PENGGUNAAN JET PENGUDARA UNTUK PENYEJUKAN KOMPONEN ELEKTRONIK

(ELECTRONIC COMPONENT COOLING USING JET AERATION)

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Mac 2005

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ACKNOWLEDGEMENT

I would like to take this opportunity to thank all the people that have helped me in ensuring that I could complete my project. My first acknowledgement goes to my family whom gave me encouragement and motivation in order to complete this project.

A huge vote of thanks goes to my final year project supervisor Associate Professor Afzal Ahmed for guiding me through this project. His guidance was invaluable and really helped my project progress.

I would like to express my gratitude to the technical staff whom helped me in the lab work and experiment running. I would like to thank Mr. Zalmi, Mr.Hashim, Mr.Abdul Latif and the other technical staff for their help.

There are also acknowledgements for all my friends who were a pillar of strength not only during the duration of this project but also during my university life.

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ABSTRACT

Electronic components play a pivotal part in many industries around the world. They range from the telecommunications industry all the way to the automotive industry. The number of components on a chip has increased many folds and the chip size has decreased through years of research. This is done to ensure more memory can be kept in a computer. But, this has caused an increase of heat generation as there are too many components on a single chip. Thermal management has become very important as the reliability of the component is very important in ensuring greater efficiency. Many electronic component cooling methods have been developed to fasten electronic component cooling. For this project, a method called immersion cooling will be used. However a new way of immersion cooling will be introduced called jet aeration. Jet aerators were used as a device to cool the liquids. The liquids will circulate as one system. The nozzle with a particular velocity of the liquids will hit the water being used. A plunging jet aerator is simply a liquid jet plunging into a pool of liquid and thereby entering the surrounding air into the liquid pool as swarm bubbles. Various sizes of nozzles have been used to investigate the heat dissipated to the air due to the formation of the bubbles. Multi jets were also used to find out whether it can promote better cooling. Comparisons were done through calculations and representations using graphs.

ABSTRAK

Komponen elektronik memainkan peranan yang penting di kebanyakan industri di dunia. Penggunaan komponen elektronik merangkumi industri telekomunikasi sehingga industri automotif. Bilangan komponen di dalam satu cip telah bertambah dengan mendadak sedangkan saiz cip tersebut dikurangkan. Ini dilakukan untuk menambahkan keupayaan menyimpan memori di dalam computer. Namun begitu, ini telah membawa kepada masalah penghasilan haba yang belebihan. Pengurusan haba menjadi sangat penting disebabkan reliabiliti komponen sanagt penting di dalam memastikan kecekapannya. Banyak cara penyejukan komponen elektronik telah diperkenalkan untuk mempercepatkan penyejukan. Cara penyejukan yang dipanggil penyejukan perendaman digunakan bagi projek ini. Projek ini memperkenalkan cara penyejukan perendaman yang baru menggunakan jet pengudara. Jet pengudara digunakan sebagai peralatan untuk menyejukkan komponen. Cecair akan berkitar di dalam satu sistem. Nozel dengan kelajuan yang tertentu akan mengena air yang digunakan. Pancutan jet pengudara adalah pancutan ke atas permukaan cecair yang akan menghasilkan buih apabila pancutan ini mengena permukaan cecair. Nozel dengan pelbagai saiz digunakan untuk mengetahui haba yang terbebas ke udara yang disebabkan oleh penghasilan buih di dalam cecair. Penggunaan beberapa jet serentak juga diujikaji bagi menentukan sama ada keasan penyejukan adalah lebih baik. Perbandingan dilakukan melalui pengiraan dan ditunjukkan melalui graf.

CHAPTER 1

1.0 INTRODUCTION

1.1 GENERAL

Electronic equipment has made great inroads to modern life. The overall reliability of a system relies heavily on the reliability of the electronics of the system. Electronic components depend on the passage of electrical current to perform their duties and they become potential sites for excessive heating since the current flow through a resistance is accompanied by heat generation. Continued miniaturization of electronic systems has resulted in dramatic increase in the amount of heat generated per unit volume. High rates of heat generation result in high operating temperatures for electronic equipment which affect its safety and reliability unless it is properly designed and controlled. Cooling electronic systems is the focal point of the design process and the key to a successful product launch.

1.2 BACKGROUND

The field of electronics deals with the construction and utilization of devices that involve current flow through a vacuum, gas or a semiconductor. The creation of the vacuum tube by Thomas Edison in 1883 really started this field. However, vacuum tubes had high failure rates and the computers developed through it had poor reliability and required large amounts of power.

The invention of the bipolar transistor in 1948 was a great step for the electronics industry. Transistor circuits performed the functions of the vacuum tubes with greater reliability, while occupying negligible space and power compared with vacuum tubes. The introduction of silicon transistors replacing germanium ones enabled them to operate at temperatures above 100°C. The next great stride came with the introduction of integrated circuits (IC) where many different components are placed in a single chip. The continued miniaturization of electronic components has resulted in medium-scale integration (MSI) in the 1960s with 50-1000 components per chip, large-scale integration (LSI) in the 1970s with 1000-100,000 components per chip and very large-scale integration (VLSI) in the 1980s with 100,000 to 10,000,000 components per chip. The graph below shows this fact.

