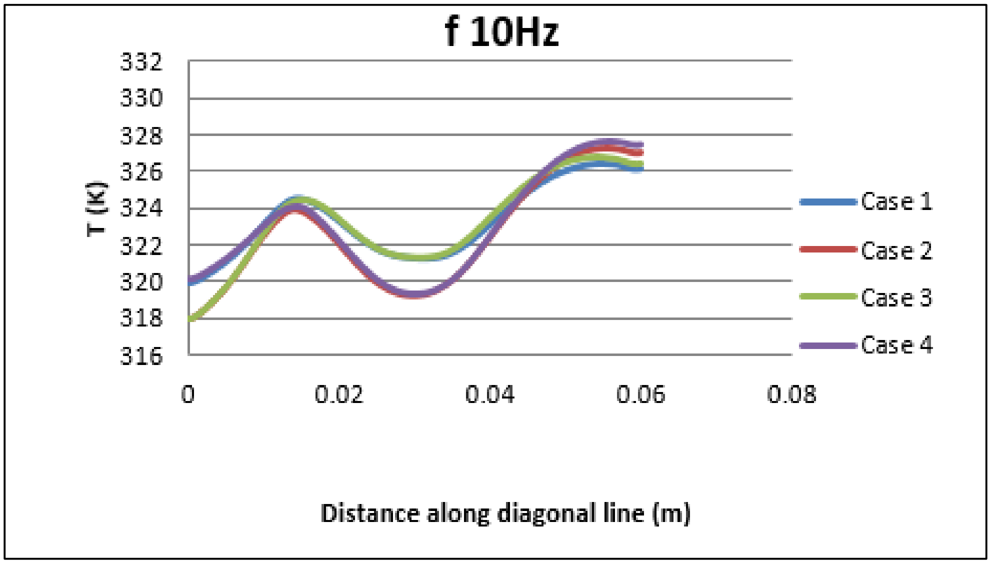

Fig. 6: Temperature vs. distance along diagonal line for frequency 10Hz

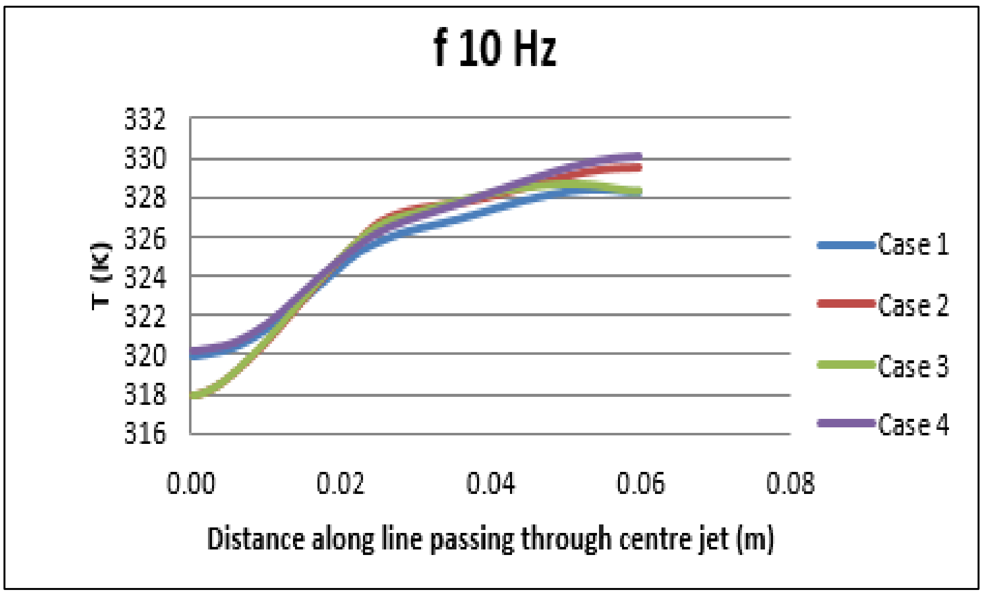

Fig. 7: Temperature vs. distance along line passing through centre jet for frequency 10Hz

