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NUMERICAL AND EXPERIMENTAL INVESTIGATION ONAIR JET IMPINGEMENT COOLING

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Abstract

In recent years there has been significant increase in chip level heat fluxes, along with increasing demand for miniaturization. Design engineers are always seeking better methods for packing high-power dissipating electronic equipment's .As the power dissipation continue to increase, standard conduction and forced-air convection techniques no longer provide adequate cooling for sophisticated electronic systems This work deals with experimental analysis and numerical analysis of microprocessor cooling using jet impingement. The analysis is done with the help of ANSYS FLUENT 14.0 software Circular orifice of diameter 2mm and 3mm were tested for various Reynolds number, distances between orifice and impinged plate and heat fluxes. Using SST k-w model the effect of jet Reynolds number, target spacing to jet diameter ratio (Z/d) and heat fluxes on average Nusselt number of the target plate are examined. An optimum cooling range is obtained for both 2mm and 3mm nozzle when the Z/d ratio lies between 10and 15. Correlations are proposed for Nusselt number in terms of Reynolds number and it is applicable for air as the jet cooling medium.

Introduction

In the present scenario of many advanced technologies, use of Electronic equipment has become almost inevitable. This electronic equipment plays a vital role in many critical areas of technology and resulted in high density of components in small volume. Therefore, there has been a steady increase in heat dissipation rate from electronic components for the last few decades. Optimization also led to greater power in the components and there is a considerable increase in the heat dissipation of electronic components. Various scientists and researchers mostly used the concept of forced convection flow to remove heat at the surface of the components. It is necessary not only to maintain low temperatures of components but also avoid hot spots. For the improvement in the integrated circuit design for greater heat transfer area is almost impossible. Only way out seem to be development of unconventional forced convection cooling methods like impingement jets. This method looks attractive since the cooling can be directed towards the hot components and advantage of impingement jets is that it is very effective with system, where the electronic component density is high. The importance of considering impingement jets in cooling of electronic components in which advancements in heat transfer rates relies on the ability to dissipate large heat fluxes with high yielded load and averaged heat transfer coefficients. Jet impingement cooling is a mechanism of heat transfer by means of collision of fluid molecules on to a surface. The impinging jet is defined as a high-velocity jet of cooling fluid forced through a hole or slot which impinges on the surface to be cooled, which results in high heat transfer rate between the wall and the fluid. Heat transfer takes place due to the collision of high velocity fluid molecules on to the surface. A large number of investigations have been carried out in the area of jet impingement heat transfer over the years. Most of the earlier works have focused on optimizing transport processes associated with continuous impinging jets. In that context, parameters such as the spacing between the jet outlet and the impingement surface, the magnitude of the jet velocities i.e Reynolds numbers, turbulence intensity, and the angle of impingement have been extensively studied. A detailed review of literature is presented below both the experimental and numerical studies carried out on the problem of forced convection heat transfer from jet arrays.

James W.Gauntner et.al (1972) conducted a detailed survey on the flow characteristics of a single jet impinging on a flat surface and he explained mechanism of heat transfer and also the different flow regions the effect of entrainment on the heat transfer to a heated jet was presented by Goldstein et al (1975). At jet Reynolds numbers of 61,000 and 124,000, and several nozzle-plate spacing's. Martin (1977) has conducted studies on the heat and mass transfer between gas jets and solid surfaces and proposed few empirical correlations for evaluating either local or area mean heat transfer. These correlations do not take account of an expected radial variation in the effect of Reynolds. Jambunathan and Viskanta et al. (1992) studied the heat transfer and fluid flow for impinging jets by investigating experimentally the entrainment effects of jets for circular jet. It has been shown that the jet-to-target spacing has a much greater influence on heat transfer for submerged jets than for free-surface jets. Lytel and Webb (1994) explored the consequence of low nozzle-plate spacing's on the impingement heat transfer many studies have shown little change in stagnation and average heat transfer for $Z/D < 4$, then a decrease in heat transfer as Z/D increases beyond this point. The relative consistency of heat transfer for $Z/D <4$ in the above studies can be explained by the jet impingement taking place within the potential core with its nearly uniform velocity, while the decrease in heat transfer at higher Z/D values is attributed to complete degradation of the potential core prior to impingement. The performances of free jets and sprays were compared experimentally by Kurt A.Estes and Issam Mudawar (1995) in chip cooling to ascertain the key parameters on cooling performance and developed correlations. A