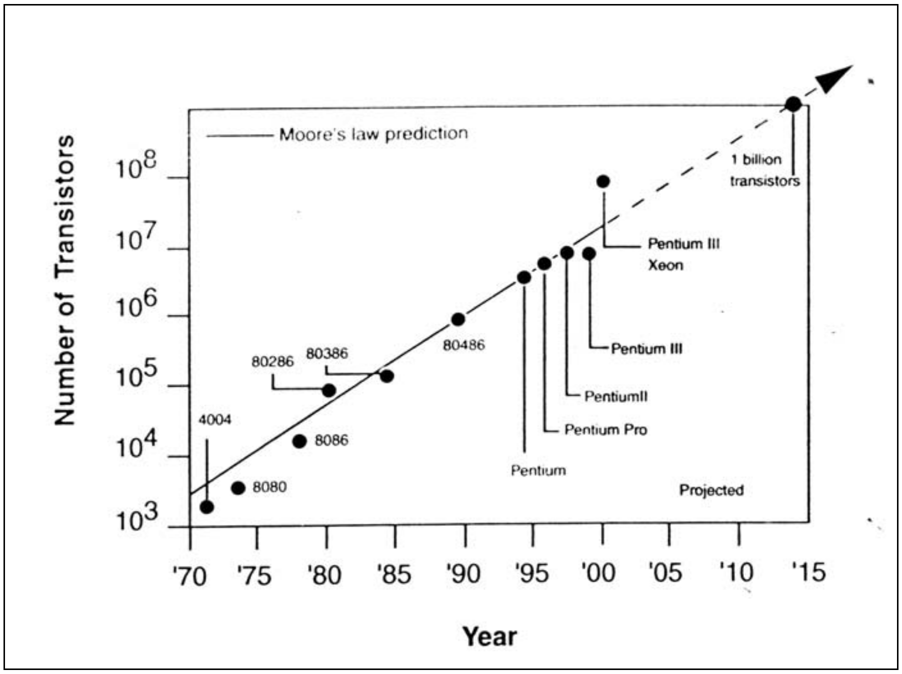

Figure 1.1 The IC integration every 18 months according to Moore's Law [1]

The development of the microprocessor in the early 1970s was a big breakthrough. The accompanying rapid development of large-capacity memory chips in this decade made it possible to introduce capable personal computers for use at work or home at reasonable prices.

The current flow through a resistance is always accompanied by heat generation in the amount of I^2R where I is the electrical current and R is the resistance. Although one transistor generates a low amount of heat, millions of such components packed in a small volume generates heat at high levels that affects the reliability of the electronic device. Heat is generated in a resistive element as long as there is a current flow. This creates a heat build-up and a subsequent temperature rise at and around the component. The temperature of the component keeps increasing till the component is destroyed unless heat is transferred away from it. The failure rate of electronic devices increases almost exponentially with the operating temperatures as shown in figure below.

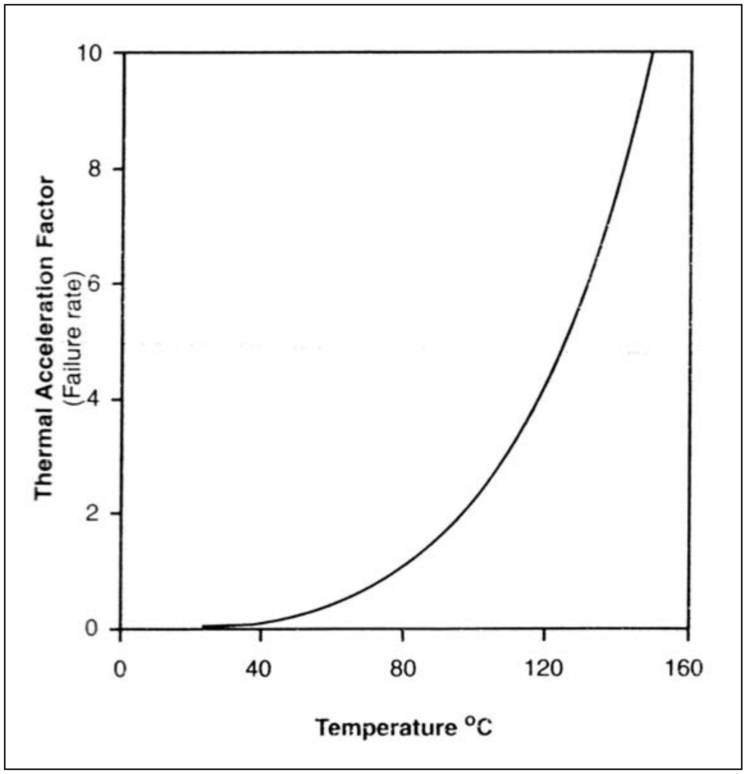

Figure 1.2 Effect of temperature on failure rate [1]

Therefore, cooling electronic systems is the focal point of the design process and the key to a successful product launch. Many options to attain successful operation are available that range from passive cooling to active cooling. From a market success stand point, the solution with the least operation and maintenance cost is the most desirable one. However, systems operation (device frequency) and packaging constraints often dictate solution alternatives that may not fit the least cost and maintenance model. Therefore, a review of commercially available cooling technologies will be made.

The cooling technology can be divided into two broad categories:

- Passive cooling- where nature does the fluid movement (e.g. natural convection) or energy is transported by conduction and/or radiation heat transfer.

- Active cooling- where the fluid motion is assisted by an external source, a fan in a forced air cooled system, or pump and fan of an immersion or refrigeration cooled system.

It is clear that active cooling is the most desired solution from the product stand point since it has the least implementation-cost and requires, effectively, no maintenance. However, as the power dissipation increases and packaging space becomes limited, passive cooling begins to take hold and becomes the method of choice despite its higher implementation-cost and concerns for the operational reliability.

1.3 COOLING TECHNOLOGIES

There are many cooling technologies such as heat sinks, thermal vias, heat pipe cooling, jet impingement cooling, immersion cooling and thermoelectric cooling. Heat sink is the most reliable and well-designed electronic device can malfunction or fail if it overheats. When thermal issues are left until completion of the design, the only remaining solution may be a costly custom heat sink that requires all the space available. Incorporating a heat sink or a fan into a product after it is fully developed can be expensive, and still may not provide sufficient cooling of the device.

The increased cooling provided by adding a fan to a system makes it a popular part of many thermal solutions. Increased airflow significantly lowers the temperature of any critical device, while providing additional cooling for all the devices in the enclosure. Increased airflow also increases the cooling efficiency of heat sinks, allowing a smaller or less efficient heat sink to perform adequately.