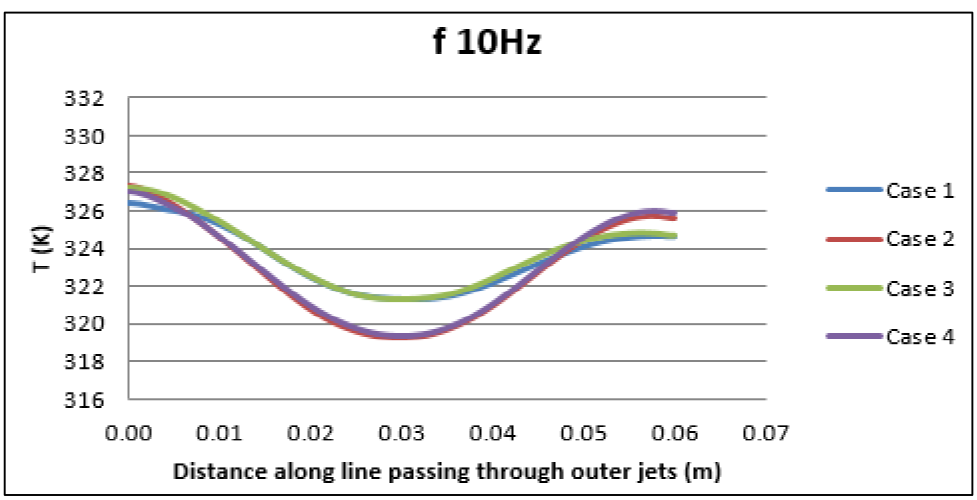

Fig. 8: Temperature vs. distance along line passing through outer jets for frequency 10Hz