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thermal characterization study of laminar air jet impingement cooling of electronic components within a CPU of a typical portable computer is reported by John R.Guarino and Vincent P.Manno (2002) H .Kimoto et al (2007) studied the effect of orifice geometry on heat transfer characteristics of impingement cooling jet. It is found that the heat transfer enhancement in impingement region strongly depends on the orifice geometry. It is found that the jet through rectangular orifice shows some peculiar characteristics due to the different spreading rate along major and minor axis.Vadiraj and prabhu (2008) conducted theoretical and experimental investigations for the local heat transfer distribution between smooth flat surface and impinging air jet from a circular nozzle. They found that an increase in Reynolds number increases the heat transfer at all radial locations for a given radial distances. An experimental investigation by Mangesh Chaudhary et.al(2009) on synthetic jet shown that a rectangular jet performs better at lower axial distances than circular jet Avinash patil et al(2011) studied the effect of variation of jet impingement distances on cooling of horizontal plate with square fins. They have found that the components shows poor performance at high Reynolds number and low z\d ratio. The reason is that air after impingement with components does not get space to spread because of close impingement. In 2011, chougule et .al. presented a numerical analysis of multi-jet air impingement on flat plate. They have found that SST k-w turbulence model produce better predictions of fluid properties in impinging jet flows. It is also shown that ,compared to multi-jet impingement ,more uniform temperature distribution is observed at all ranges of Re and Z/d.Muhammed A.R.sharif (2013) studied the heat transfer from an isothermally heated flat surface due to twin oblique slot-jet impingement. For normally impinging jet, one shortcoming is that high heat transfer is achieved only around the impingement region of the heated surface while the remaining parts of the surface under the wall jet region is subjected to significantly lower heat transfer rate .In order to achieve more distributed heat transfer along an extended heated surface, the use of twin oblique impinging jet is proposed .It is found that at 450 impingement angle, heat transfer is reasonably distributed with a corresponding decrease of about 36%overall heat transfer. To improve the design of the system using jet impingement, knowledge of the parameters affecting the heat transfer is desired. The heat transfer rates to or from a jet impingement onto a surface is a complex function of many parameters like, Reynolds number (Re), the non-dimensional nozzle-to-plate spacing (Z/d), effect of nozzle geometry, flow confinement, turbulence, dissipation of jet temperature The objective of this work is to conduct the numerical investigations on jet impingement for electronic cooling and validate the results obtained from the numerical simulation with the experimental results. The numerical and experimental study is conducted for two nozzles having diameters 2mm and 3mm.The ratio of the jet target spacing (Z) to jet diameter (d) is varied for each case and investigate the optimum range of Z/d ratio for effective cooling. To conduct a parametric study by varying the Reynolds number and its effect on the heat transfer coefficient (h) and Nusselt number (Nu) is to be investigated.

Experimental set up

Experimental system

The figure below shows the schematic diagram of the experimental set up the study is based on the steady state method. In the present study the coolant used is air. The thermal environment of the microprocessor is simulated using a copper plate of size 5cm X 5cm X 1cm with a heater placed underneath. The source of air is from a compressor. A rubber tube of 0.5cm internal diameter is used to connect the compressor outlet with a nozzle made of mild steel. Thermocouples (K type) are used to measure the temperature at various locations of the copper plate. The supply voltage is measured using a voltmeter and the current is measured using an ammeter. The jet to target or plate spacing (z) is adjusted using a hook gauge.