Passive heat sinks use a mass of thermally conductive material to move heat away from the device into the air stream, where it can be carried away. Heat sink designs include fins or other protrusions to increase the surface area, thus increasing its ability to remove heat from the device. Segmenting the fins further increases the surface area to get more heat removal in the same envelope, although often at the expense of a large pressure drop across the heat sink. Pin-fin and cross-cut fin heat sinks are examples of this solution. Passive heat sinks optimize both cost and long-term reliability.

When a passive heat sink cannot remove heat fast enough, a small fan may be added directly to the heat sink itself, making the heat sink an active component. These active heat sinks, often used to cool microprocessors, provide a dedicated air stream for a critical device. Active heat sinks often are a good choice when an enclosure fan is impractical. As with enclosure fans, active heat sinks carry the drawbacks of reduced reliability, higher system cost, and higher system operating power.

In the 1990's, with the advent of surface mounting of semiconductor packages, multilayer printed circuit boards and multilayer substrates for Ball Grid Array packages were introduced. In order to create electrical interconnections between the different metal layers, vias are fabricated. In most cases vias are hollow cylinders of copper, created by plating a thin layer on the inside surface of a hole drilled through the laminated metal and dielectric layers. As was soon discovered, vias not only provided an electrical path through the dielectric layers but also an enhanced thermal path for heat flow.

A die is adhesively bonded to a laminate consisting of a BT substrate sandwiched between two copper layers. The two metal layers are electrically connected together by a matrix of vias.

The heat is generated uniformly on the surface of the die. The heat is intercepted by the top metal plane. Because of the high thermal conductivity of the copper compared to that of the BT, most of the heat will converge to the via location, flow along the length of the via, and then diverge upon reaching the bottom metal plane. A small portion of the heat will flow directly from the top plane to the bottom one through the substrate.

The heat is then removed from the bottom metal layer with a thermal efficiency that would be representative of an array of solder balls covering 20% of the surface of the bottom layer. This is represented in the model as an effective heat transfer coefficient applied to the bottom surface. Thermal vias can be a very effective design feature for reducing the through-thickness thermal resistance of multilayer substrates. The use of the circular fin equation to account for the spreading of heat in the laminate metal layers leads to greater accuracy than that obtained with 1-D calculations. The spreading effect due to the silicon die itself should be taken to account for further accuracy.

Heat pipes, a type of phase-change recirculating system, use the cooling power of vaporization to move heat from one place to another. Within a closed heat removal system, such as a sealed copper pipe, a fluid at the hot end (near a device) is changed into a vapor. Then the gas passes through a heat removal area, typically a heat sink using either air-cooling or liquid-cooling techniques. The temperature reduction causes the fluid to recondense into a liquid, giving off its heat to the environment. A heat pipe is a cost-effective solution, and it spreads the heat uniformly throughout the heat sink condenser section, increasing its thermal effectiveness.

Jet impingement has been used in applications where high convective heat transfer rates are required. In confined jet impingement, the spent fluid from a single nozzle or an array of nozzles, flows outward in a narrow channel bounded by the plate containing the nozzle and impingement surface. Air jet impingement, especially using multiple jets in conjunction with surface enhancement, is an attractive option for the cooling of advanced electronic components, since heat flux levels similar to liquid cooling can be achieved by this means.

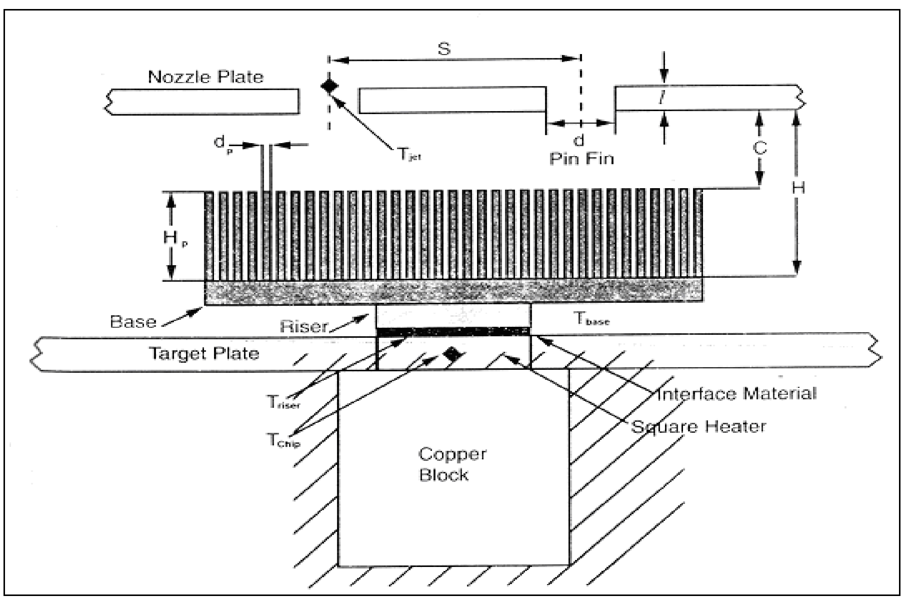

Figure 1.3 Jet impingement cooling [1]

Since the late 1940’s, direct immersion has been used in low boiling point dielectric liquids for thermal control of operational electronic components. Due to elimination of solid-solid interface resistance, immersion cooling is well suited to the cooling of advanced electronic systems now under development. Most practical immersion cooling systems operate in a loop where the vapor of the dielectric liquid is condensed and returned to the electronic enclosure. Two such systems are shown in the figures below. For figure 6a, a remote condenser, external to the electronic enclosure and cooled by water, air or other fluid condenses the vapor leaving the enclosure and directs the condensate back to the enclosure for reuse. In figure 6b the condenser is located in the vapor space above the liquid, producing a more compact immersion module design and then condensate drips back into the liquid.