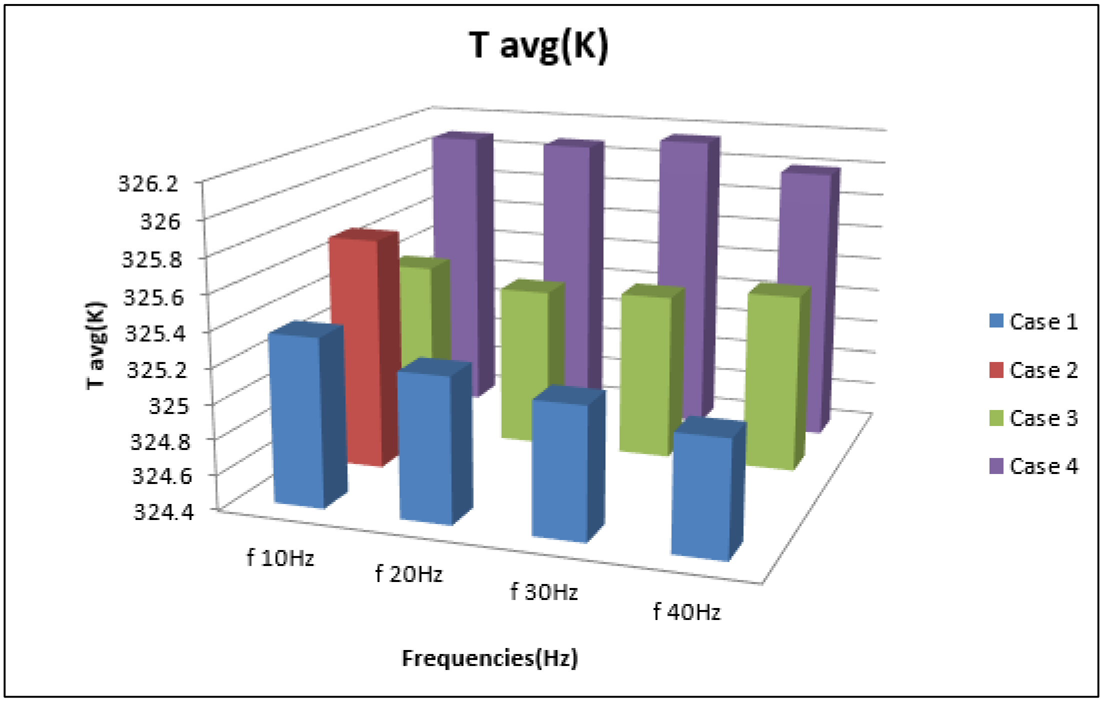

Fig. 9: Overall comparison of average temperature

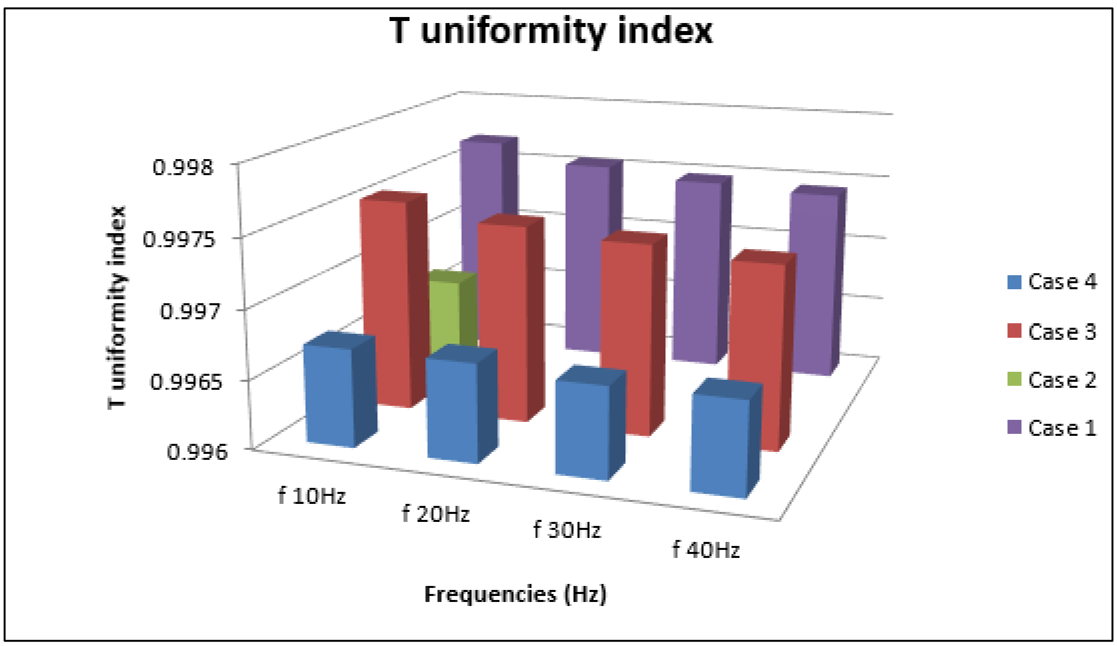

Fig. 10: Overall comparison of temperature uniformity index

CFD simulation of jet impingement cooling is done and results are obtained. Temperature contour taken for various cases gives an overview of heat transfer that is taking place. Temperatures at three different lines are plotted for various frequencies even though only plots at 10Hz frequency are shown here.

The average temperature bar charts for all the case are shown as a single figure, this helps in easy comparison of results. To know about the uniformity in heat transfer, temperature uniformity index is determined. It denotes how uniform the temperature variation in the plate is.

IV. CONCLUSIONS

The steady jet has better heat transfer near to the stagnation region. In the wall jet region, steady jets exhibit lower heat transfer rates compared to the pulsating ones. When taking the average, pulsed jets have more heat transfer capacity when compared to steady jets. For case 1 i.e. for all jets to be pulsating, it is seen that when frequency increases, heat transfer is increasing. From all the thirteen cases considered maximum overall heat transfer is for case 1 at a frequency of 40 Hz. Highest uniformity index is for case 1 i.e. when all the jets are pulsating ones. Next highest is for case 3 ie when centre jet is steady and the remaining ones are pulsed. Now comes the case where all jets are steady. Minimum uniformity index is for case 4 where centre jet is pulsed and remaining are steady. It is also found that for pulsating jets uniformity index decreases when frequency increases.

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