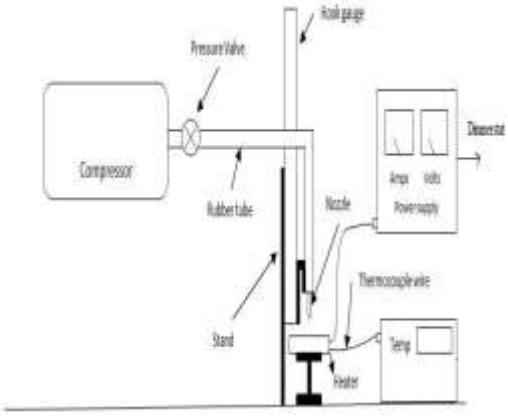

Figure1Schematic diagram of the experimental Setup

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Experimental procedure

Prior to experimental measurements the thermocouples were calibrated using a constant temperature bath (JulaboF25). Experiments have been conducted by varying the nozzle diameter, nozzle to plate spacing, jet spacing to diameter ratio and the Reynolds number.

Numerical procedure

The three dimensional model has been developed with the help of commercial package ANSYS ICEM 14.0 software .The turbulence model used is shear stress transport(SST)k-w turbulence model which is found to work the best among the available turbulence models for this configuration and is also chosen due to its simplicity, computational economy and wide acceptability The flow is assumed to be steady ,incompressible and three dimensional A heat sink of dimensions 5cm×5cm×1cm is created and placed in such a way that the .air jet impinges normally on the top surface of heat sink. . Separate models have been constructed by varying the pipe diameter as 2mm and 3mm.Here the nozzle to plate spacing (Z/d) considered are 5,10,15,25. Thus the investigation is carried out on total number of 8 models using ¼th of geometry with symmetry on two sides. Geomerties are discretized into unstructured hexahedral mesh using block-meshing strategy. A minimum grid quality of 60% is maintained throughout the analysis. The number of elements of the domain is approximately 3 lakhs and which changes slightly with geometries.

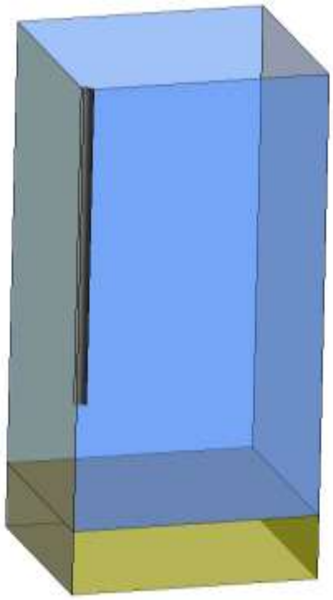

Figure 2 The computational domain/model

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Figure 3 The model with mesh

Results and Discussion

Validation of the Scheme

Studies have been conducted to see the effect of jet spacing to diameter ratio (Z\d) .Figure 4 below shows variations of temperature of the heat sink with Z\d. The results obtained from numerical investigation and experiments are shown for comparison. Here the diameter of the jet is 2 mm and the velocity of flow of air is taken as 75 m/s. The heat flux considered is 6000 w\m2. It is found that there is only marginal difference in the temperatures obtained from the studies. It is also clear from the graph that the temperature first decreases with Z/d ratio and then increases as Z\d ratio increases.

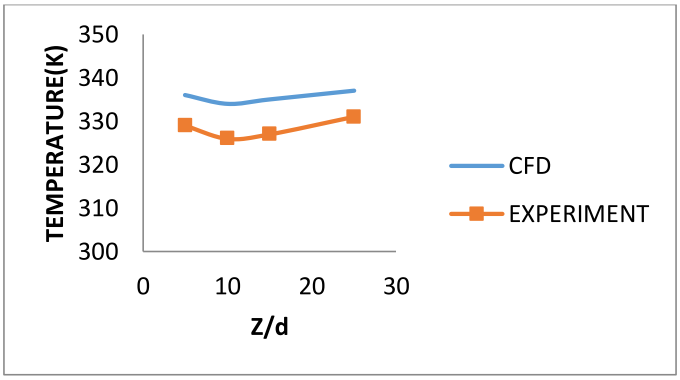

Figure 4 shows the variation of temperature of heat sink with Z/d ratio, Diameter of the jet =2mm

Effect of Z\D ratio on heat transfer

The figures given below shows the effect of Z\d on temperature. Here the diameter of the nozzle is 2mm and 3mm. The Reynolds number is maintained constant and is equal to 1370. The heat flux considered is 6000W\m2. It is clear from the graph that the temperature decreases with Z\d ratio reaches a minimum value and then increases in both the cases. It is found that the temperature of the heat sink is lower when the z/d ratio lies between 10 and 15 in both the cases.