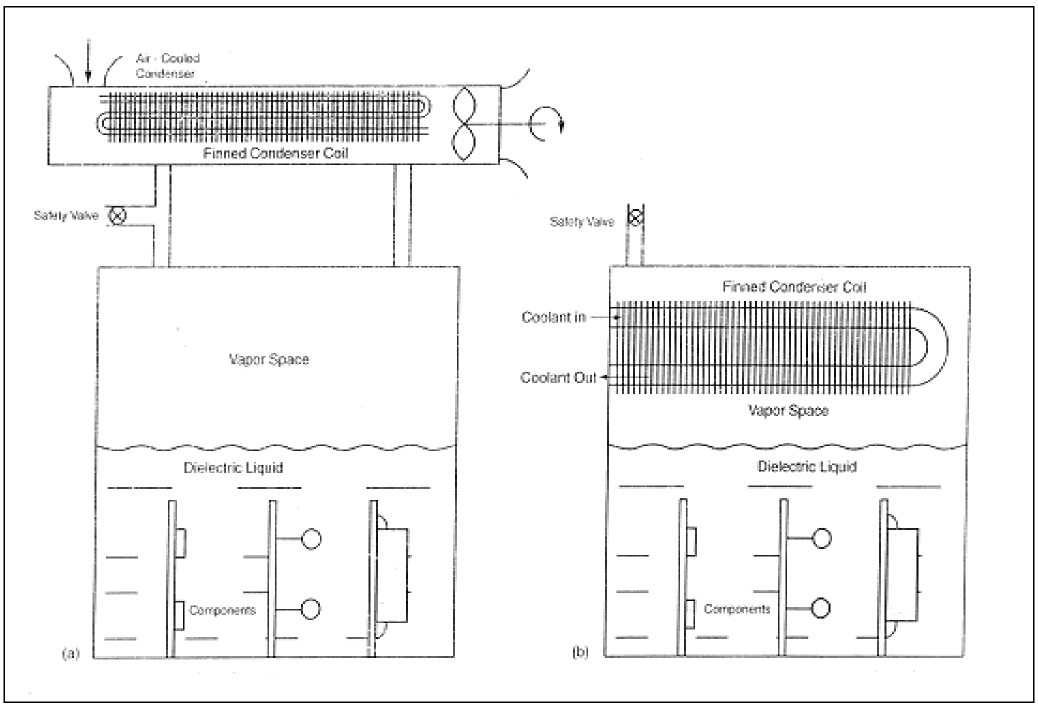

Figure 1.4 Two closed loop immersion cooling systems [1]

Due to the high solubility of air in the perfluorinated fluorocarbons often used as immersion cooling liquids, it is not uncommon for vapor space condensers to be adversely affected by a buildup of noncondensable gas. Such difficulties can be avoided by submerging the condenser in the liquid as shown in figure 1.5a. The circulating water through the tubes absorbs the heat from the dielectric liquid thus subcooling the liquid. Any vapor bubbles generated by boiling on the component surfaces collapse and condense in the subcooled liquid. The side and top walls of the liquid-filled enclosure are further modifies to serve as submerged condenser which can then be externally air-cooled or liquid cooled as shown in figure 1.5b.

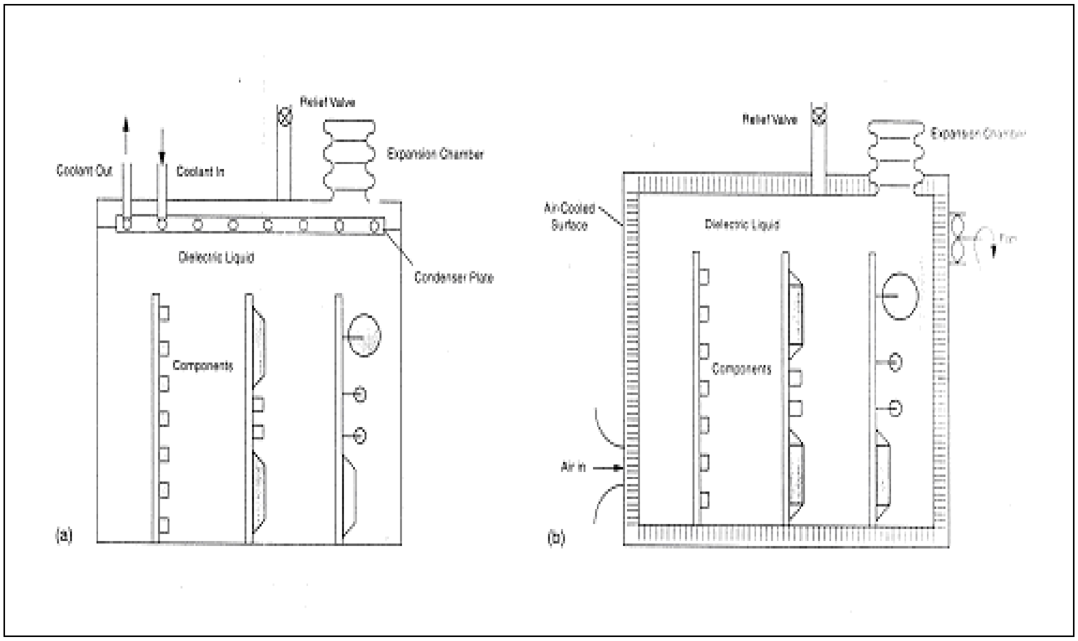

Figure 1.5. Submerged condenser immersion cooling systems [1]

Immersion cooling is one of the most reliable technologies since all the components reside in a completely sealed liquid environment.

Thermoelectric coolers offer the potential to enhance the cooling of electronic module packages to reduce chip operating temperatures or to allow higher module powers. Thermoelectric coolers also offer the advantages of being compact, quiet, free of moving parts, and their degree of cooling may be controlled by the current supplied.

