CHAPTER I

INTRODUCTION

In the modern life, electronic equipments have made their way in to practically every part, which is from electronic gadgets to high power computers. Electronic components have become probable sites for high heating, because of the heat generation due to resistance to current flow. The miniaturization of electronic system has caused significant increase in the heat generation per unit volume. If not properly designed and controlled there is risk of its reliability and safety. Increased operating temperature of electronic systems exponentially increases the failure rate of electronic equipments. The effective cooling and thermal control of electronic components has become important in the design and working of electronic equipments.

1.1 NEED FOR COOLING OF ELECTRONIC COMPONENTS

The power consumption and heat dissipation from the electronic components is very vital. The restrictions in both speed and size of the electronic components compelled to upgrade the circuit design and materials to decrease power dissipation considerably through cooling technologies such as free convection and forced convection.

Large numbers of industries are interested in high speed computing. Most of the industries considered the cooling of electronic components as a thermal management problem and tried to solve it by
incorporating the heat sinks. The requirements of high speed initiated smaller devices and systems. The speed of the personal computers is increasing constantly and is reaching a point where traditional cooling methods are insufficient. Because of this concern, the electronic world is looking for new and more effective cooling techniques. The solution to this problem may be through the introduction of new materials, latest cooling technologies and change in cooling technology concepts and methods of execution.

1.2 ELECTRONIC COOLING MECHANISMS

The cooling mechanism selected for electronic equipment depends on the amount of the heat generated, safety, reliability, cost and conditions of environment. For low cost electronic equipment, inexpensive cooling mechanism such as natural or forced convection with air as the coolant is commonly used. For high cost, high performance electronic equipment, however, it is often necessary to resort to expensive and complicated cooling techniques. Some of the cooling methods used for electronic equipment include:

- Conduction cooling
- Natural and forced convection cooling
- Radiation cooling
- Liquid cooling
- Spray cooling
• Jet impingement cooling

The conduction cooling is generally used to cool electronic components by removing heat from the device through a thermal conducting material to a large part of a metal with cooling fins or a heat sink. A heat sink is a device which effectively removes the heat generated within a solid body by different coolants. The commonly used coolants are air and water, but oil and refrigerants are also used in the case of heat exchangers. Microprocessors and power handling semiconductors require a heat sink to decrease their temperature from higher heat dissipation. Conduction cooling can be easily implemented and less maintenance. But some of its demerits are the fluid effects on the heat surface and it’s essentiality to maintain intimate contact with the heat source.

Natural convection and radiation methods are commonly used to cool low power electronic systems. In natural convection, the circulation of the fluid medium is caused by buoyancy effect; that is by the difference in the densities of the cold and heated particles. Natural convection cooling is effective when the path of fluid is without obstacles. When the fluid has to pass through a constricted flow passages or when the flow has obstacles natural convection is least effective. The advantage of natural air convection is that it is free and easily available as well as attainable. But high heat removal rate cannot be obtained by this method.
When natural convection cooling is not sufficient, forced convection using a fan can be used, by blowing air through the area that houses the electronic components. A forced convection method is employed to increase the flow rate and consequently the velocity of the fluid increases the heat transfer. It means that the heat can be removed at much higher rate for a specified temperature difference between the components and the surrounding air and decreases the surface temperature of the components significantly for specific heat dissipation. In the forced convection cooling of electronic systems, radiation heat transfer is usually ignored for two reasons. First, forced convection heat transfer is usually much larger than that due to radiation. Second, the electronic components and circuit boards in convection cooled systems are mounted so close to each other that a component is almost entirely surrounded by other components at about the same high temperature.

When hot surfaces are surrounded by cooler surfaces such as the walls and ceilings of a room, the surfaces are also cooled by radiation. Radiation heat transfer is negligible for polished metals because of very low emissivity and for bodies surrounded by surfaces at about the same temperature.