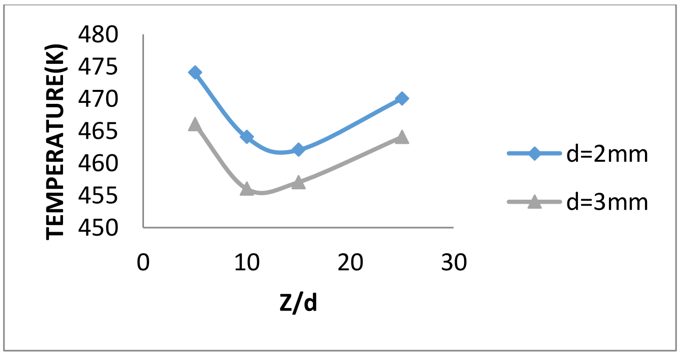

Figure 5 shows the variation of temperature of heat sink with Z/d ratio Diameters of the jet are 2mm and 3mm ,Heat flux=6000W/m^2

In case of higher Z/d ratio there is a higher momentum exchange between impinging fluid and surrounding fluid due to this the jet diameter becomes broader and spreads over more surface area. The decrease in heat transfer rate at large z\d ratio is attributed to complete degradation of potential core prior to impingement.

Effect of Reynolds number on temperature

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The figures below shows the variations of the temperature of the heat sink with Reynolds number at Z\d=10.

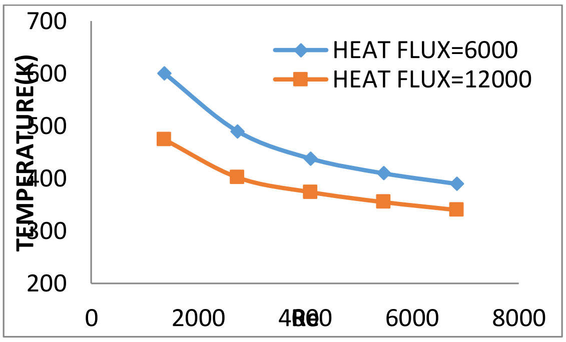

Figure 6 shows the variation of temperature of heat sink with Reynolds number Diameter of the jet is 2mm, Heat fluxes are 6000 and 12000W\m^2

Here the diameter of the jet is 2mm and the heat fluxes are 6000W/m2and12000W/m2.It is clear from the graph that as Reynolds number increases, the temperature of the heat sink decreases in both the cases. The figure below shows the variations of the temperature of the heat sink with Reynolds number at z/d=10 for 3mm diameter nozzle.

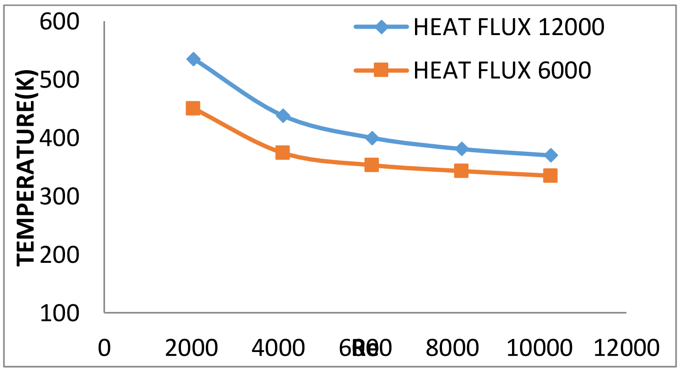

Figure 7 shows the variation of temperature of heat sink with Reynolds number Diameter of the jet is 3mm, Heat fluxes are 6000 and 12000W\m^2

It is clear from the graph that as Reynolds number increases, the temperature of the heat sink decreases. It is also observed that the chip can be maintained within the safe temperature limit when the Reynolds number is more than 10000 for 3mm diameter nozzle.

Effect of Reynolds number on nusselt number

The figure shows the variations of the average value of Nusselt number of heat sink with Reynolds number. The diameter of the jet is 2 mm.