A proposal was made to mount high power components on a diamond substrate, which would be the top or cold side substrate of a thin film thermoelectric cooler. There was the possibility of achieving cooling power densities above 100 W/cm^2.

Many thermal solutions exist to maintain high reliability of electronic components. Leaving thermal considerations until the end of the design process can result in the need for larger or more expensive thermal management components. The need to add an active thermal component may increase the system cost while compromising reliability. By considering all the options during the initial board design, the system designer can reduce overall thermal management costs, optimize board layout, and maintain high system reliability.

1.4 OBJECTIVE

The objective of this project is to introduce a new method for cooling called jet aeration. The proposed method is simple, economical, flexible and copes with high heat fluxes. A liquid jet impinges on the surface of the liquid. At the plunge point of the jet a dent is formed which is successively closed by the surface deformation of the jet. This traps the air which gets entrained in the bulk liquid by the penetrating jet. The air entrained is dispersed in the form of bubbles by the shearing action of the jet. This air can be used to cool the hot liquid heated by the heat dissipating electronic component.

The experiments will be conducted with different parameters to find out the cooling effectiveness. The parameters are

1. Different flow rates such as 3, 5 and 10G/min
2. Different nozzle sizes 5, 10, 15 and 20mm
3. Different number of jets or multiple jets

1.5 SCOPE

The temperature difference is recorded and corresponding calculations are done. The scope of this project is Electronic Packaging, Heat Transfer and Fluid Mechanics. The calculations done pertaining to the mentioned fields will help determine the effectiveness of the experiment. The calculations done will be velocity of the jet, Reynold's number, heat dissipated, air entrainment and power of jet.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 IMMERSION COOLING

For this project, the cooling method used will be immersion cooling. An article titled 'Direct liquid immersion cooling for high power density microelectronics' was written in 1996 by Robert E. Simons. This article discussed about the application of liquid cooling for microelectronics which may be categorized as either indirect or direct. Then it mentioned about coolant considerations for the cooling applications. There was also information on modes of heat transfer which could be natural convection, forced convection or boiling and application examples.

Indirect liquid cooling is one in which the liquid does not contact the microelectronic chips, nor the substrate upon which the chips are mounted. In such cases a good thermal conduction path is provided from the microelectronic heat sources to a liquid cooled cold-plate attached to the module surface[2]. Since there is no contact with the electronics, water can be used as the liquid coolant, taking advantage of its superior thermophysical properties.

Direct liquid cooling may also be termed direct liquid immersion cooling, since there are no physical walls separating the microelectronic chips and the surface of the substrate from the liquid coolant. This form of cooling offers the opportunity to remove heat directly from the chip(s) with no intervening thermal conduction resistance, other than that between the device heat sources and the chip surfaces in contact with the liquid. Direct liquid immersion cooling offers a high heat transfer coefficient which reduces the temperature rise of the chip surface above the liquid coolant temperature. As shown in Appendix A, the relative magnitude of a heat transfer coefficient is affected by both the coolant and the mode of convective heat transfer (i.e. natural convection, forced convection, or boiling). Water is the most effective coolant and the boiling mode offers the highest heat transfer coefficient[2]. Direct liquid immersion cooling also offers greater uniformity of chip temperatures than is provided by air cooling.

The selection of a liquid for direct immersion cooling cannot be made on the basis of heat transfer characteristics alone. Chemical compatibility of the coolant with the chips and other packaging materials exposed to the liquid must be a primary consideration. Water is an example of a liquid which has very desirable heat transfer characteristics, but which is generally unsuitable for direct immersion cooling on account of its chemical characteristics. Fluorocarbon liquids (e.g. FC-72, FC-86, FC-77, etc.) are generally considered to be the most suitable liquids for direct immersion cooling, in spite of their poorer thermo-physical properties. The thermal conductivity, specific heat, and heat of vaporization of fluorocarbon coolants are lower than water. These coolants are clear, colorless per-fluorinated liquids with a relatively high density and low viscosity[2]. They also exhibit a high dielectric strength and a high volume resistivity. . The comparison of thermophysical properties of fluorocarbon and water are shown in Appendix B.

These liquids should not be confused with the "Freon" coolants which are chlorofluorocarbons (CFCs). Although some of the "Freons" (e.g. R-113) exhibit similar cooling characteristics, concern over their environmental effect on the ozone layer preclude their use.

The convective heat transfer processes upon which liquid immersion cooling depends may be classified as natural convection, forced convection, or boiling modes. As in the case of air cooling, natural convection is a heat transfer process in which mixing and fluid motion is induced by coolant density differences caused by the heat transferred to the coolant. Natural convection would typically be employed within a closed container to transfer heat from chips or modules to liquid, and then from the liquid to the walls of the container. Heat could then be transferred from the walls to outside air by natural or forced convection.

Higher heat transfer rates may be attained by utilizing a pump to provide forced circulation of the liquid coolant over the chip or module surfaces. This process is termed forced convection; and as with air cooling, the allowable heat flux for a given surface-to-liquid temperature difference can be increased by increasing the velocity of the liquid over the heated surface. Boiling is a complex convective heat transfer process depending upon liquid-to-vapor phase change by the formation of vapor bubbles at the heated surface. It is commonly characterized as either pool boiling (occurring in a stagnant liquid) or flow boiling.

As with indirect liquid cooling, these applications have been almost exclusively in the large mainframe and supercomputer arena. This is not surprising, since this has been the microelectronics technology sector with the highest packaging densities and concentration of heat.

This article has relevance to my project since immersion cooling is the main topic. The use of a relevant coolant is also discussed and is important when I run the experiments.

2.2 USAGE OF PUMP

In order to run the experiments, a choice had to be made between the use of a water pump or whether there could be other methods that do not require pumps. An article was written in a forum and describes the importance of water cooling. This article which was produced in 2003 and is titled 'CPU Cooling Challenge - Time For Water??'. It was written by Joe Citarella. It stated about pumpless methods available in the market.