Normally, gases have lower thermal conductivities than liquids. Because of this, liquid cooling is more efficient than the gas cooling. Liquid cooling methods have certain drawbacks such as corrosion, leakage of fluid, condensation and additional weight. Therefore, liquid
cooling is suitable for applications where power densities are very high for safe dissipation by air cooling. Liquid cooling systems are generally classified as indirect cooling and direct cooling systems. The electronic components in the direct cooling system are usually immersed in the liquid.

In the direct cooling, the electronic components are immersed into a thermally conductive liquid. In this case, any electronic device to be cooled is directly immersed into the thermally conducting fluid where the heat transfer between the electronic device and the liquid takes place because of conduction and convection. The cooling liquid must have desirable qualities such as high thermal conductivity for faster rate of heat disposal and low electrical conductivity. It is necessary to insulate some parts of components because liquids are usually electrically conductive; because of this reason it is preferable to have dielectric liquid. Various oils, such as silicon oil and motor oils are used successfully to cool personal computers.

Indirect liquid cooling system of electronic devices operates just like the cooling system of a car engine. In an electronic system, the heat is generated in the components. The components in this case are mounted on a metal plate made of a highly conducting material such as copper or aluminum. The metal plate is cooled by circulating cooling fluid through tubes attached to it. The heated liquid is then cooled in a heat exchanger, usually by air and is circulated by a pump through the tubes. The expansion and storage tank accommodates
any expansion and contractions of the cooling liquid due to temperature variations while acting as a liquid reservoir.

A spray cooling method may be used for high heat flux applications. In this method, a dielectric liquid is sprayed on the surface and it evaporates after impact. After the condensation the liquid may be pumped back to the spray nozzles. Commonly used spray technologies are ink jet technology and pressure nozzles. Much higher heat transfer rates are possible with spray cooling, because the vapors can be easily removed from the surface. Higher heat transfer rates than pool boiling can be achieved. A closed loop system provides protection from contamination by air, moisture or dirt. Spray cooling helps to create uniform temperatures and reduce magnetic field and electrical noise.

A jet impingement cooling is an encouraging technique which has acquired significant attention. This is a very attractive cooling method because of its ability of attaining high heat transfer rates. Different industrial uses such as cooling of gas turbine blades, annealing of metals and cooling of electronic components use this method of cooling. The capacity to disperse extremely high heat flux is possible by jet impingement, which is of specific interest in the cooling of electronic components. A liquid coolant, a dielectric fluid, is impinged on the chip surface in the form of jets/ micro jets. Cooling is achieved due to sensible heat removal. However, certain two-phase systems which remove heat through the latent heat of the fluid are
also being studied. Jet impingement cooling method can be used for an extensive range of fluids like water, air and dielectrics. The flow structure of an impinging jet consists of the free jet, stagnation flow and the wall jet regions as shown in Fig 1.1.

The free jet region is divided into flow development and fully developed regions. The width of the potential core in the free jet flow is reduced in the downstream direction because of the growth of shear flow. A shear layer exists between the potential core and the ambient fluid where the turbulence is relatively high and the mean velocity is lower than the jet exit velocity. The increase in turbulence in the shear layer entrains ambient fluid and causes the jet to spread radially. In the fully developed jet flow, the velocity profile shows the maximum velocity on the centerline. The jet flow impinging on a surface forms the stagnation flow region in which the radial velocity increases rapidly as the surface is approached. Subsequently the outward radial flow generates the wall-jet region.

The heat transfer distribution in the wall jet region is non-uniform due to complex flow patterns involving changing flow direction, acceleration, transition etc. Advanced experiments and simulations are being conducted to understand the heat transfer phenomenon in impinging jets.
Fig 1.1: Schematic diagram of flow region around an impinging jet

Fig 1.2 shows the schematic of the arrangement of the direct liquid jet impingement cooling method. Different cooling capacities are obtained using various types of liquid coolants. Dielectric liquids and refrigerants show comparatively poor specific heat properties and thermal conductivity when compared to water or other fluids. Dielectric liquids have an advantage, however in that they may be placed in direct physical contact with the electronic devices and interconnects without adverse affects such as corrosion or electric short-circuits. When compared to dielectric fluids, water provides a better specific heat and thermal conductivity.
Jet impingement cooling using air has a number of advantages over liquid cooling: Air is freely available; leakages of air do not cause any hazards and does not damage neighboring devices; in some applications air can be exhausted into the environment. Air has a much wider operating temperature range than most liquids whose performance is limited to the range spanned by their freezing and boiling point temperatures. The thermo physical properties of air render it unsuitable for removing high heat fluxes with traditional approaches.