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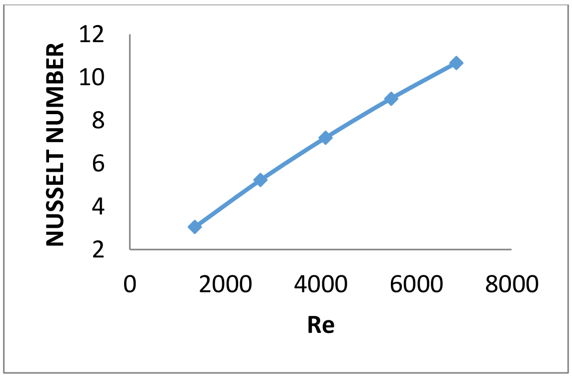

Figure8 Shows the variation of Nusselt number of the heat sink with Reynolds number Diameter of the jet is 2mm, Heat flux 12000W\m²

The Nusselt number corresponding to a Reynolds number of 1370 is 3 and corresponding value for Reynolds number of 2740 is 5.5.From the studies it is clear that Nusselt number increases by 83% if the Reynolds number is increased from 1370to 2740 at z\d=10

The figure shows the variations of the average value of Nusselt number of heat sink with Reynolds number the diameter of the jet is 3mm

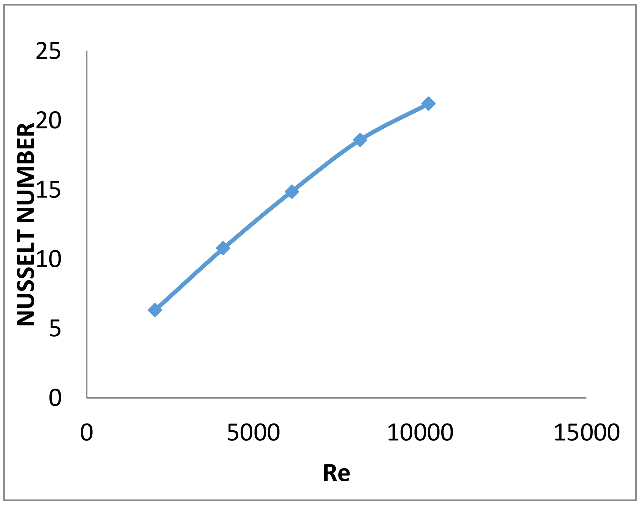

Figure9 Shows the variation of Nusselt number of the heat sink with Reynolds number Diameter of the jet is 3mm, Heat flux 12000W\m²

The Nusselt number corresponding to a Reynolds number of 2054 is 6 and corresponding value for Reynolds number of 4110 is 11.From the studies it is clear that Nusselt number increases by 83% if the Reynolds number is increased from 2054to 4110 at Z\d=10.

Correlation

The A correlation is proposed for Nusselt number in terms of Reynolds number and this is valid for air as the cooling medium. This correlation is based on the numerical experiments. The Nusselt number is calculated based on the average value of heat transfer coefficient and the heat transfer coefficient (h) is estimated using the correlation

$$h = q / (Tw-Tj)$$

Here q is the heat flux, Tw is the average wall temperature and Tj is the temperature of jet. The correlation proposed is Nu =0.011Re0.779 and this is applicable for a jet diameter of 2mm. The correlation can be used in the range of Reynolds number 1370 to 6850. For a jet diameter of 3mm, the coreration is Nu =0.019Re0.762 and it can be used in the range of Reynolds number 2054 to10270.

Conclusion

Numerical investigations have been carried out on jet impingement cooling used for cooling of electronic equipment. The simulation scheme is validated using the results obtained from experimental investigations. The following conclusions are derived

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out of the study (1) Fair agreement between the results obtained from numerical investigations and experiments (2.) From the studies it is found that for a constant jet diameter , increase in Reynolds number increases the heat transfer at all the given z\d ratios.(3) Higher heat transfer performance is observed for for both 2mm and 3mm diameter nozzles when the z\d ratio is between 10 and 15. . Correlations are proposed for Nusselt number in terms of Reynolds number.

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