Current materials (copper and aluminum) are about stretched to the limit of what they can efficiently handle. While water cooling is currently more expensive and complex, the increased attention it appears to be getting from larger companies now entering the field may alter this markedly. As larger companies with more extensive financial and engineering resources enter the market, more effective solutions may see the light of day.

In addition, suppliers of key components, such as water pumps and radiators, are beginning to take notice of this market and we can expect more products specifically geared for CPU cooling. One of the issues water cooling faces is the need for an active pump. One technology that is pumpless is the Thermosyphon. It is a heat transport system that uses gravity to transfer heat from the source to sink[3]. It requires no pump and reservoir. It can be made compact such that the evaporator is the size of the module.

The attraction of a pumpless system is clear: water pumps are relatively expensive and a clear "failure point" in a water cooling system. If it could be eliminated, costs drop markedly. One key point is that vaporizing the liquid is required by the CPU; this may require a liquid with a lower boiling point than water[3]. The design challenge then becomes selecting the right fluid for the application.

As CPU frequencies increase and size shrinks, escalating chip power densities will inevitably drive CPU cooling to more efficient solutions.

Water cooling has become a very important aspect of cooling. The experiments that will be carried out will use this technology although a pump will be used since a pumpless method is still new and not yet cost effective.

2.3 USAGE OF WATER

There are so many liquids which could be used to run the experiments. The effect of these equipments on cooling and its compatibility with electronic components is a very important factor in choosing the right fluid. An article was written in a forum. It was written by Scott Morrison in 2000 and is titled ‘Cooling - Methods and Madness – III’. It talks about the various liquids which can be used for cooling methods such as water, perfluorocarbons (PFCs) and their cousins, perfluorinated hydrocarbons (PFHCs). It also talks about their advantages as well as disadvantages.

In direct immersion cooling, the system components (at least the ones without moving parts) are submerged in a non-conductive liquid. The liquid is generally circulated within the enclosure to enhance cooling, and also pumped out of the enclosure for cooling. In the case of the Cray, these were large spill towers and a heat exchanger. Within the enclosure, cooling of specific components could be enhanced by directing freshly cooled fluid to the hotspots with directed flow from jets or nozzles.

The selection of a cooling fluid is the single most critical item. There are families of chemicals called perfluorocarbons (PFCs) and their cousins, perfluorinated hydrocarbons (PFHCs), which are long chains of carbon and fluorine, which are ideal for this.[5] Their conductivity and dielectric strength are several orders of magnitude higher than that of air. While they conduct heat only about a quarter as well as water does, they are still better than air by a factor of five or six times.

The advantages of this method of cooling should be pretty obvious. The high cooling potential of the cooling fluids remove the need for complex, dangerous to your system watercooling equipment, and you don't have to have huge complexes of fans[4]. One single large fan through a radiator could cool your entire system.

There are disadvantages of course, and some technological hurdles to overcome as well. The properties of PFCS, for instance, provide some unique challenges. It is not environmentally friendly. But the chemicals evaporate relatively easily, and they hang out in the atmosphere for a long time. They are biologically non-reactive but they are also big long chains of carbon and fluorine. They are greenhouse gases, that is, they promote global warming, and they do it almost as much as CFCs (which destroy ozone and causes warming). PFHCs don not have this problem at all, decaying quickly in the atmosphere. Another disadvantage is the fact that both PFCs and PFHCs have virtually no surface tension, and have an incredibly low viscosity. A pipe joint or pump seal that could hold water at 10 atmospheres could leak these fluids. These are all issues that can be overcome, though, through careful sealing of the enclosure and low pressures.

An issue unique to using PFHCs is that it is a solublizing hydrocarbon. That means other hydrocarbons are soluble in PFHC. If you were to use some hydrocarbon based plastics, or plastics with hydrocarbon plasticizers, it slowly leaches away the plasticizer, or decays the plastic[4]. Once the fluid is saturated with the plastics, it may redeposit it on surfaces, or worse, builds up phenomenal static charges until it discharges through a conductive path. The final disadvantage is probably price. Building your PC into a welded acrylic aquarium probably is not cost friendly.

Although there are advantages using PFC and PHFC, there are many disadvantages too. Therefore the most suitable liquid used should be water. The experiment will be conducted using water.

2.4 USAGE OF JET

It has been agreed that immersion cooling will be used. However, there are many ways of applying this cooling method. An article titled 'Enhanced Boiling Heat Transfer by Submerged, Vibration Induced Jets' was done in 2003 by Steven W. Tillery, Marc K. Smith, Ari Glezer and Sam N. Heffington. This article was done by NASA research team. It talks about two phase heat transfer which is suitable with immersion cooling. The goal of their research is to develop a new two-phase heat transfer cell based on a submerged vibration-induced bubble ejection process (VIBE) in which small vapor bubbles attached to a solid surface are dislodged and propelled into the cooler bulk liquid by a turbulent jet.

Two-phase heat transfer, involving the evaporation of a liquid in a hot region and the condensation of the resulting vapor in a cooler region, can provide the large heat fluxes needed for microelectronic packages to operate at acceptable temperature levels. By changing the phase of the working fluid, a two-phase heat transfer cooling scheme supports high heat transfer rates across moderately small temperature differences[5]. Immersion cooling, which involves the pool boiling of a working fluid on a heated surface, is an example of a two-phase cooling technology used in microelectronic applications.

The performance of an immersion cooler at the high heat fluxes required of applications in the future is possible because of the nucleate boiling that occurs with direct contact between the liquid and the hot electronic package. A key reason for the efficient heat transfer that occurs during boiling is that buoyancy forces (i.e., gravity) remove the vapor bubbles generated at the heated surface. When the heat flux from the surface is increased past a critical level, a large increase in temperature occurs due to an insulating layer of film that forms on the surface[5]. This transition from nucleate to film boiling occurs at much lower heat fluxes in microgravity because buoyancy forces are almost negligible.