Ahead of the limitations of air-cooling systems, researchers have developed a new technique for water cooling known as direct jet impingement. A closed system with an array of micro jets and a complex tree-like branched return structure is shown in Fig 1.3.
Water is made to pass through the back of the chip and it is sucked off again in a perfectly closed system.

Coolant does not get into the electronics on the chips because the system is completely closed. IBM has achieved cooling capacities of up to 370W/cm² with water as a cooling fluid. According to the researchers, it is more than six times beyond the present limits of air-cooling of about 75W/cm². The advantage of this system is that it requires a smaller amount of energy for pumping the fluids than the other cooling systems.

Cooling by means of jet impingement provides a desirable opportunity to conventional electronic thermal packages. Jet impingement cooling has shown prospective for high transfer coefficients. Impinging jets are best if implemented in multiple arrays for electronic cooling.
1.3 RESEARCH OBJECTIVES

The present research work was carried out for the better understanding of the multiple jet impingement method for effective applications to the high power electronic cooling problems. The jet impingement cooling method is not fully understood, and there is a strong need for systematic studies involving the various geometric and flow conditions which are of practical interest to the electronic industry.

The objectives of the present investigation are:

- To conduct experiments to cool an electrically heated test plate of size 2cmx2cm which simulates an electronic component dissipating heat in the range of 25 to 200 W/cm².

- To conduct parametric studies of the multiple water and air jet impingement cooling method for better understanding of the various parameters which influences the heat transfer process, especially at high heat dissipation rates, up to 200 W/cm².

- Comparison of multiple jet impingement cooling process with water and air as coolants.

- To develop correlations relating the important flow and geometric parameters and heat transfer for application to electronic cooling.
This investigation is expected to provide better understanding of the effects of the various flow and geometric parameters in the multiple jet impingement cooling problems. Correlations have been developed relating Nusselt number, heat flux and Reynolds numbers to facilitate application of this method to practical multiple jet impingement cooling problem.

1.4 METHODOLOGY

The methodology used in this research work is to design and fabricate the test set up to carry out the experimental investigations and to meet the objectives of the present study. Tests were conducted on a 2cmX2cm electrically heated copper plate which simulates a typical electronic component. The effects of the following test parameters were examined.

- Heat flux
- Jet diameter
- Reynolds number
- Flow rate
- Distance between test surface and jet exit
- Horizontal and vertical positioning of the jets

Tests were conducted with water and air as coolants. Results of the experimental investigations, development of correlations and
comparisons of the present results with the data available in the literature are presented.

1.5 THESIS ORGANIZATION

This thesis is organized into the following seven chapters.

- Chapter 1 highlights the importance and role of various electronic cooling technologies and the jet impingement cooling method.

- Chapter 2 describes the review of literatures, in which the work of various investigations related to the jet impingement cooling method was discussed briefly.

- Chapter 3 is focused to experimental procedures, details of the experimental setup, procedures for conducting the experiments, data acquisition procedures and the uncertainty analysis of the experimental data.

- Chapter 4 covers the results and discussions of heat transfer enhancement using impingement of multiple water jets.

- Chapter 5 contains the results and discussions of enhancement of heat transfer using impingement of multiple air jets.
• Chapter 6 includes the comparison of the results obtained with multiple water and air jets and correlations on heat transfer process. Comparisons of the present results with available data in the literature are also presented.

• Chapter 7 comprises of the conclusions from this research work and recommendations for the future work.