The goal of this research is to develop a new two-phase heat transfer cell based on a submerged vibration-induced bubble ejection process (VIBE) in which small vapor bubbles attached to a solid surface are dislodged and propelled into the cooler bulk liquid by a turbulent jet. The turbulent jet is formed by driving an 18.2 mm diameter brass piezoelectric diaphragm so that its surface acceleration exceeds 3200 g. With this surface acceleration, pressure oscillations in the liquid near the surface of the diaphragm result in the time-periodic formation and collapse of cavitation bubbles that entrain surrounding liquid and generate a turbulent jet directed normal to the surface of the diaphragm and flowing away from its center. Initial tests indicate that when the diaphragm is positioned approximately 5 to 10 mm away from a heated surface, the direct impingement of the turbulent jet onto the surface will dislodge small vapor bubbles and induce convection of cooler bulk fluid over the surface. These two effects lead to a large increase in heat transfer.

The first heat transfer data showing the effect of the VIBE process was obtained using a thermal test die and a diaphragm located at an optimal distance away from and parallel to the heated surface. The heat flux from the test die was slowly increased and the surface temperature of the die was measured. At the highest die temperature recorded of 120 °C, the heat flux from the surface increased by 230% when the VIBE jet was on compared to the same conditions with no jet. This large increase demonstrates the attractiveness of this simple VIBE process for microelectronic cooling and for other applications as well.

The project will be done with jets as an idea from this article.

2.5 MAIN COMMENTS

Immersion cooling will be the most suitable technology for cooling methods in the future and it will be used for my project. The use of water will be most suitable for the cooling method. A pump will be used to enhance water cooling since pumpless methods are relatively new. The experiment will also use nozzles as jets and different nozzle sizes will be used to see their effectiveness. There will also be applications using a few nozzles together to see their effectiveness. The full experiment will be called jet aeration as there will also be an effect of ambient air which will help further cooling.

CHAPTER 3

3.0 METHODOLOGY

3.1 GENERAL

This experiment was done last year and therefore the basic setup was already there. Modifications were done to the setup and measurement apparatus was also different. The basic setup consists of a base which will house the tank. The tank is connected to a motor which pumps water and the measurement is taken by a flow meter. This is connected to a nozzle. A nozzle will shoot the water at a high velocity which will hit the water in the tank.

3.2 PIPING SYSTEM

The piping system was completely changed. Last year steel was used for half the system and Polyvinyl Chloride (PVC) for the other half. This year, the whole piping system comprised of PVC. This was due to the fact that PVC is cheaper than steel and that PVC cannot accommodate temperatures at approximately 140°C although the maximum temperature of the apparatus will not exceed 60°C.

Figure 3.1 The connection of the whole experiment

Figure 3.2 The connection of the experiment in another angle

3.3 MEASUREMENT SYSTEM

Last year, an orifice plate was used along with a manometer to do all the measurements together with an anemometer. This year, a flow meter was used to measure the volumetric flow rate. A thermometer was used to measure the water temperature in the tank. A velocity meter was used to measure air velocity.

3.4 NOZZLE

Last year, there were four nozzles which were used that were 5, 10, 15 and 20mm. This year the existing four nozzles will be used. However, for the 5 and 10mm nozzles, extra holes will be made. Four holes were made for the 5mm nozzle to study effects of multi jets. Two jets were made for the 10mm nozzle to study their effectiveness. The extra holes were made using the hydraulic drilling machine in the lab.

Figure 3.3 The hydraulic drilling machine used to make holes

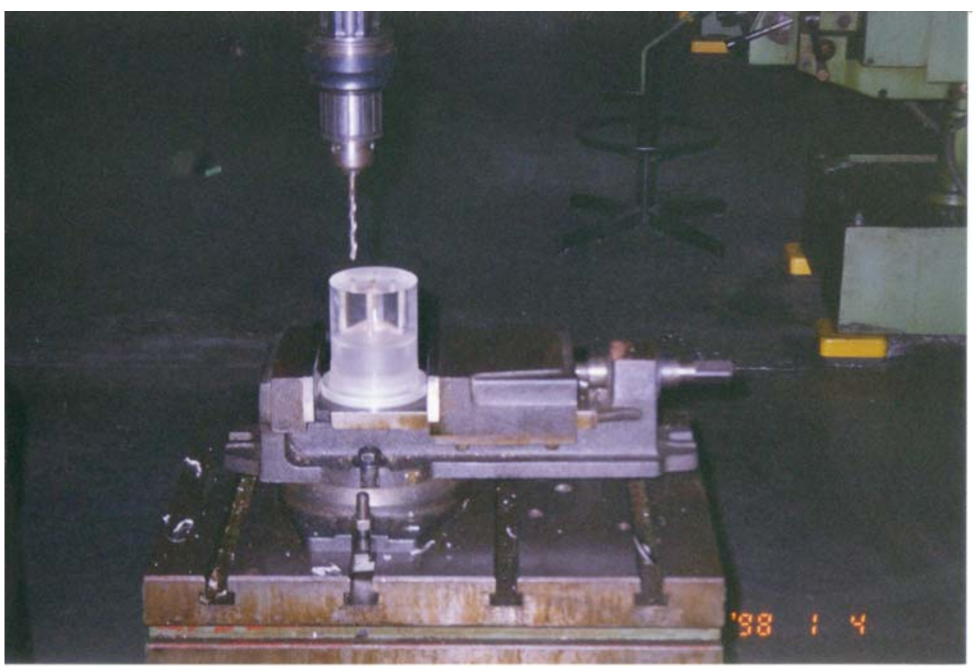

Figure 3.4 The process of making the hole

Figure 3.5 Some of the nozzles used during the experiment

3.5 EXPERIMENTAL PROCEDURE

The experimental procedure which will be applied is same for all the experiments. Water is filled in the tank to a certain level. Then, the tank is heated up. This is done using a burner. The heating is stopped once the temperature reaches 55°C. The motor is started and water is pumped to the nozzle which hits the water at a certain velocity. The gate valve controls the level of the flow rate. For 120 minutes, the temperature drop is recorded for five minute durations. The air velocity is recorded at the beginning of the experiment. After two hours, the motor is stopped and the next experiment continues.

The experiment must be conducted carefully without the use of excessive flow rates as this can cause leakages and cause the motor to get spoilt. This is especially the case with the nozzle size 5mm which must be handled carefully due to the high pressures involved. The tank water must be cleaned as soon as signs of rusty water appear. This is because rusty water could affect the experimental values obtained. The use of the velocity meter to take readings must be carefully done as the meter is very delicate and mishandling can cause damage.

Figure 3.6 Flow of water from the nozzle for 3 5mm jets

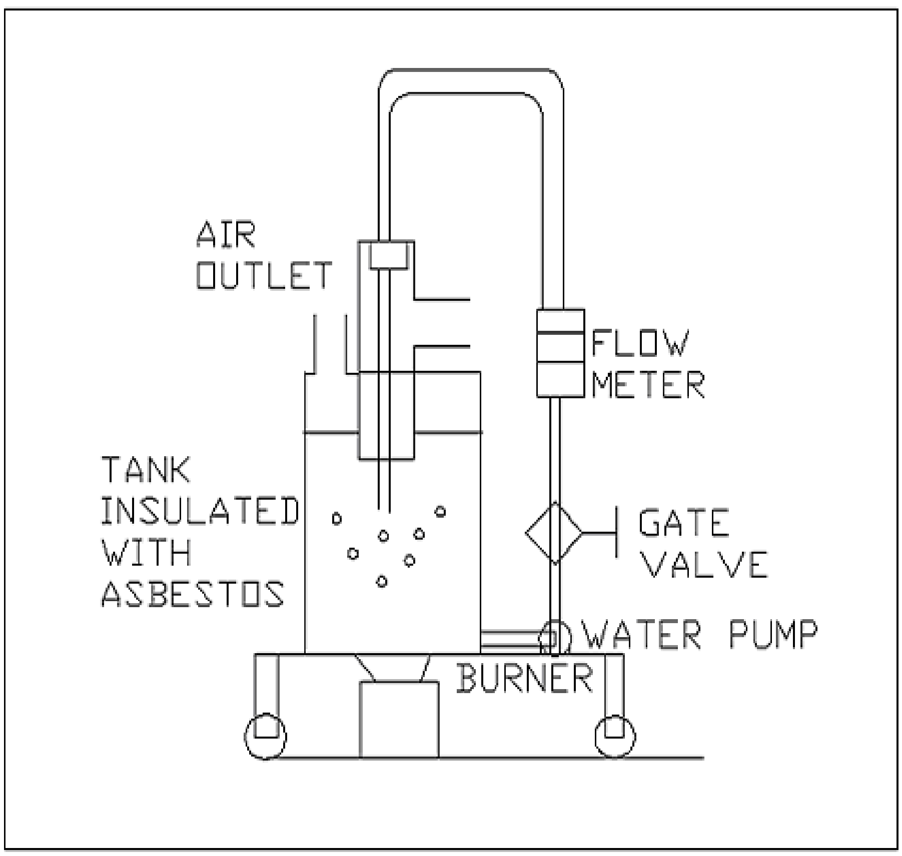

Figure 3.7 Diagram of the experiment setup

CHAPTER 4

4.0 RESULTS

4.1 CALIBRATION OF FLOW METER

Calibration was done for the flow meter to determine whether it was measuring in US gal or imperial gal. Here is the table showing the obtained values.

Table 4.1 Data for the calibration process

Flow rate (G/min)	3	5	10
Volume (m^3)	0.02	0.02	0.02
Time (s)	103.16	65.41	34.20

$$\text{Flow rate } (m^3/s) = \frac{0.02}{34.20}$$

$$= 5.847 \text{ E-04 } m^3/s$$

Results of the calibration process are calculated with the US and imperial gal values.

$0.0283\ m^3$ = 7.481 US gal = 6.299 im gal

For US gal

$$5 \text{ G/min} = \frac{0.0283}{7.481} x \frac{5}{60}$$

$$= 3.153 \text{ E-04 } m^3/s$$

For im gal

$$5 \text{ G/min} = \frac{0.0283}{6.299} x \frac{5}{60}$$

$$= 3.743 \text{ E-04 } m^3/s$$

Table 4.2 Results and comparison of the calibration process

Flow Rate (G/min)	3	5	10
Experiment ($x10^{-4}$)	1.939	3.058	5.848
US gal ($x10^{-4}$)	1.892	3.153	6.305
Im gal ($x10^{-4}$)	2.247	3.743	7.488

4.2 EXPERIMENTAL DATA

Nozzle size (mm) : 20
Number of nozzles : 1
Flow rate (G/min) : 5

Table 4.3 Single 20mm nozzle for 5G/min

Time (mins)	Temperature(°C)
START	55.0
5	54.9
10	54.8
15	54.6
20	54.5
25	54.4
30	54.2
35	54.1
40	53.9
45	53.8
50	53.6
55	53.5
60	53.4
65	53.2
70	53.1
75	53.0
80	52.9
85	52.7
90	52.6
95	52.5
100	52.4
105	52.3
110	52.2
115	52.1
120	52.0

Nozzle size (mm) : 20

Number of nozzles : 1

Flow rate (G/min) : 10

Table 4.4 Single 20mm nozzle for 10G/min

Time (mins)	Temperature(°C)
START	55.0
5	54.9
10	54.8
15	54.6
20	54.2
25	54.0
30	53.9
35	53.8
40	53.7
45	53.6
50	53.5
55	53.4
60	53.3
65	53.1
70	53.0
75	52.9
80	52.7
85	52.6
90	52.4
95	52.0
100	51.9
105	51.8
110	51.7
115	51.6
120	51.5